1-7 Pager - only receives, doesn't transmit

1-8 Cell phone - transmits over longer distances than cordless phone

1-9 If the user has one 3-minute call every day

$$\text{the battery life} = \frac{60\times1000\ (\text{mA-minute})}{(60\times24-3)\times35+3\times250\ (\text{mA-minute})}$$

$$\doteq 1.175 \text{ days} \doteq \underline{\underline{28.2 \text{ hours}}}$$

If the user has one 3-minute call every 6 hours

$$\text{the battery life} = \frac{60\times1000}{(60\times6-3)\times35+3\times250}\times6 \doteq \underline{\underline{27.18 \text{ hours}}}$$

If the user has one 3-minute call every hour.

$$\text{the battery life} = \frac{60\times1000}{(60-3)\times55+3\times250} \doteq \underline{\underline{21.86 \text{ hours}}}$$

$$\text{The maximum talk time} = \frac{60\times1000}{250} = 240 \text{ minutes} = \underline{\underline{4 \text{ hours}}}$$

1.10

1. Battery = 1000 mA/hr

Call = 250 mA
Receiver = 35 mA
Call Duration = 3 min = 0.05 hr

a) If the user makes one 3-minute call every day...
Average battery life =

during call: $r_c = 250\text{ mA} \cdot (0.05\text{ hr}) = 12.5\text{ mA·hr}$

during rec: $r_w = 35\text{ mA} \cdot \dfrac{(1440 - 3\text{ min})}{60} = 838.25\text{ mA·hr}$

total for 1 day = 850.75 mA·hr

Average life = $\dfrac{1000\text{mA} \cdot \text{hr}}{850.75\text{mA} \cdot \text{hr}} \cdot 24\text{ hr}$ = **28.21 hours**

b) If the user makes 1 call every 6 hours...

Average battery life =

during call: $r_c = 12.5\text{ mA·hr}$

during rec: $r_w = \dfrac{357}{60} \cdot 35 = 208.75\text{ mA·hr}$

avg. For 1 call/6 hrs = 220.75 mA·hr

Average life = $\dfrac{1000\text{ma} \cdot \text{hr}}{220.75\text{ma} \cdot \text{hr}} \cdot 6\text{hr}$ = **27.18 hr**

If the user makes 1 call every hour...
Average battery life =

during call: $r_c = 12.5\text{ mA·hr}$

during rec: $r_w = \dfrac{57}{60} \cdot 35 = 33.25\text{ mA·hr}$

avg. For 1 call/hr = 45.75 mA·hr

1.10 Cont'd

$$\text{Average life} = \frac{\frac{1000\,\text{ma}\cdot\text{hr}}{45.75\,\text{ma}\cdot\text{hr}}\cdot 1\text{hr}}{} = \mathbf{21.86\ hr}$$

$$\text{Maximum talk time} = \frac{1000\,\text{ma}\cdot\text{hr}}{250\,\text{mA}} = \mathbf{4\ hours}$$

3 battery states

idle = 1mA
wake-up = 5 mA
transceiver = mA
Average battery life =

In order to verify the influence of the duration of these periods (idle, wake-up, and transceiver), let us write the expression for 1 hour:

1 hour:

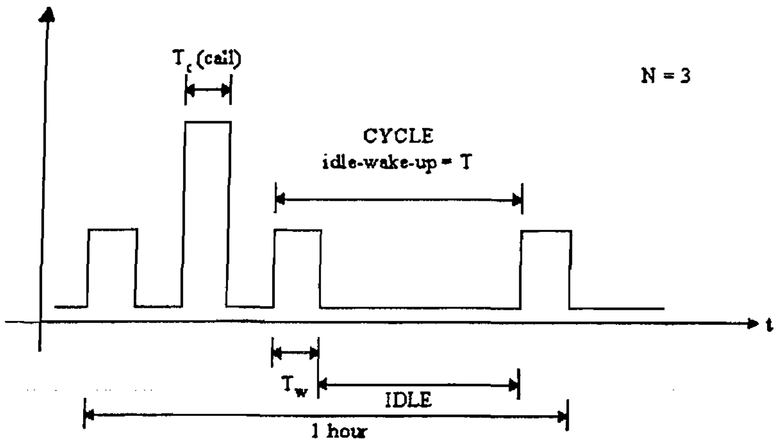
1 Tc-hour call
1 Tw-hour wake-up mode
1 T-hour idle mode

So we can write:

1 A·hr =
$$u\left\{T_c \times 0.25A + N_x t_w \times 0.035A + \left[N(T - T_w) - T_c\right]0.001\right\}$$

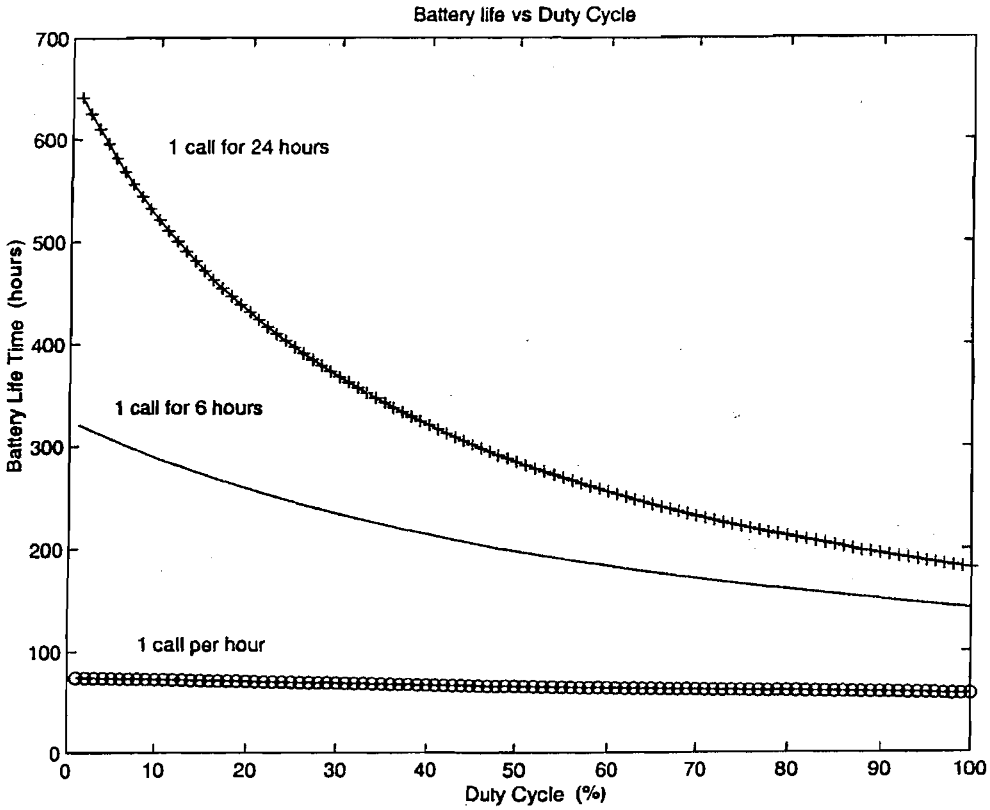
where u = # of hours of battery life

N = # of cycles (idle-wake-up" per hour



Observe that we consider that the call occurs during idle mode.

1.10 Cont'd



Battery life vs Duty Cycle
Battery Life Time (hours)
Duty Cycle (%)
1 call for 24 hours
1 call for 6 hours
1 call per hour
0
100
200
300
400
500
600
700
0
10
20
30
40
50
60
70
80
90
100

1.10 Cont'd

```
% Text 1.10

% Battery life for one 3 minute call every hour

for i=1:100
    x(i)=1/(((i/100)*(57/60)*0.005)+(((100-i)/100)*(57/60)*0.001)+(0.25*3/60)
);
end
plot(x,'o');

hold on;

% Battery life for one 3 minute call 6 hours

for j=1:100
    y(j)=(1/(((j/100)*(357/60)*0.005)+(((100-j)/100)*(357/60)*0.001)+(0.25*3/
60)))*6;
end;
plot(y);

hold on;

% Battery life for one 3 minute call every day

for k=1:100
    z(k)=(1/(((k/100)*(1437/60)*0.005)+(((100-k)/100)*(1437/60)*0.001)+(0.25*
3/60)))*24;
end;
plot(z,'+');

xlabel('Duty Cycle');
ylabel('Battery Life Time');
title('Battery life vs Duty Cycle');
```

1.10 Cont'd

Now, defining he duty cycle by,

$$D = \frac{T_w}{T} \rightarrow T_w = DT$$

Also, since N is the # of cycles during 1 hour, 1=NT

So, we can rewrite the expression for the battery life as:

$$1 = u\{T_c\,0.25A + D0.035A + [1 - D - T_c]0.001\}$$

or

$$u = \{T_c\,0.25A + D0.035A + [1 - D - T_c]0.001\}^{-1}$$

hours

In the figure on page 7a, we can see the curve for battery life x duty cycle for one 3 min. call/day, four 3 min. calls/day, and 24 3 min. calls/day.

We observe that since the power required by the phone during a call is much higher (250 mA) than during idle and wake-up states, the battery life is reduced dramatically.

1.11 For 3-minute call/day

$$\text{battery life} = \frac{60 \times 1000\ (\text{mA-minute})}{(60 \times 24 - 3) \times 5 + 3 \times 80} \doteq 8.08 \text{ days} = \underline{\underline{193.94 \text{ hours}}}$$

For 3 minute-call / 6 hours,

$$\text{battery life} = \frac{60 \times 1000}{(60 \times 6 - 3) \times 5 + 3 \times 80} \times 6 \doteq \underline{\underline{177.78 \text{ hours}}}$$

For 3 minute-call / hour,

$$\text{battery life} = \frac{60 \times 1000}{(60 - 3) \times 5 + 3 \times 80} \doteq \underline{\underline{114.29 \text{ hours}}}$$

$$\text{The maximum talk time} = \frac{60 \times 1000}{80} = 750 \text{ minutes} = \underline{\underline{12.5 \text{ hours}}}$$

CHAPTER 3

3.1 Generally, for $N = i^2 + i \cdot j + j^2$, we can do the following to find the nearest co-channel neighbors of a particular cell:

(1) move i cells along any chain of hexagons and then

(2) turn 60 degree counter-clockwise and move j cells

From the following figure, using the cosine law, we have

$$D^2 = [i \cdot (2R')]^2 + [j \cdot (2R')]^2 - 2 i \cdot (2R') \cdot j \cdot (2R') \cdot \cos 120^\circ$$

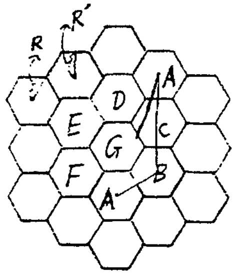
where $R' = \frac{\sqrt{3}}{2} R$, therefore

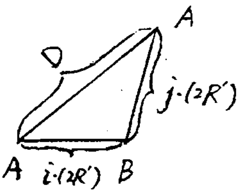
$$D = \sqrt{3i^2 \cdot R^2 + 3j^2 \cdot R^2 + i \cdot j \cdot 3R^2}$$

$$= \sqrt{3(i^2 + i \cdot j + j^2)} \cdot R$$

$$= \sqrt{3N} \cdot R$$

Hence, $Q = \frac{D}{R} = \sqrt{3N}$





3-4 (a) 20 MHz / [25 kHz × 2] = 400 channels

(b) 400 / 4 = 100

3-5 (a) Let i_o be the number of co-channel interfering cells, for omni-derectional antennas, $i_o = 6$. Assume $n = 4$, we have $\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_o} > 15\,dB = 31.623 \Rightarrow N > 4.59$

$\Rightarrow N = 7$

(b) For 120° sectoring, $i_o = 2$.

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_o} > 31.623 \Rightarrow N > 2.65 \Rightarrow N = 3.$$

(c) For 60° sectoring, $i_o = 1$.

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_o} > 31.623 \Rightarrow N > 1.87 \Rightarrow N = 3$$

From (a), (b) and (c) we can see that using 120° sectoring can increase the capacity by a factor of 7/3, or 2.333. Although using 60° sectoring can also increase the capacity by the same factor, it will decrease the trunking efficiency therefore we choose the 120° sectoring.

3.6 solution not available

3-7

a) Calls are not lost due to weak signal condition during handoff if:

$$\frac{\text{distance traveled during handoff}}{\text{mobile speed}} = \frac{d_{min} - d_{HO}}{v} \geq 4.5 \text{ seconds} \quad (2)$$

* $d_{min} \Rightarrow$ received power at BS_1 reaches $P_{r,min}$

$$P_{r,min} = -29\log_{10}(d_{min}) \Rightarrow d_{min} = 10^{-P_{r,min}/29} = 1083 \text{ m} \quad (3)$$

* $d_{HO} \Rightarrow$ received power at BS_1 reaches $P_{r,HO}$

$$P_{r,HO} = -29\log_{10}(d_{HO}) \Rightarrow d_{HO} = 10^{-P_{HO}/29} \quad (4)$$

Using (2),

$$\frac{1083 - 10^{-P_{r,HO}/29}}{22.22(m/s)} \geq 4.5 \text{ seconds} \quad (5)$$

$$P_{HO} \geq -86.8 \text{ dBm} \quad (6)$$

Thus,

$$\Delta = P_{r,HO} - P_{r,min} \Rightarrow \Delta \geq 1.2\text{dB}. \quad (7)$$

b) If we set Δ *too large*, several unnecessary handoffs will be requested and performed, increasing the signaling traffic between the base stations and mobile switching center (MSC). On the other hand, if Δ is *too small*, that is, $P_{r,HO}$ is only slightly greater than $P_{r,min}$, there will not be enough time to complete the handoff (especially for high speed mobiles), and calls may be lost due to weak signal condition.

3-8 For $n=3$.

(a) $i_0=6$, $\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 31.623 \Rightarrow N > 11 \Rightarrow \underline{\underline{N=12}}$

(b) $i_0=2$, $\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 31.623 \Rightarrow N > 5.29 \Rightarrow \underline{\underline{N=7}}$

(c) $i_0=1$, $\frac{S}{I} = \frac{(\sqrt{3N})^n}{i_0} > 31.623 \Rightarrow N > 3.33 \Rightarrow \underline{\underline{N=4}}$

From (a), (b) and (c), we can see that using 60° sectoring can increase the capacity by a factor of 12/3, or 4. For 120° sectoring, this factor is only 12/7, or 1.714. Therefore, we choose the 60° sectoring.

3-10

(a) $\dfrac{24\text{ MHz}}{2\cdot 30\text{ kHz}} = 400$ channels

$\dfrac{400\text{ channels}}{4\text{ cells}} = 100$ channels/cell

(b) 90% of 100 Erlangs = 90 Erlangs

$90 = U A_u = U(0.1) \Rightarrow U = 900$ users

(c) offered: 90E ; $C = 100 \Rightarrow 0.03$ from graph (Fig. 3-6)

3% GOS

(d) Each sector has 33.3 channels ; GOS = 3%

from graph (Fig. 3-6) $\Rightarrow \approx 25$ Erlangs/sector

$25 = U A_u$ (per sector)

$\Rightarrow U = 250 \times 3$ sectors

$U = 750$ users

(e) $\dfrac{2500\text{ km}^2}{5\text{ km}^2} = 500$ cells $\Rightarrow 500 \times 900$ users/cell $= 450{,}000$ users

(f) 500 cells $\Rightarrow 500 \times 750$ user/cell $= 375{,}000$ users

3-11 By the same method used in example 3-9, when going from omni-directional antennas to 60° sectored antennas, the number of channels per sector $= \frac{57}{6} = 9.5$. Given $Pr[\text{blocking}] = 1\%$, from the Erlang B distribution we have the total offered traffic intensity per sector $A \doteq 4.1$ Erlangs.

For $\mu = 1$ call/hour, $H = 2$ minute/call, the number of calls that each seach sector can handle per hour is

$$U = \frac{A}{\mu H} = \frac{4.1}{\frac{1}{60} \cdot 2} = 123 \text{ users}$$

$\Rightarrow$ cell capacity $= 6 \times 123 = 738$ users, from example 2-9.

$\Rightarrow$ loss in trunking efficiency $= 1 - \frac{738}{1326} \doteq 0.44 = \underline{\underline{44\%}}$

3-12

(EIRP = 32 watts, cell radius = 10 km. GOS is 5%, blocked calls cleared. H = 2 minutes, andμ = 2 calls pr hour. Assume cell will be split into 4 cells.)

a) What is the current capacity of the "Radio Knob" cell?

Using the functions defined in problem 2.7

$\mu := 2$ $\quad H := \frac{2}{60}$ $\quad A_u := 0.067$ Erlangs

$P := .05$ Probability of blocked calls
$C := 57$ Assume N=7 cell, AMPS
$A := 40$ Initial guess
$A_T(P,C) := \text{root}(GOS(A,C)-P,A)$ Solve iteratively for total traffic
$A_T(P,C) = 51.528$ Erlangs

Number of users is $U := \frac{A_T(P,C)}{A_u}$ $\quad U = 772.921$ or 772 users

b) What is the radius and transmit power of the new cells?

Since the 4 new cells must cover the area of the old cell, the radius of the new cells must be R/2, where R is the radius of the old cell. Then the area covered by the new cells is

$4\pi\left(\frac{R}{2}\right)^2 := 4\pi\left(\frac{R^2}{4}\right) = \pi R^2$ which equals the area of the original cell

3-12 Cont'd

To maintain the same SNR, the power at the edge of the new cells must equal the power at the edge of the original cell or

$P_{org}:=P_{new}$ $\qquad P_1R^{-4}:=P_2\left(\frac{R}{2}\right)^{-4}$ $\qquad$ and $\qquad P_2:=\frac{P_1}{16}$.

where P_1 and P_2 are the powers of the base station in the old and new cells respectively.

If P_1=32 watts, then P_2=2 watts.

c) How many channels are needed in the new cells to maintain frequency reuse stability in the system?

C:=57 $\qquad$ **Each new cell gets the number of channels of the original cell once the cell splitting process is complete.**

d) It traffic is uniformly distributed, what is the new traffic carried by each new cell? Will the probability of blocking in these new cells be below 0.1% after the split?

$U:=\frac{772}{4}$ $\qquad$ **U=193 users per new cell**

$A:=U\cdot A_u$ $\qquad$ A=12.867 Erlangs

GOS(12.87,57)=0 $\qquad$ **The probability of blocking is less than .1%**

3-13 Since users are uniformly distributed over the area, each cell in the cluster is assigned the same number of channels:

$$N_C = \frac{M}{N}, \qquad (8)$$

where

N_C = number of channels per cell
M = number of channels available in the system (300 channels)
N = cluster size $\qquad$ (9)

Given the number of channels per cell and the designed blocking probability $P_b = 1\%$, we can compute the maximum carried traffic per cell in Erlang (C_C) using the Erlang B formula

$$C_C = Erlang(N_C, P_b), \qquad (10)$$

and the maximum carried traffic in the system C:

$$C = C_C \times 84 \qquad (11)$$

Since each user offers a traffic of 0.04 Erlangs, the maximum number of users supported by the system is

$$N_U = \frac{C}{0.04} \qquad (12)$$

Table 2: Number of channels per cell (N_C), carried traffic per cell (C_C), total carried traffic in the system (C), and maximum number of users in the system (N_U), for cluster sizes N = 4, 7 and 12. Blocking probability 1%.

Cluster size N	channels per cell (N_C)	carried traffic per cell (N_C)	total carried traffic C	number of users N_U
4	75	60.73 Erl	5101.09 Erl	127527
7	42	30.77 Erl	2584.81 Erl	64620
12	25	16.12 Erl	1354.49 Erl	33862

$\boxed{3\text{-}17}$ area of a cell (hexagon) $= \frac{3\sqrt{3}}{2} \cdot r^2 = \frac{3\sqrt{3}}{2} \cdot (0.4701)^2 \doteq 0.574\,Km^2$

number of users in a cell U = area of a cell x user density

$= 0.574 \times 9000 \doteq 5167$ users

$\Rightarrow A = U \cdot u \cdot H = 5167 \times \frac{1}{60} \times 1 \doteq 86.1$ Erlangs.

Given $C = 90$, from Erlang C chart, we have the probability that a call will be delayed

$Pr[\text{delay} > 0] \doteq 0.5$

$\Rightarrow Pr[\text{delay} > 20\text{ sec}] = Pr[\text{delay} > 0] \cdot Pr[\text{delay} > 20 \mid \text{delay}]$

$= 0.5 \times \exp[-(90 - 86.1) \times 20/60]$

$\doteq \underline{\underline{0.136}}$