Lecture 15

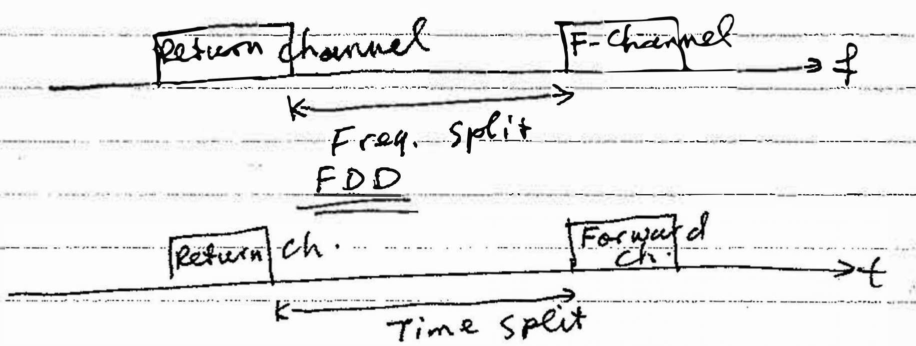
Multiple Access Techniques:

Multiple Access Techniques are used in order to allow several subscribers ~~use~~ share a finite amount of radio spectrum in an efficient manner.

Multiple Access Techniques:

- FDMA
- TDMA
- CDMA
- SDMA
- Hybrid Schemes: MF-TDMA / TCDMA, ...
- Random Access Techniques: Aloha, S-Aloha CSMA, etc.

- Difference between Multiplexing & Multiple Access
- Duplexing Techniques: TDD, FDD.



TDD

Multiple Access Technique used in Different Wireless Communication Systems:

System	Scheme
Advanced Mobile Phone System (AMPS)	FDMA/FDD
Global System for Mobile (GSM)	TDMA/FDD
US Digital Cellular	TDMA/FDD
U.S. Narrow-band SS (IS-95)	CDMA/FDD
Japanese Digital Cellular (JDS	TDMA/FDD
CT2 (Cordless Phone)	FDMA/TDD
Digital European Cordless Tel. (DECT)	FDMA/TDD

FDMA

The features of FDMA:

1) The FDMA channel carries only one phone circuit at a time.

2) If an FDMA channel is not in use, then it sits idle and cannot be used by other users, i.e., it is wasted.

3) After channel assignment: base and mobile transmit simultaneously and continuously.

4) The symbol time is large compared to the average time spread. This implies that the amount of ISI is small ⇒ no equalization (or little equlization) reqd.

5) Lower overhead for synchronization: since unlike TDMA, it is continuous transmission.

This means higher efficiency (transmission efficieny

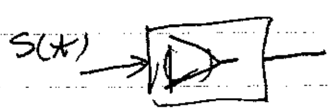
6) Lower digital circuit Complexity compared to TDMA.

7) FDMA requires costly BPFs at the base to eliminate spurious radiation ⇒ <u>higher cost per cell site</u>.

8) Since both Xmitter & receiver work at the same time, handsets require duplexers ⇒ higher handset cost.

9) FDMA requires tight RF filtering to reduce ACI

10) The problem of IM (Intermodulation) ⇒ need for linear amplifiers at the base to avoid IM terms. ⇒ less power efficiency.



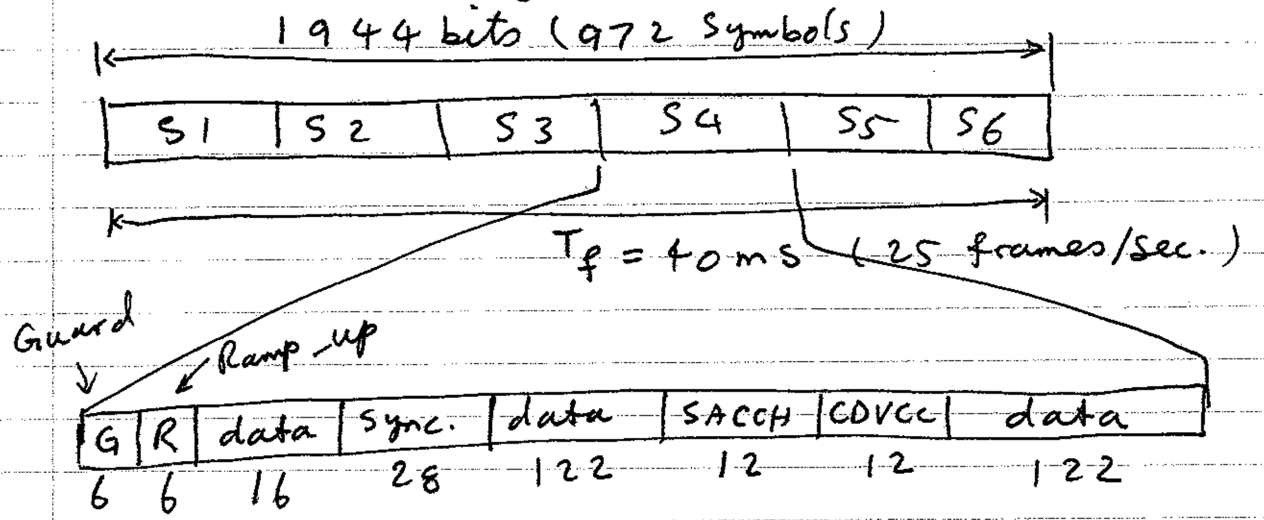
$a_1 s(t) + a_2 s^2(t) + \cdots$

TDMA

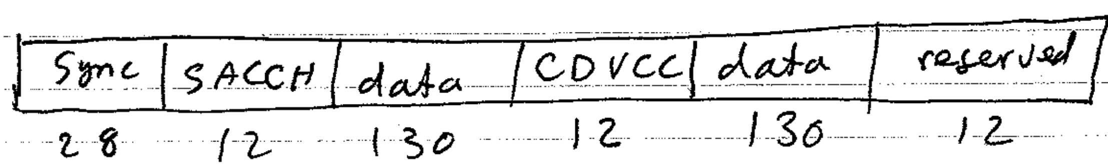
- The time is divided into frames.
- each frame contains several Time Slots (TS)
- During each TS, only one subscriber transmits or receives.
- The transmission is not continuous (burst transmission).

Example of TDMA frame structure:

IS-54 : USDC



Mobile to Base Station



Base to Mobile.

CDVCC = Coded Digital Verification Color Code
is an 8 bit number from 1 to 255 encoded
using a shortened (12, 8) BCH code.
It is sent by the base to mobile → mobile receives
it → decodes it and transmits it back,
if this handshake is not done properly,
then the time slot is taken from the subscriber
and given to someone else.
SACCH : Slow Associated Signalling Channel
is sent in each TS in parallel with data
and is used to send power level measurement,
handoff requests, signal strength in neighbor
sites (from Mobile to Base), etc.

Properties of TDMA

- In TDMA data is transmitted in bursts. Transmitter only transmit once every frame for a period of time (a TS) and is silent rest of the time ⇒ synchronization issue. ⇒ high synch. overhead & complexity.
- The peak to average power is high ⇒ higher power amplifiers. (Note: the battery usage is the same as FDMA since the average Power is the same.)
- No IM problem since only one carrier is used.
- ISI a problem (shorter bit duration) ⇒ need of equalizer.
- Flexibility: (rate flexibility) is achieved by giving more TSs to a user.

Efficiency of TDMA

USDC

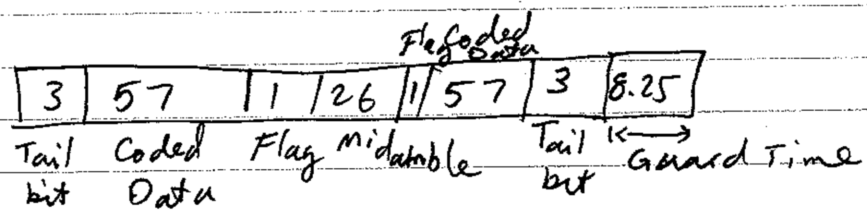
$$\eta = \frac{b_T - b_{OH}}{b_T} = 1 - \frac{b_{OH}}{b_T}$$

$b_T = 6 + 6 + 28 + 12 + 12 + 260 = 324$ bits

$b_{OH} = 6 + 6 + 28 + 12 + 12 = 64$

$$\eta = 1 - \frac{64}{324} \cong 80\% \quad (0.802469)$$

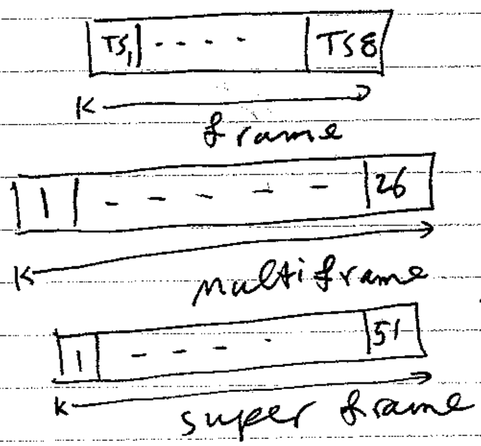
GSM



$b_T = 3 + 57 + 1 + 26 + 1 + 57 + 3 + 8.25 = 156.25$

$b_{OH} = 42.25$

$$\eta = 1 - \frac{42.25}{156.25} \approx 73\% \quad (0.7296)$$



26 frames in 1 multiframe

51 Mframes in a super frame

13th and 26th frame are used for control so, the actual efficiency is:

$$\eta' = 0.73 \times \frac{24}{26} \simeq 67.4\%$$

Code Division Multiple Access (CDMA)

Properties:

1) Many users use the same spectrum simultaneou

2) Unlike TDMA and FDMA, CDMA has a soft capacity limit.

3) The multipath effects are mitigated using CDMA since the BW is usually much higher than the coherence BW of the channel.

4) Channel data rates (chip rate) are usually ~~much higher~~ very high in CDMA. So, the symbol (chip) duration is very short and much less than the channel delay spread. Since PN sequences have low autocorrelation, multipath which is greater than a chip will appear as noise. RAKE receiver can be used to improve reception

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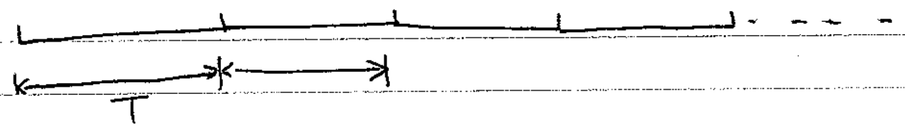
5) Near-far problems occur at CDMA receiver if an undesired user has a high detected power as compared to the desired user

⇒ importance of power control.

Random Access Techniques (Packet Radio).

ALOHA



We assume that the arrival is a Poisson process with

$$P_r(n) = \frac{(\lambda\tau)^n e^{-\lambda\tau}}{n!}$$

Where $P_r(n)$ is the probability of having n arrivals in the time duration τ ~~if~~

where λ is the ~~average~~ mean arrival rate ~~~~.

interpretation of quantities:

Let the channel bit rate be R and the packet size be b bits, then

$$T = \frac{b}{R} \quad \text{packet duration}$$

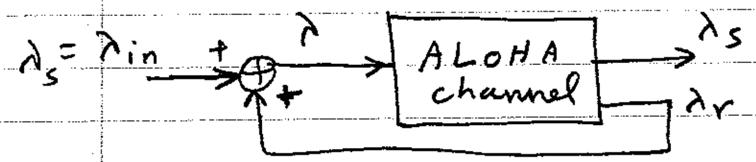
total offered load is λb bps.

If we normalize this by the channel rate (what fraction of channel capacity it takes), we get:

$$G = \frac{\lambda b}{R} = \lambda T$$

Similarly for the successful traffic, we have the throughput as $\lambda_s b$ bps, i.e., $\lambda_s b$ bits leave the system every second. Normalizing this, we get:

$$S = \frac{\lambda_s b}{R} = \lambda_s T$$



The probability of success can be expressed as

$$P_s = \frac{\lambda_s}{\lambda} \qquad (1)$$

λ includes λ_r, i.e., the rejected packets being retransmitted.

P_s can also be express as the probability of no arrival during $2T$ seconds

so:

$$P_s = P_{2T}(0) = e^{-2\lambda T} \qquad (2)$$

equating (1) and (2) we get

$$\frac{\lambda_s}{\lambda} = e^{-2\lambda T}$$

or $\lambda_s = \lambda e^{-2\lambda T}$

let $G = \lambda T$ be the total offered traffic.

and $S = \lambda_s T$ be the normalized throughput.

then

$$\boxed{S = G e^{-2G}}$$

Maximum throughput of ALOHA (Pure ALOHA) Scheme.

$$S = Ge^{-2G}$$

take derivative w.r.t. G to get:

$$\frac{\partial S}{\partial G} = e^{-2G} - 2Ge^{-2G} = 0 \Rightarrow G = \frac{1}{2}$$

$$S_{max} = Ge^{-2G}\Big|_{G=1/2} = \frac{1}{2}e^{-1} = \frac{1}{2e} = 0.1839 \cong 18\%$$

Slotted Aloha: (S-ALOHA)

In this scheme: the time is divided into slots each with a duration of T. ~~##~~ Users only Transmit at the beginning of a packet time (or frame time). Any buffer filled (~~call~~ packet arrived) during T seconds prior to beginning of the frame is sent at the beginning of the packet time. So, one may only collide with those packets arriving in T (not 2T) seconds, so:

$$P_S = P_T(0) = e^{-\lambda T}$$

$$\frac{\lambda_S}{\lambda} = e^{-\lambda T} \Rightarrow S = Ge^{-G}$$

The maximum throughput:

$$\frac{\partial S}{\partial G} = e^{-G} - G e^{-G} = 0 \Rightarrow G = 1$$

$$S_{max} = e^{-1} = \frac{1}{e} \approx 0.3679 \approx 37\%$$

Example:

In a satellite Communications Network:
The total capacity of a link is 2.048 Mbps and each earth terminal has an average data rate of 16 kbps. The packet length is 500 bits. How many earth stations the link can support:

a) For pure ALOHA.
b) For S-ALOHA.

1) ALOHA:

$$T = \frac{500}{2.048 \times 10^{6}} = 0.244 \text{ msec}$$

$$S_{max} = 0.18 = \lambda T = M \lambda_i T$$

$$\lambda_{max} = \frac{0.18}{0.244 \times 10^{-3}} \cong 737.7 \text{ packets for } M \text{ users}$$

$$\lambda_i = \frac{16000}{500} = 32 \text{ packets/sec./user.}$$

$$M = \frac{\lambda}{\lambda_i} = \frac{737}{32} \approx 23 \text{ users.}$$

2) S-ALOHA

$$S_{max} = 0.37 \Rightarrow \lambda_{max} = \frac{0.37}{0.244 \times 10^{-3}} = 1516$$

$$M = \frac{1516}{32} \approx 47 \text{ users.}$$

Capacity of cellular Systems

$$Q = \frac{D}{R}$$

where D is the distance between two co-channel cells.

R is the cell radius.

Q is called co-channel re-use ratio.

We have $Q = \sqrt{3N}$

where N is the number of cells in a frequency re-use pattern.

We want to relate carrier-to-interference ratio $\frac{C}{I}$ to the capacity of the system.

We start with

$$\frac{C}{I} = \frac{D_o^{-n_o}}{\sum_{k=1}^{M} D_k^{-n_k}}$$

D_o is the distance from the desired BS.

n_o is the path loss exponent in the desired cell

D_k is the distance from kth interfering BS.

n_k is the path loss exponent to the kth interfering station.

Take $n_k = n_o = n$ all k

and $D_k = D$

we have (for hexagonal tesselation):

$$\frac{C}{I} = \frac{D_o^{-n}}{6D^{-n}}$$

Take the worst case (max. interference), i.e., when the mobile is at the edge of the cell, i.e., when $D_o = R$, then:

$$\frac{C}{I} = \frac{1}{6}\left(\frac{R}{D}\right)^{-n}$$

Assume that system requires a minimum of $\frac{C}{I}$, say, $\left(\frac{C}{I}\right)_{min}$ to ensure good quality of reception, then

$$\frac{1}{6}\left(\frac{R}{D}\right)^{-n} \geq \left(\frac{C}{I}\right)_{min}$$

or $$\frac{1}{6}(Q)^{n} \geq \left(\frac{C}{I}\right)_{min}$$

or $$Q = \left[6\left(\frac{C}{I}\right)_{min}\right]^{1/n}$$

The radio capacity of a cellular system is defined a

$$m = \frac{B_t}{B_c N} \quad \text{radio channels/cell}$$

where B_t is the total allocated spectrum and B_c is the channel Bandwidth.

$$Q = \sqrt{3N} \Rightarrow N = \frac{Q^2}{3}$$

So:

$$m = \frac{B_t}{B_c \frac{Q^2}{3}} = \frac{B_t}{B_c \left[\frac{6}{3^{n/2}} \left(\frac{C}{I}\right)_{min}\right]^{2/n}}$$

For $n=4$, we have:

$$m = \frac{B_t}{B_c \sqrt{\frac{2}{3}\left(\frac{C}{I}\right)_{min}}} \text{ radio channels/cell}$$

Typical values of $\left(\frac{C}{I}\right)_{min}$ is 12^{dB} for digital systems and 18^{dB} for analog systems.

If B_t and m remain unchanged (only B_c is changed) we have

$$\left(\frac{C}{I}\right)_{eq} = \left(\frac{C}{I}\right)_{min} \left(\frac{B_c}{B_c'}\right)^2$$

that is for a doubling of BW (i.e., $B_c' = 2B_c$) we reduce the minimum required $\frac{C}{I}$ by 4.

($\left(\frac{C}{I}\right)_{eq} = \frac{1}{4}\left(\frac{C}{I}\right)_{min}$) [this means that the new system has to

In a digital system (not considering thermal noise):

$$\frac{C}{I} = \frac{E_b R_b}{I} = \frac{E_c R_c}{I}$$

R_c is the rate of channel coded bits and E_c is energy per coded bit.

~~Here~~ For FDMA: $B_c = \frac{B_t}{m}$ so,

$$m = \frac{B_t}{\frac{B_t}{m}\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)}} = \frac{m}{\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)}} = \frac{m}{\sqrt{\frac{2}{3}\left(\frac{E_b R_b}{I}\right)}}$$

or

$$m = \frac{m}{\sqrt{\frac{2}{3}\left(\frac{E_b R_b}{I_o B_c}\right)}}$$

for TDMA

$B_c = B_t$ and

$$m' = \frac{1}{\sqrt{\frac{2}{3}\left(\frac{C'}{I'}\right)}}$$ channels/cell $\Rightarrow$ $$m = \frac{m}{\sqrt{\frac{2}{3}\left(\frac{C'}{I'}\right)}}$$ users/cell

~~$C' = E_b R_b$ but $I = I_o B_t = m I_o B_c$~~

~~$m_{TDMA} = m_{FDMA}$~~

Example:

Consider an FDMA system with three channels, each with a BW of 10 kHz and a rate of 10 kbps. A TDMA system has three time slots channel BW of 30 kHz and a rate of 30 kbps.

For the TDMA system, the receive $\frac{C}{I}$ for a single user is measured for $\frac{1}{3}$ of the time channel is ~~used~~ in use. So:

$$C' = E_b R_b' = \frac{E_b \times 10^4}{0.333} = 3 E_b R_b = 3C$$

and

$$I' = I_o B_c' = I_o \times 30 \text{ kHz} = 3I$$

So:

$$\frac{C'}{I'} = \frac{C}{I}$$

The Capacity of Cellular CDMA

The capacity of the CDMA is interference limited so any reduction in interference level has a linear effect on the capacity increase. Use of multi-sectorized antennas (directional antennas, receiving signals from only a fraction of the present users), Discontinuous Transmission Mode (DTX), i.e., turning off transmitter during silence are two methods to reduce interference and, as a results increase the capacity of the CDMA system.

We begin the study of the CDMA, by considering a single cell system.

Assume there are M users each with power S, then

$$SIR = \frac{S}{(M-1)S} = \frac{1}{M-1}$$

$SIR \triangleq$ Signal to interference ratio let $E_b = \frac{S}{R}$ and $I = W I_o$

then

$$\frac{E_b}{I_o} = \frac{S/R}{(M-1)S/W} = \frac{W/R}{M-1}$$

This is similar to $\frac{E_b}{N_o}$ and represents the effect of interference only without taking the effect of thermal noise into consideration.

Taking the effect of thermal Noise into account, we have

$$SNIR = \frac{S}{(M-1)S + N}$$

$$\left(\frac{E_b}{N_o'}\right)_e = \frac{S/R}{(m-1)\frac{S}{W} + \frac{N}{W}} = \frac{W/R}{(m-1) + \frac{N}{S}}$$

|| $\left(\frac{E_b}{N_o'}\right)_e$ represents the combination of thermal & interfer. noise

$$\left(\frac{E_b}{N_o'}\right)_e = \frac{W/R}{(m-1) + \frac{N_o W}{E_b R}} = \frac{W/R}{(m-1) + \left(\frac{E_b}{N_o}\right)^{-1}\frac{W}{R}}$$

$\frac{W}{R}$ is the processing gain. Solving for M, we get

$$M = \frac{W/R}{\left(\frac{E_b}{N_o'}\right)_e} - \frac{W/R}{\frac{E_b}{N_o}} + 1 = \frac{W/R}{\left(\frac{E_b}{I_o}\right)} + 1$$

Now, let's consider the effect of antenna sectorization and voice activity on the capacity of CDMA. Assume that there are k sectors and the voice activity factor is α.

Then for ~~all users~~ an M user system, we have M/k users per sector and the multiple Access interference is:

$$\left(\frac{M}{k}-1\right)\alpha S$$

So:

$$SNIR = \frac{R E_b}{W N_0'} = \frac{S}{\left(\frac{M}{k}-1\right)\alpha S + N_0 W}$$

$$\frac{E_b}{N_0'} = \frac{W/R}{\left(\frac{M}{k}-1\right)\alpha + \frac{N_0 W}{S}} = \frac{W/R}{\left(\frac{M}{k}-1\right)\alpha + \left(\frac{E_b}{N_0}\right)^{-1}\frac{W}{R}}$$

or

$$M = k + \frac{k}{\alpha}\cdot\frac{W/R}{\frac{E_b}{I_0}}$$

take $\alpha = \frac{3}{8}$ and $k = 3$

then

$$M = 3 + 8\,\frac{W/R}{\frac{E_b}{I_0}} \approx 8 \text{ times}\left[\frac{W/R}{\frac{E_b}{I_0}} + 1\right]$$

Example:

$W = 1.25$ MHz, $R = 9600$ bps

and minimum acceptable $\frac{E_b}{N_0'}$ is 10 dB

find the capacity of a CDMA system.

a) For an omni-directional antenna at BS. and no voice activity.

b) For a 3 sector BS antenna and $\alpha = \frac{3}{8}$.

Assume thermal $\frac{E_b}{N_0}$ to be 20 dB

$$\left(\frac{E_b}{N_0'}\right)^{-1} = \left(\frac{E_b}{I_0}\right)^{-1} + \left(\frac{E_b}{N_0}\right)^{-1}$$

$$10^{-1} = \left(\frac{E_b}{I_0}\right)^{-1} + 10^{-2} \Rightarrow \frac{E_b}{I_0} \approx \frac{E_b}{N_0'} = 10$$

then:

a) $$M = \frac{\frac{1.25 \times 10^6}{9600}}{10} + 1 = 14 \quad \text{users/cell}$$

b) $$M = 3 + \frac{\frac{1.25 \times 10^6}{9600}}{10} \times 8 = 107 \quad \text{users/cell}$$

The capacity of multiple-cell CDMA

The major advantage of CDMA comes from the fact that, in comparison to FDMA and TDMA, it has higher frequency re-use. CDMA has a frequency re-use factor f which is very close to 1. ($f=1$) while for FDMA and TDMA f ~~can be~~ is usually $\frac{1}{7}$, i.e., that is a given frequency band is used every 7th. cell.

For CDMA frequency re-use ~~factor~~ efficiency is

$$f = \frac{N_0}{N_0 + \sum_i U_i N_{ai}} \qquad N_{ai} = \sum_j \frac{N_{ij}}{U_i}$$

where N_0 is total interference from the $M-1$ users in the desired cell and U_i and N_{ai} are the number of users and the average interfer from each user in the ith. interfering cell.

f depends on the cell diameter the distribution of mobiles as well as the exponent of propagatio (n) and is typically between 0.3 and 0.7.

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Table 9.4 Frequency Reuse Factor for Reverse Channel of CDMA Cellular System, as a Function of n for Two System Implementations [from [Rap92b] © IEEE]

		Frequency reuse efficiency		
d (km)	n	lower bound $W_1 = 3.0$ $W_2 = 0.0$	hex $W_1 = 1.38$ $W_2 = 0.78$	upper bound $W_1 = 1.0$ $W_2 = 1.0$
2	2	0.316	0.425	0.462
2	3	0.408	0.558	0.613
2	4	0.479	0.646	0.707
10	2	0.308	0.419	0.455
10	3	0.396	0.550	0.603
10	4	0.462	0.634	0.695