Lec9

Saturday, January 27, 2018 10:08 AM

2-dim - 15min

Tuesday, February 19, 2008 4:10 PM

Two-dimensional case:

Ⓠ What equi-lateral geometric shapes can tesselate an infinite 2-dim space?

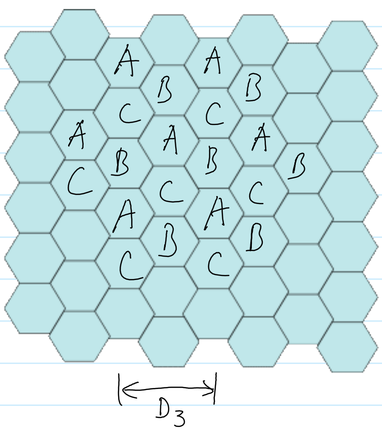
Ⓐ square, triangle, hexagon

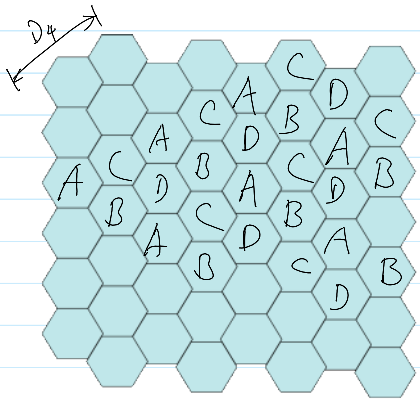
↑ closest to circle.

Hexagon Cells

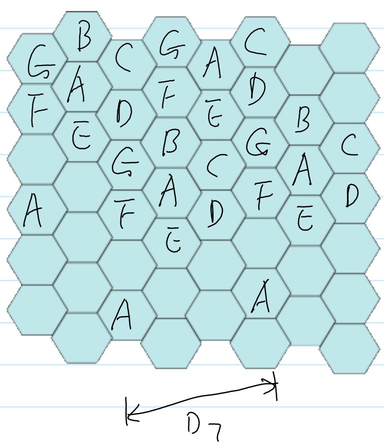
Show 3, 4, 7 - reuse patterns (p66-67)

cells of the same channel also forms a hexagon.





A B A B



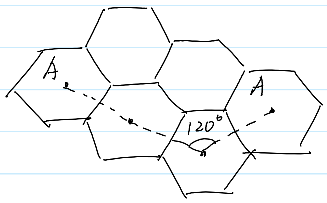
Reuse factor C

⇒ every cluster of C cells repeats itself

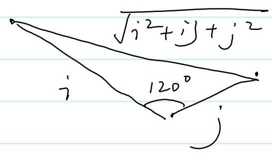
Reuse distance D

For uniform hexagon cells, the reuse factor C must satisfy

$$C = i^2 + ij + j^2 \quad , i, j \text{ are positive integers.}$$



Two closest cell that use the same channel.



We can show that a cluster covers i^2+ij+j^2 times the area of a single cell

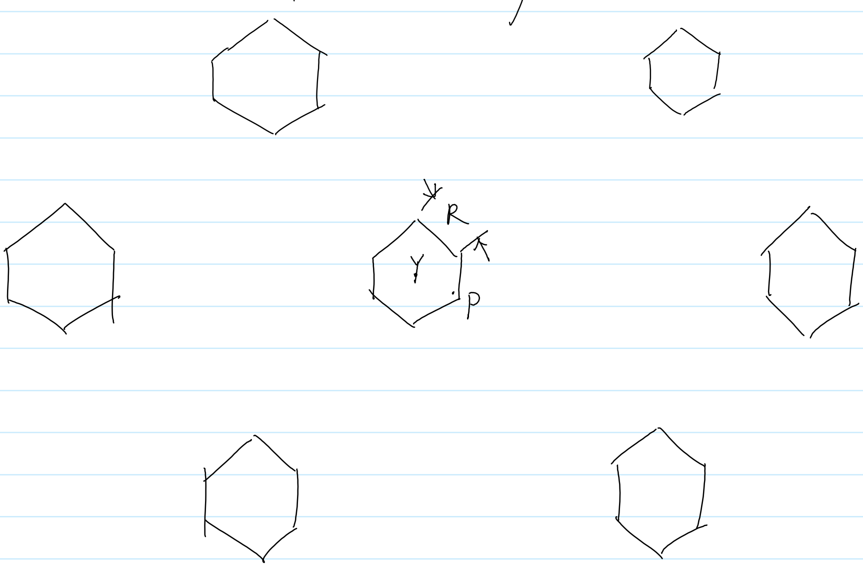
$\Rightarrow C = i^2+ij+j^2$

$\Rightarrow$ The reuse-distance is related to the reuse-factor C by

$$D = \sqrt{C} \quad 2 \cdot \frac{\sqrt{3}}{2} R = \sqrt{3C}\, R.$$

S2R calculation:

- same assumption as Linear case
- Six 1st-tier interferers.



received signal P_T / R^n

1st-tier interferers

$$\approx \frac{P_T}{(D-R)^n} + \frac{P_T}{(D+R)^n} + 4 \cdot \frac{P_T}{D^n}$$

$$(D-R)^n \quad \cdot \quad (D+R)^n \quad \cdot \quad D^n$$

$$\Rightarrow \; S2R \simeq \frac{1}{\left(\frac{D}{R}-1\right)^{-n} + \left(\frac{D}{R}+1\right)^{-n} + 4\left(\frac{D}{R}\right)^{-n}}$$

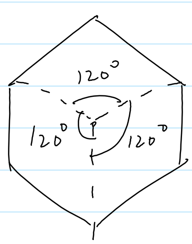
c	$D/R=\sqrt{3c}$	S2NR (dB) $n=3$	S2NR (dB) $n=4$
3	3	5.3	9.3
7	4.58	11.6	18
12	6	14.8	22.2

Various other approximations are used in the literature. The relative difference of the approximations decreases as the reuse factor becomes large.

Implications

AMPS: Threshold 18dB,
Need 7-reuse at $n=4$
In practice, use $C=7$ plus 120°C sectional antenna.

$\Rightarrow$ only two first-tier interferers per sector



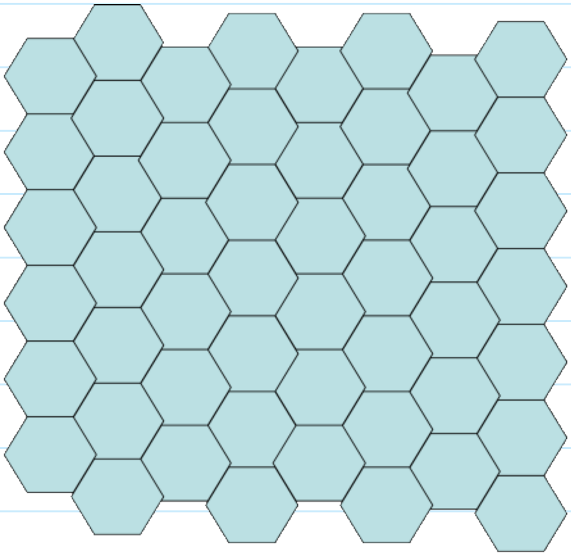
GSM: Threshold 7dB
Need 3-reuse (at $n=4$)

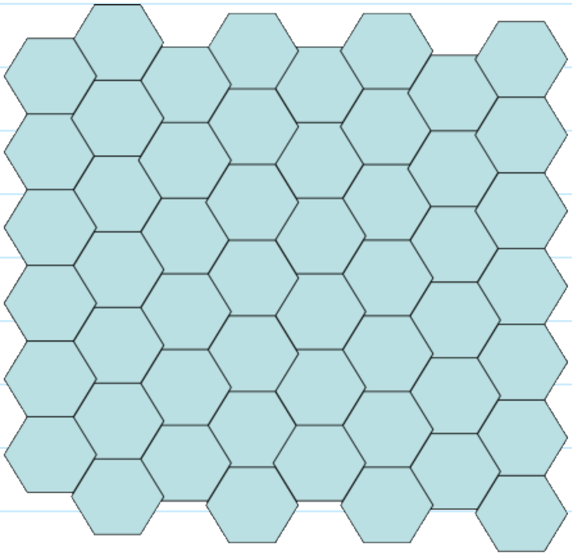
Revisit the Assumptions.

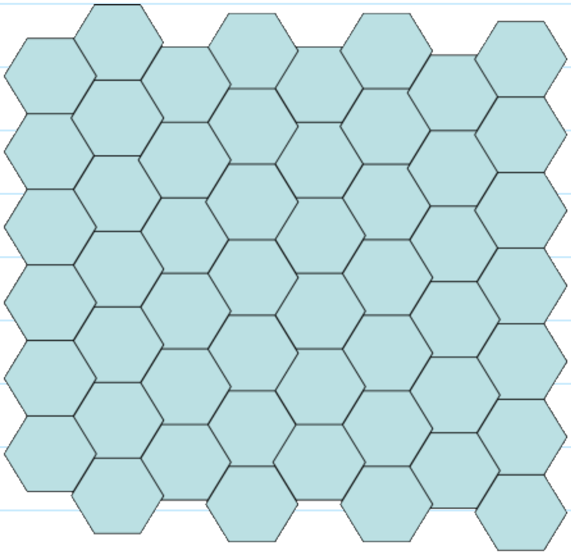
4D

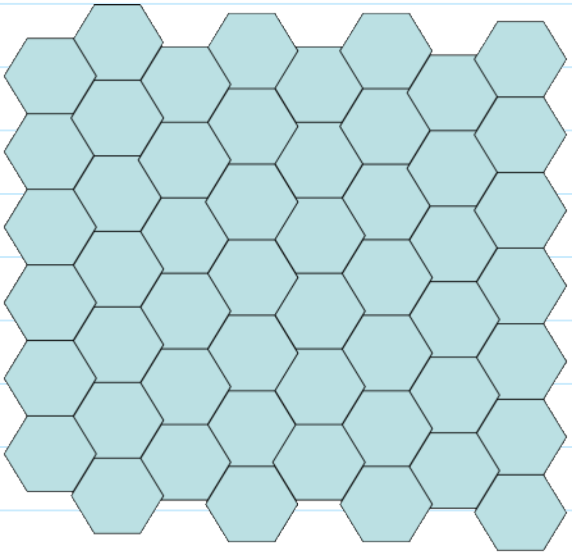
Cellular patterns in 2-d

Tuesday, February 19, 2008 4:26 PM





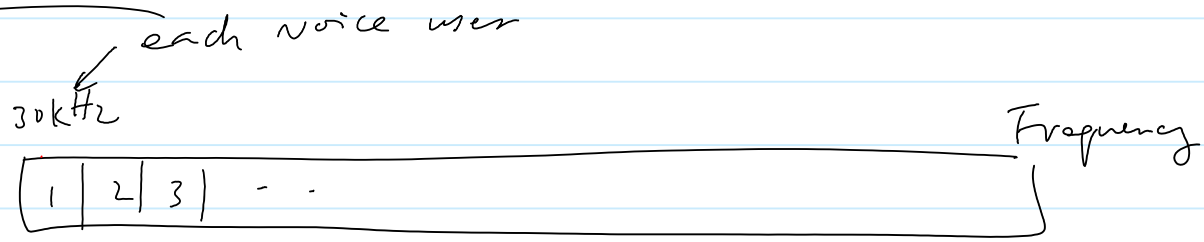




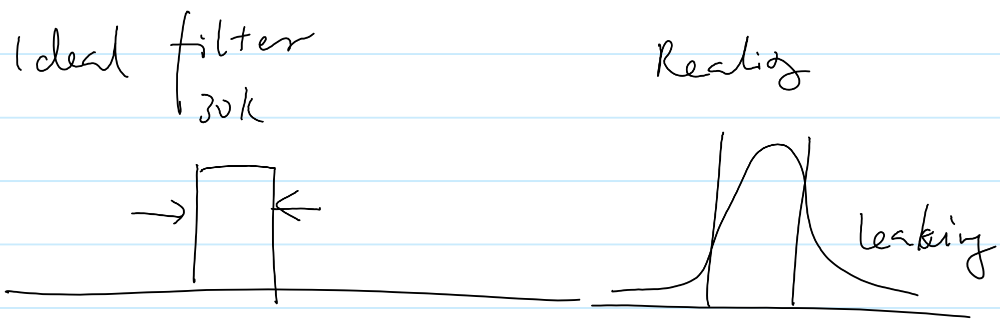
TDMA vs FDMA - 10min

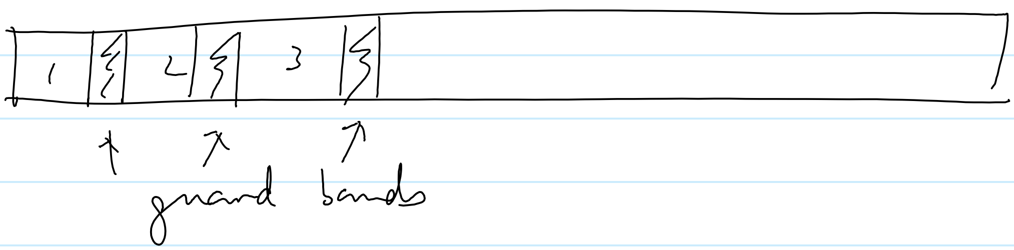
Sunday, January 06, 2008 4:06 PM

FDMA

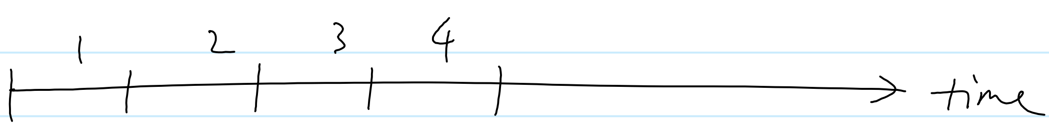


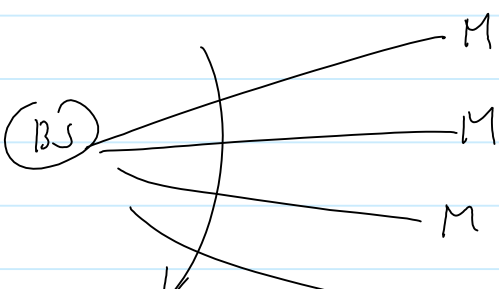
filter

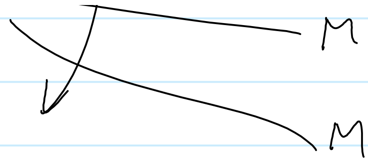




TDMA







Both BS and M maitain acurate & identical clock.

Each user speaks with the BS at a specific time.

(Q) What is the advantage of TDMA?

- Time slots can be tightly packed, with no intervals in between.
- In reality, some time is used for synchronization sequence (guard time)

Sync	1	2	3	4	

Sync. sequence is a code-sequence known to the receiver, so that the receiver knows when data time slots starts

- Basestation only needs one radio
  $\Rightarrow$ the cost per user of BS equipment is lower

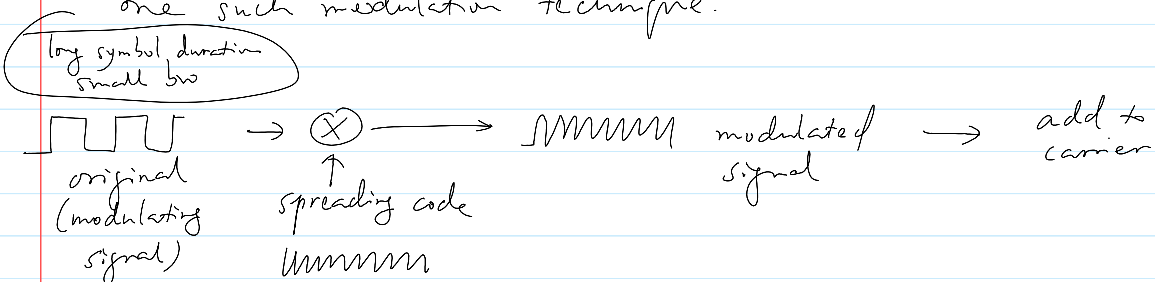
20min

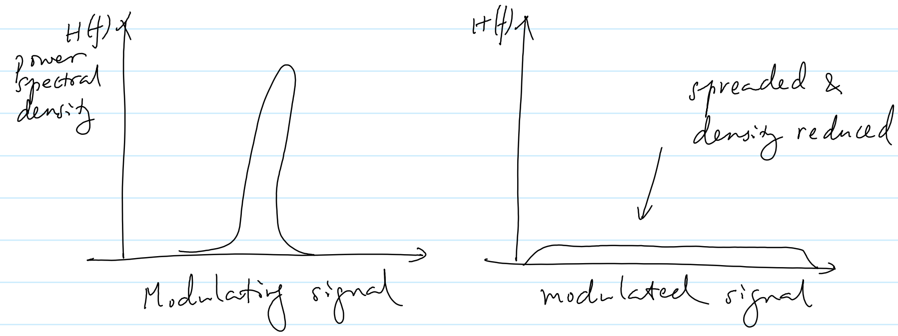
The 3rd Multi-access technology that appears in 2G is CDMA.

CDMA is based on spread-spectrum technologies.

Spread-spectrum modulations refer to any modulation techniques in which the BW of modulated signal is much larger than the BW of the modulating signal

DS-SS (Direct Sequence - Spread Spectrum) is one such modulation technique.

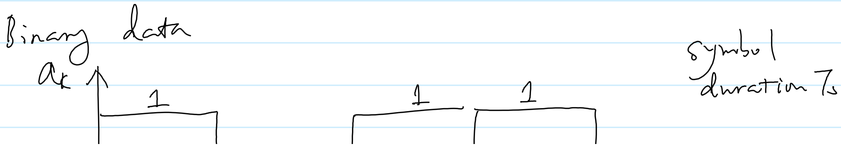


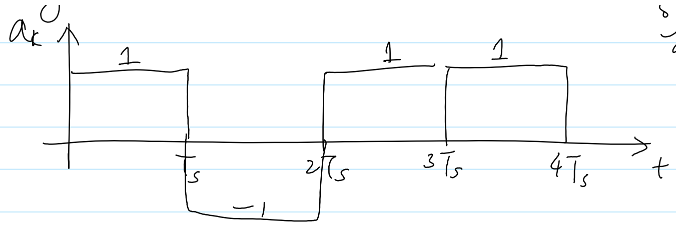


With good spreading codes (Pseudo-random sequence), the modulated signal looks like a random background noise

- special significance in military apps
- Communication is stealthy.
- We will focus more on the capacity aspect.

To be more precise:





symbol duration T_s

With normal BPSK

$$a_k \to \underset{\uparrow \\ \cos\omega_0 t}{\otimes} \to s_d(t)$$

$$s_d(t) = \underset{\substack{\uparrow \\ \text{total power } P}}{\sqrt{2P}} \cos(\omega_0 t) \cdot \underset{\substack{\uparrow \\ \text{phase modulation } 0,\pi}}{a_k(t)}$$

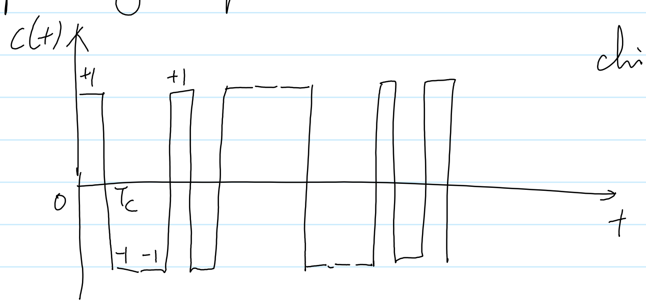
- At the receiver

$$s_d(t) \to \underset{\uparrow \\ \cos\omega_0 (t)}{\otimes} \to r_d(t) \to \boxed{\int_0^{T_s}}$$

$$r_d(t) = \sqrt{2P}\cos^2(\omega_0 t) \cdot a_k(t)$$

$$\int_0^{T_s} r_d(t) = a_k(t) \cdot \underbrace{\int_0^{T_s} \sqrt{2P}\cos^2(\omega_0 t)\, dt}_{\text{constant} > 0}$$

Spreading sequence



chip-duration $T_c \ll T_s$

$$a_k \to \underset{\uparrow \\ \cos\omega_0 t}{\otimes} \to \underset{\uparrow \\ c(t)}{\otimes} \to s(t)$$

$$s(t) = \sqrt{2p}\cos(\omega_0 t)\cdot a_k(t)\cdot c(t)$$

At the receiver

$$\underset{\substack{\uparrow \\ \text{noise}}}{s(t)+n(t)} \rightarrow \underset{\substack{\uparrow \\ c'(t)}}{\otimes} \longrightarrow \underset{\substack{\uparrow \\ \cos\omega_0 t}}{\otimes} \longrightarrow r(t)$$

$$r(t) = \sqrt{2p}\; c(t)\, c'(t)\cdot a_k(t)\cdot \cos^2(\omega_0 t) + n'(t)$$

① If $c(t) = c'(t)$ (i.e, the same spreading code and perfect synchonization achieved),

Then $r(t) = \sqrt{2p}\cdot a_k(t)\cos^2(\omega_0 t) + n'(t)$

- No spreading effect at the receiver!
- $r(t)$ is then feed to the detector to retrieve $a_k(t)$.

What is the bandwidth of the signal
- Modulating signal $a_k(t)$:
  Symbol rate T_s, bw $B_s = \frac{1}{T_s}$
  - same without spreading $s_d(t)$
- With spreading $s(t)$
  Chip rate $T_c \ll T_s$, bw $B_c = \frac{1}{T_c} \gg B_s$
  At the same total power P, the PSD of the modulated signal $\ll$ PSD of the modulating signal (by $1/w$)
- At the receiver, if $c(t) = c'(t)$,
  the bw of $r(t)$ is still B_s

② Consider instead the transmission of another user

$$\tilde{s}(t) = \sqrt{2p}\cos(\omega_0 t)\cdot \tilde{a}_k(t)\cdot \tilde{c}(t)$$

At the receiver

$$\tilde{r}(t) = \sqrt{2p}\;\tilde{c}(t)\, c(t)\cdot \tilde{a}_k(t)\cos^2(\omega_0 t)$$

Since $\tilde{c}(t) \neq c(t)$, $\tilde{r}(t)$ looks like another pseudo-random sequence

If $\tilde{c}(t)$ & $c(t)$ are perfectly ...

$\Rightarrow$ bw of $\tilde{r}(t)$ is $B_c \gg B_s$

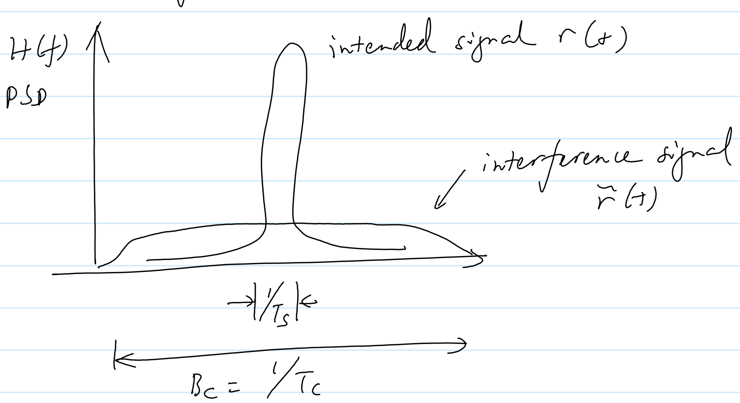
1 1 −1 −1

If $c_1(t)$ & $c(t)$ are perfectly orthogonal $\Rightarrow$ no interference! However, # of orthogonal codes is small

$1 \quad 1 \quad -1 \quad -1$

$1 \quad -1 \quad -1 \quad 1$

$\Rightarrow$ bw of $\tilde{r}(t)$ is $B_C >> B_S$



When we put a band-pass filter with bw $B_S = 1/T_S$, the power of the interfering signal is reduced to

$$P \frac{\frac{1}{T_S}}{\frac{1}{T_C}} = P/W$$

where $W = \frac{T_S}{T_C}$ is processing gain

If W is large, the receiver will be able to decode even when two CDMA users transmit simultaneously.

$\Rightarrow$ Each "code" serves as a channel: A user can successfully communicate provided that the same code is not used by other users in the same cell.

(Q) If the # of codes is infinite, can CDMA support infinite # of channels then?

(A) No.

The signal-to-noise-interference ratio at the receiver is then (assuming received signal strength is the same)

$$\frac{P}{\frac{P}{W}\underbrace{(N-1)}_{\#\text{ of users}} + \underbrace{\eta}_{\text{background noise}}}$$

The # of users N that can be supported

depends on the required SINR level.

$\Rightarrow$ The # of available channels in CDMA systems is limited by interference, not by reuse pattern

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For example, in IS-95

- Each freq channel is 1.25MHz
- Chip sequence at 1.2288 Mcps
- data sequence at 19.2kbps

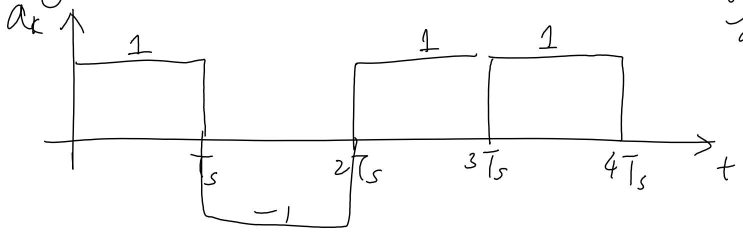
Processing gain $\frac{1228.8}{19.2} = 64$

CDMA - handout1

Thursday, February 6, 2020 9:02 AM

Sender Side:

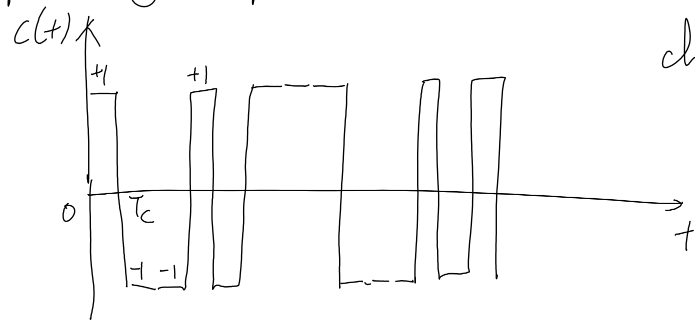
Binary data a_k



symbol duration T_s

$$a_k \rightarrow \underset{\uparrow \atop \cos\omega_0 t}{\otimes} \rightarrow \underset{\uparrow \atop c(t)}{\otimes} \rightarrow s(t) =$$

Spreading sequence $c(t)$

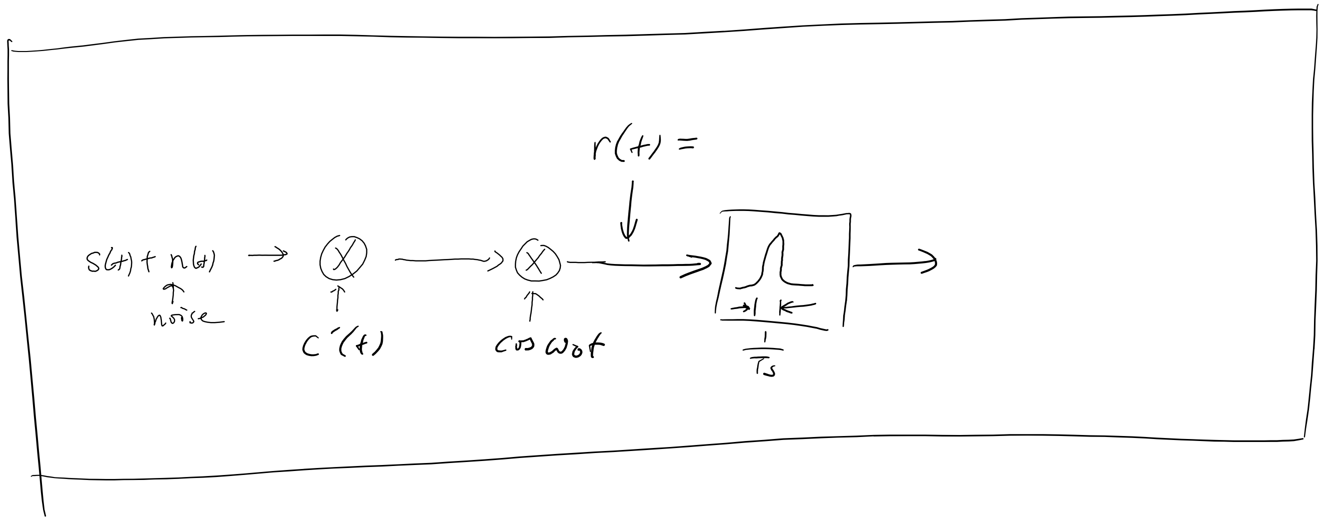


chip-duration $T_c \ll T_s$

CDMA - handout2

Thursday, February 6, 2020 9:02 AM

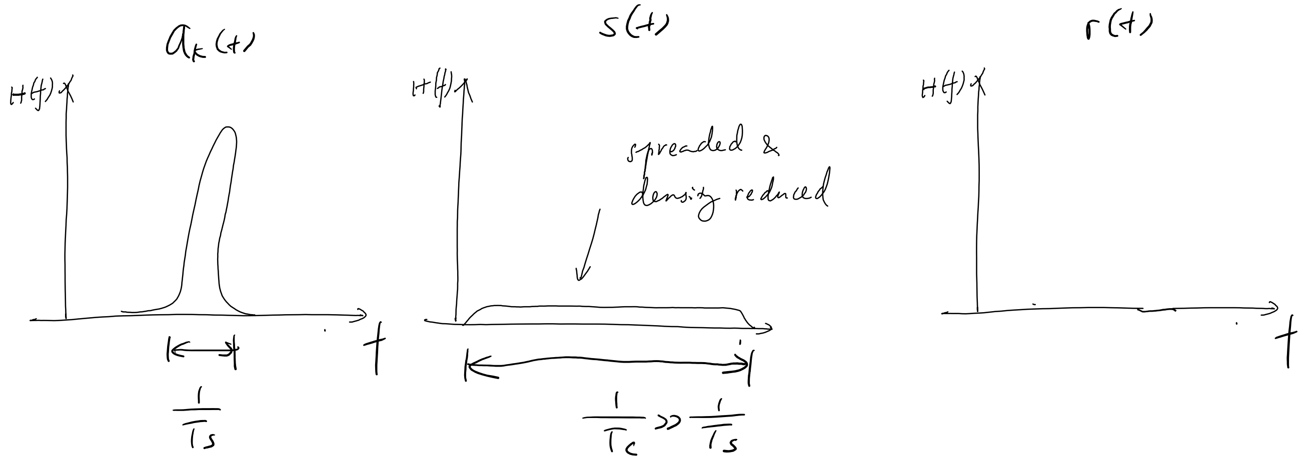
Receiver Side



① For the intended signal, take $C'(t) = C(t)$.
- the same spreading code and perfect synchronization

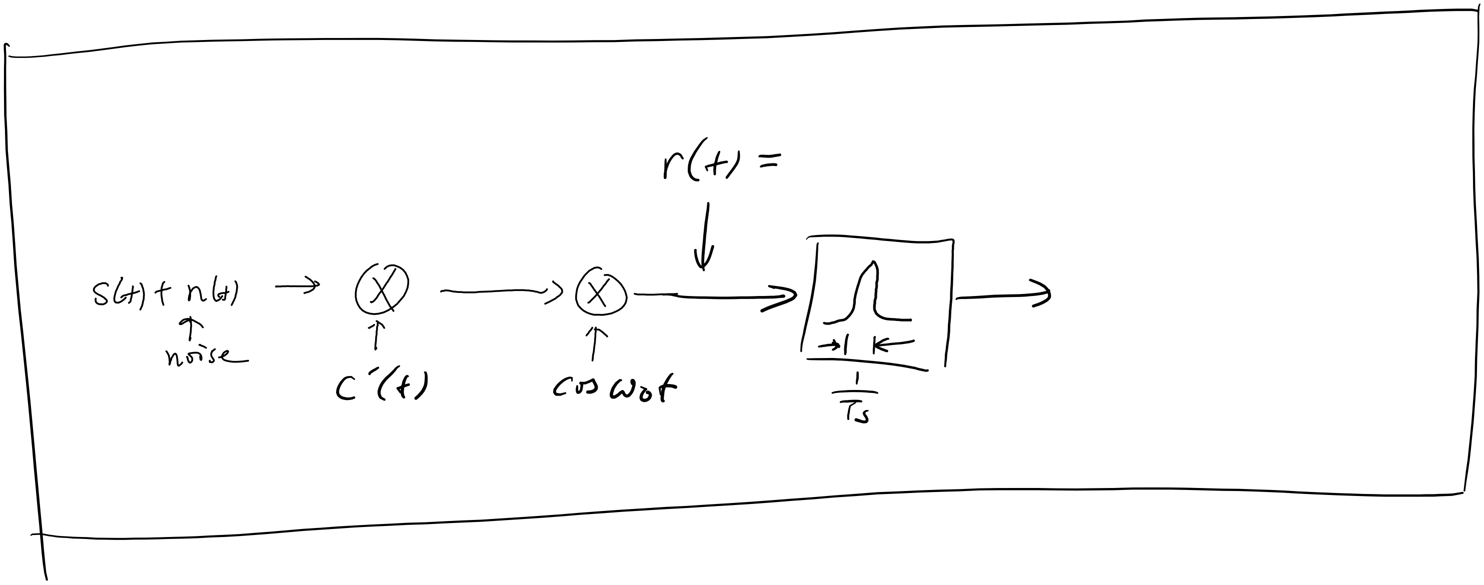
Then $r(t) =$

What are the bandwidths of the signals?



CDMA - handout3

Thursday, February 6, 2020 9:02 AM



(2) Consider instead the transmission of another user

$$\hat{s}(t) = \sqrt{2P}\cos(\omega_0 t)\cdot \hat{a}_k(t)\cdot \hat{c}(t)$$

At the receiver

$$\hat{r}(t) =$$

Since $\hat{c}(t) \neq c(t)$, $\hat{r}(t)$ looks like another pseudo-random sequence

$\Rightarrow$ bw of $\hat{r}(t)$ is $B_C \gg B_S$

— When we put a band-pass filter with bw $B_S = 1/T_s$, the power of the interfering signal is reduced to

$$P \cdot \frac{1}{T_s} \quad = P/\ldots$$

$$P \frac{\frac{1}{T_s}}{\frac{1}{T_c}} = P/W$$

where $W = \frac{T_s}{T_c}$ is processing gain

— Another possibility is to use orthogonal codes such that

$$\int_0^{T_s} \tilde{c}(t) c(t)\, dt = 0$$

- No interference from $\tilde{S}(t)$ at all!
- However, # of orthogonal codes is usually limited.
- Further, orthogonality may be lost if the synchronization is off.