In the Name of God

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**Data Network HW#1**

(Physical Layer)

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1. Give a paragraph about multiplexing techniques and their well-known applications including FDM, TDM and CDM.

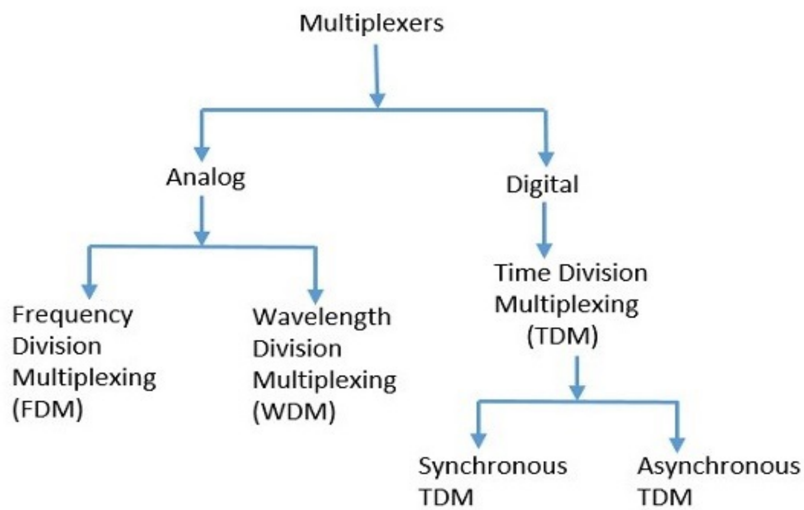
Brief Answer:

There are 3 main multiplexing techniques used in communication systems:

1. Frequency Division Multiplexing(FDM); which takes the signals to distinct frequency ranges over a single medium
2. Time Division Multiplexing(TDM); which is a digital technique, that there is time divided to slots in every frame, and the slots are allocated to every signals bit.
3. Code Division Multiplexing(CDM); which uses entire time and frequency bound for every signal where each of them uses a code, in length m bits, to transmit a message.

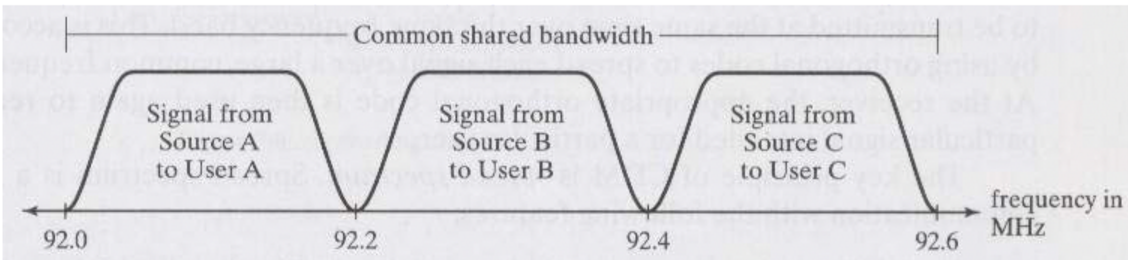
Detailed Answer:

There are mainly two types of multiplexers, namely analog and digital:



1. **Frequency Division Multiplexing:**

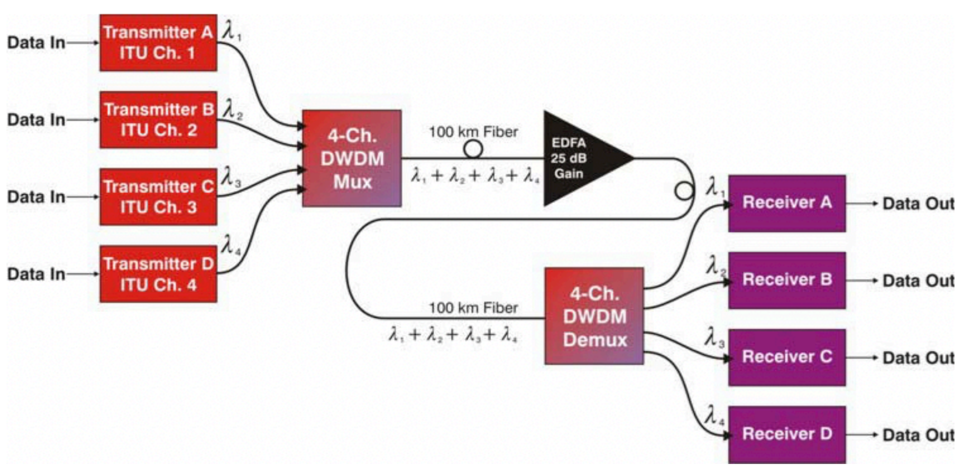
FDM is the most used technique in analog multiplexing. This technique uses various frequencies (non-overlapping frequencies, the sub-bounds of total bandwidth) to combine streams of data, for sending them on a communication medium, as a single signal.




**Example Application:** A traditional television transmitter, which sends a number of channels through a single cable uses FDM.

2. **Wavelength Division Multiplexing:**

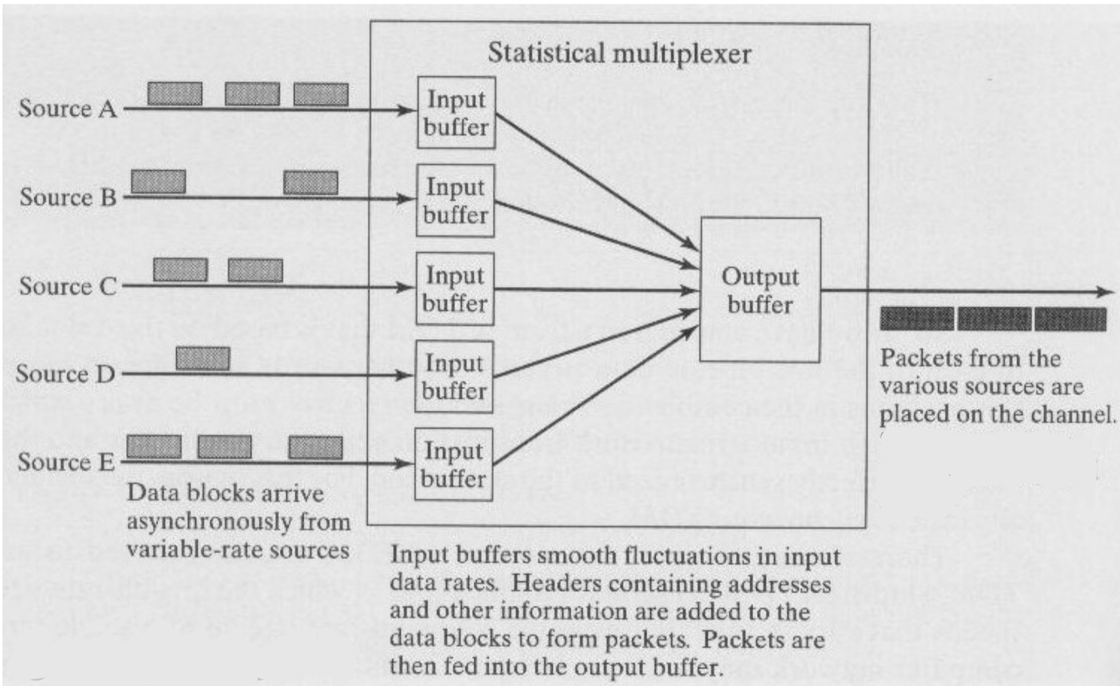
Wavelength Division multiplexing (WDM) is an analog technique, in which many data streams of different wavelengths are transmitted in the light spectrum. If the wavelength increases, the frequency of the signal decreases. A prism, which can turn different wavelengths into a single line, can be used at the output of MUX and input of DEMUX.




**Example Application:** Optical fiber communications use WDM technique, to merge different wavelengths into a single light for communication.

### 3. Time Division Multiplexing:

In Time Division Multiplexing (TDM), the time frame is divided into slots. This technique is used to transmit a signal over a single communication channel, by allotting one slot for each message.




**Example Application:** Some web proxy servers (e.g. polipo) use TDM in HTTP pipelining of multiple HTTP transactions onto the same TCP/IP connection.

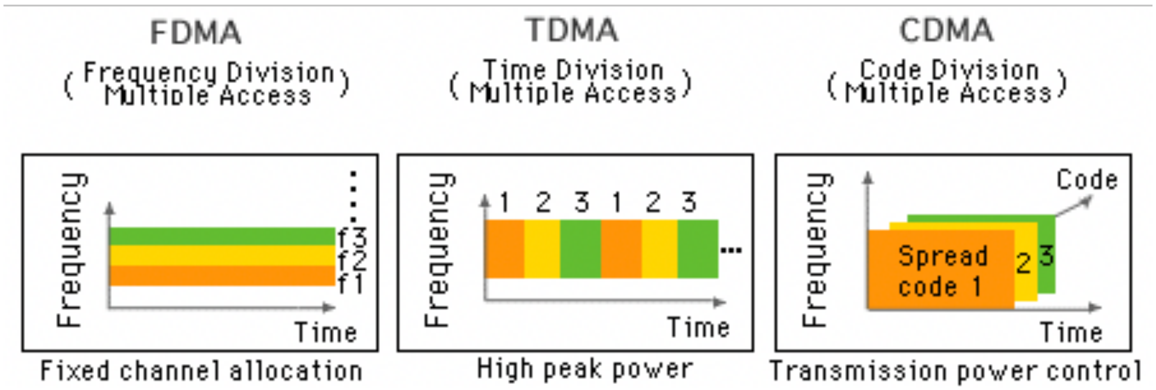
Synchronous TDM: In Synchronous TDM, the input is connected to a frame. If there are 'n' number of connections, then the frame is divided into 'n' time slots. One slot is allocated for each input line.

In this technique, the sampling rate is common for all signals and hence the same clock input is given. The MUX allocates the same slot to each device at all times.

Asynchronous TDM: In Asynchronous TDM, the sampling rate is different for each of the signals and a common clock is not required. If the allotted device for a time slot transmits nothing and sits idle, then that slot can be allotted to another device, unlike synchronous

4. **Code Division Multiplexing:**

Code division multiplexing(CDM), Code division multiple access(CDMA) or spread spectrum is a class of techniques where several channels simultaneously share the same frequency spectrum, and this spectral bandwidth is much higher than the bit rate or symbol rate. E channel transmits its bits as a coded channel-specific sequence of pulses called chips. Number of chips per bit, or chips per symbol, is the spreading factor.




**Example Application:** Global Positioning System(GPS).

Other techniques literature:

- **Space Division Multiplexing**: the use of separate point-to-point electrical conductors for each transmitted channel.
- **Polarization Division Multiplexing**: uses the polarization of electromagnetic radiation to separate orthogonal channels
- **Orbital angular momentum multiplexing:** IDK!

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2. Consider a channel with bandwidth W=1 MHz and SNR =20 dB, and we want to allocate this channel among M=10 users.

- What bit rate is available to each user if we divide the entire channel into M channels of equal bandwidth?
- What bit rate is available to each user if the entire frequency band is used as a single channel and TDM (time division multiplexing) is applied?
- How does the comparison of (a) and (b) change if the FDM (frequency division multiplexing) scheme in (a) requires a guard band between adjacent channels? Assume the guard band is 10% of the channel bandwidth.

a) $20_{dB} = 10\log(SNR) \Rightarrow SNR = 10$

$W_{user} = W/M = 100_{kHz}$

$C_{user} = W_{user}\log_2(1+SNR)\ \frac{bits}{sec} = 100_{kHz}\times\log_2(1+100) \approx 666\ kbps$

b) $SNR = 10$

$C_{total} = W\log_2(1+SNR)\ \frac{bits}{sec} = 1_{MHz}\times\log_2(1+100) \approx 6.66\ Mbps$

$\Rightarrow C_{user} = C_{total}/M = 666\ kbps$

c) $SNR = 10$

$M_{effective} = (1+10\%)\times M = 11$

$W_{user} = W/M_{effective} \approx 90.91_{kHz}$

$C_{user} = W_{user}\log_2(1+SNR)\ \frac{bits}{sec} = 90.91_{kHz}\times\log_2(1+100) \approx 605\ kbps$

**Conclusion:** In ideal world, TDM and FDM have same efficiencies; but in practice, because of the FDM guard band, TDM provides better Data Rate (but this has been extremely improved in OFDMs!).

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3. A cable company decides to provide Internet access over cable in a neighborhood consisting of 5000 houses. The company uses a coaxial cable and spectrum allocation allowing 100 Mbps downstream bandwidth per cable. To attract customers, the company decides to guarantee at least 2 Mbps downstream bandwidth to each house at any time. Describe what the cable company needs to do to provide this guarantee.

The constrains: "each house at any time" entails to provide 5000 * 2Mbps = 10Gbps downstream at any time in this neighborhood. This means the company needs at least 100 coaxial cables to do this job!

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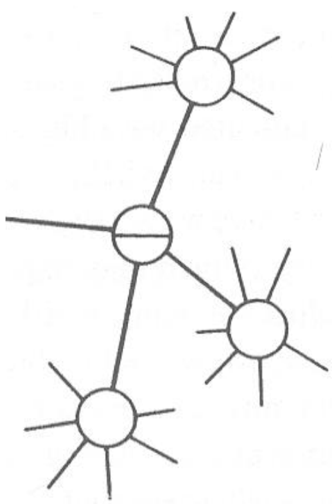
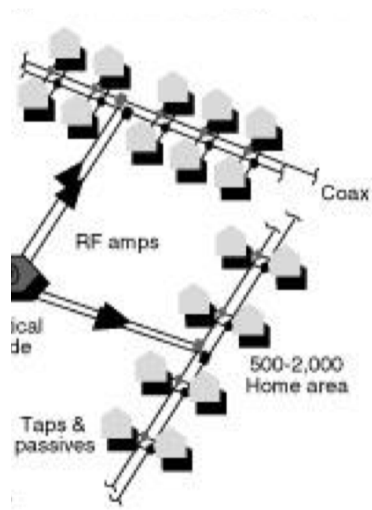
4. At the low end, the telephone system is star shaped, with all the local loops in a neighborhood converging on an end office. In contrast, cable television consists of a single long cable snaking its way past all the houses in the same neighborhood. Suppose that a future TV cable were 10 Gbps fiber instead of copper. Could it be used to simulate the telephone model of everybody having their own private line to the end office? If so, how many one-telephone houses could be hooked up to a single fiber?






Why not! (We know the telephone network is not private; so, we don't discuss about coding it safely) In fiber, by allocating a single unique wavelength to every house, we will have a private line for everybody to the end office; and also, it will be possible to allocate one wavelength to many houses by coding techniques. In this way, and by assuming 4kHz as voice bandwidth, we will have:

$$Voice\ Frequency\ Range \approx 4kHz$$

so, according to Nyquist theorem:

$$Voice\ Minimum\ Sampling\ Rate = 8000\ \frac{samples}{sec}$$

and assuming that samples are digitalized(quantized) by 8 bits:

$$\Rightarrow Minimum\ Bit\ Rate\ of\ Voice\ Communication = 8 \times 8000 = 64\ kbps$$

therefore, using a TDM and its DEMUX for houses:

$$Maximum\ Number\ of\ Houses = \frac{10\ Gbps}{64\ kbps} = 156250$$

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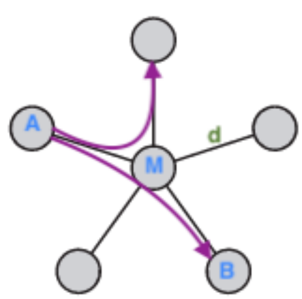
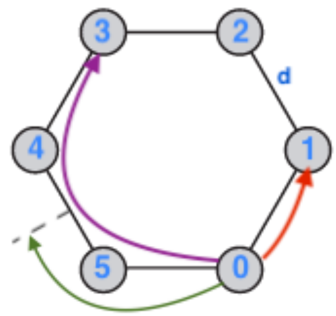
5. (Bonus)Three packet-switching networks each contain n nodes. The first network has a star topology with a central switch, the second is a (bidirectional) ring, and the third is fully interconnected, with a wire from every node to every other node. What are the best-, average-, and-worst case transmission paths in hops?

1) Star topology



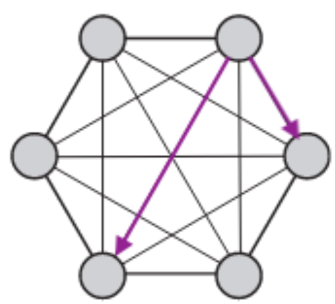

In star topology, all nodes appear the same. All paths from one node(A) to another(B), crosses the center M; so, assuming d the distance between nodes to center, all paths have the 2d distance, and min(d1+d2) is the best and max(d1+d2) is the worst ones in total network.

2) Ring topology




In an undisrupted ring topology, the nearest node, in distance d, has the best transmission time (the red arrow), the farthest node in ring is the worst (the purple arrow, with length L/2 is the total ring length is L) and in average, expectedly, a path half the longest has the average transmission path in network (the green arrow, with length L/4). But in a disrupted path, which ring topology works well in these conditions, the longest path is between two adjacent nodes with disrupted path in one direction; then the path will be L-d, and in this condition the average path will be like the purple arrow, L/2.

3) Fully interconnected topology



In big networks, providing a fully connected topology is infeasible and expensive. Topological distance between all nodes are 1; but in practice, the best transmission time is for nearest nodes, the worst for longest paths and in average, for the average path between nodes in total network.

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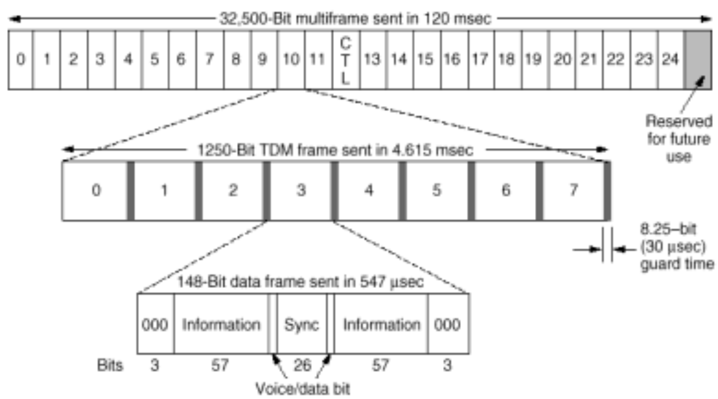
6. (Bonus)D-AMPS has appreciably worse speech quality than GSM. Is this due to the requirement that D-AMPS be backward compatible with AMPS, whereas GSM had no such constraint? If not, what is the cause?

Almost yes; D-AMPS using 30kHz channel in AMPS, and restricted frequency bound because of TDM access; so, there are many devices using only one frequency bound and this needs high digital compression. But GSM, developed to use various channels in frequency (uses FDM and TDM together) and has easier frequency re-use.

And somehow, another reason, is their data coding structures. GSM codes voice digital signal in frames with are enhanced by information bits, and some bits named Sync. These enhancements cause more efficient coding-decoding operations in GSM networks.

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7. Which technologies are using CMD today? What about TDM and FDM? List some of well-known applications.

CDMA Applications:

- Wireless laptop modems
- Internet capable cellphones
- PDA's
- Global Positioning System(GPS)
- New generations in mobile networks (3G, 4G, …)
- Military applications and radar

TDM Applications:

- GSM mobile networks
- Home telephone services (Home Wiring)
- Bluetooth (Dynamic TDMA)
- SDH/SONET networks

FDM Applications:

- Radio systems (FM/AM)
- AMPS, analog technologies
- Cable Television
- DSL Modems

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8. What is advantages of CDM to FDM or TDM? What about the disadvantages?

CDM advantages:

- Does not require any synchronization
- More number of users can share a same bandwidth
- Well-matched with other cellular technologies
- Interference is reduced due to code-word allocation.
- Much safety due to code-word allocation

CDM disadvantages:

- More complicated system required
- Both guard-band and guard-time required
- As the number of users increases, the overall quality of services decreases.
- Signal power controlling required

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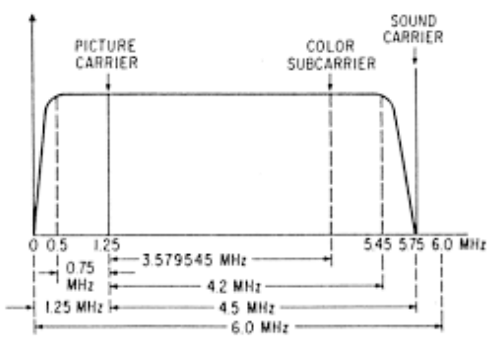
9. A cable TV system has 100 commercial channels, all of them alternating programs with advertising. Which one is more suitable, TDM or FDM? Explain your idea.

Every television user(Televisor), at one time, is watching a single channel. It means a channel must be chosen in frequencies(FDM) or distinct time slots(TDM). Obviously, it is harder for channel providers, to contract together to have their own specific time slots! So, it is more logically for channel providers to contract together to each of them have a distinct frequency bound. Therefore, the 100 channels must be transmitted by "FDM" in cable, and users can switch between channels easily by applying proper passband frequency filter on it.
Note that each channel, with various contents, is using a TDM method to broadcast different programs and advertisements along time.

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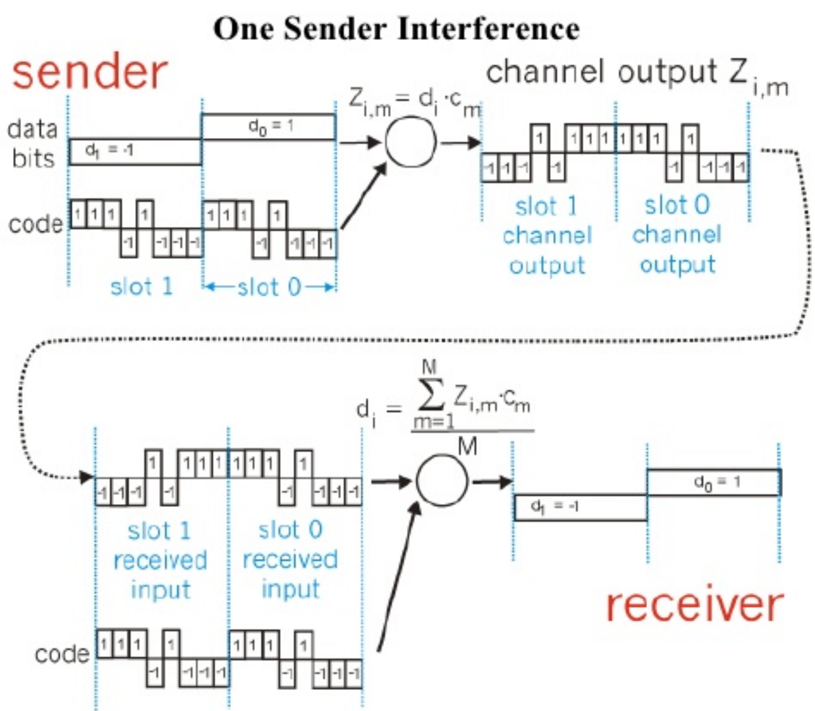
10. The following figures show the bit strings Ad = 010 and Bd = 110 that are to be transmitted by the senders A and B, respectively. Their chipping sequences (code) are given both as signal and binary sequence Ak and Bk, respectively. The question mark ? denotes an operator that you are free to choose. For both senders, draw the binary sequences and signals after spreading (Ad?Ak and Bd?Bk) as well as the resulting signal (by superposition) at the receiver.

Remarks on Operation:

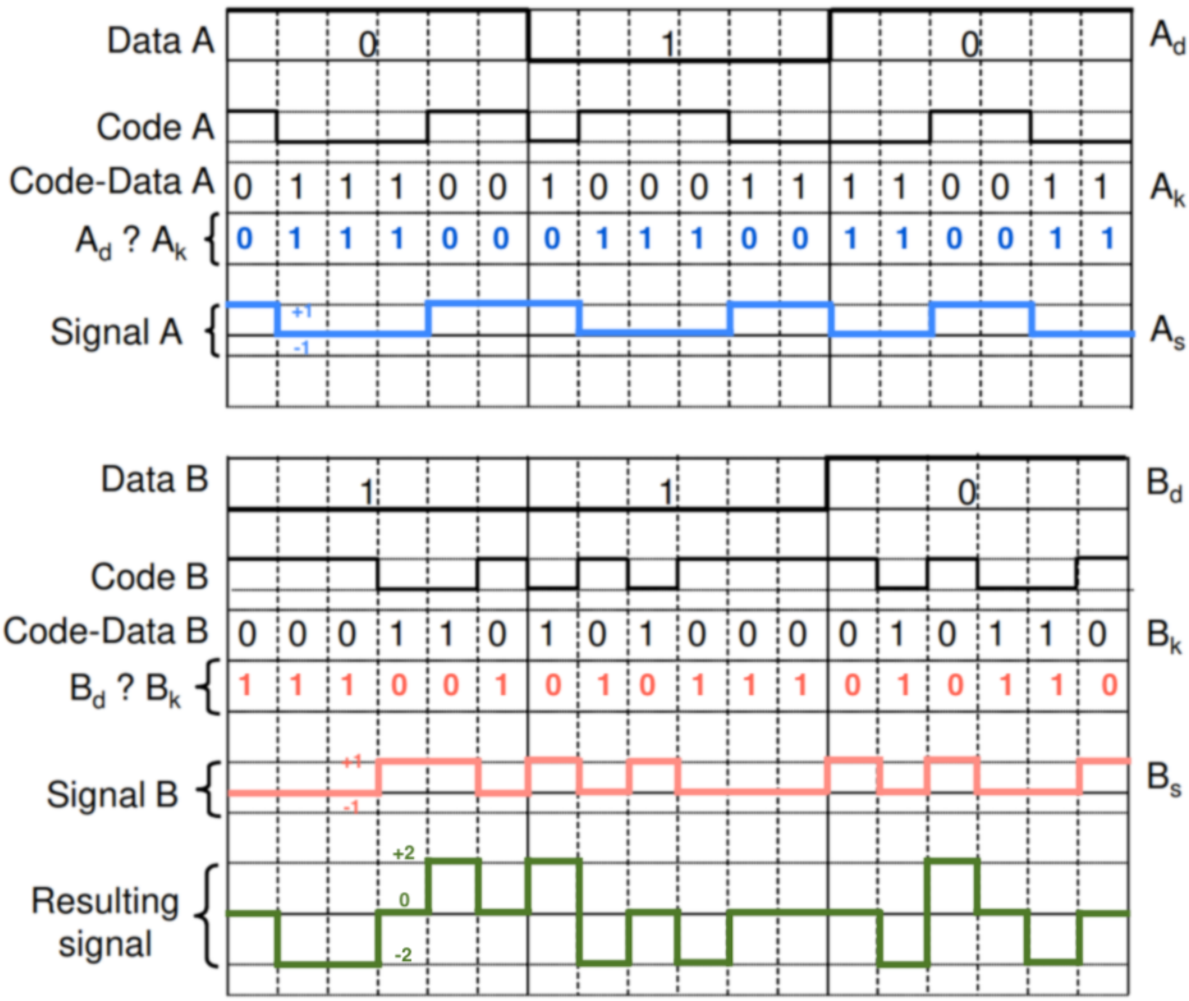
In CDMA, we are using (or, estimating) cross operator to code and decode the data. Also, voltage levels are -1 and 1 in each sender coder. For cross operator, we have:

$$
\begin{aligned}
(-1)\cdot(-1) &= (+1)\\
(-1)\cdot(+1) &= (-1)\\
(+1)\cdot(-1) &= (-1)\\
(+1)\cdot(+1) &= (+1)
\end{aligned}
$$

So, approximating this operation with a digital operator, leads us to use only XOR or XNOR. In this question, like many where, we chose XOR as '?' operator.



The result is:

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11. Show how you can extract the data bits from the received signal for sender A.

Because of code-data signals orthogonality on cross operator, we just need to do the following for each user in every time slot ("i": index of user):

$$d_i = \frac{1}{6}\sum_{m=1}^{6}\{Resulting\ Signal\}_m.\{Code\}_{m,i}$$

That we have:

$\{Code\}_A = \{[+1, -1, -1, -1, +1, +1], [-1, +1, +1, +1, -1, -1], [-1, -1, +1, +1, -1, -1]\}$
$\{Code\}_B = \{[+1, +1, +1, -1, -1, +1], [-1, +1, -1, +1, +1, +1], [+1, -1, +1, -1, -1, +1]\}$

Then for:

{Resulting Signal} = {[0, -2, -2, 0, +2, 0], [+2, -2, 0, -2, 0, 0], [0, -2, +2, 0, -2, 0]}

we get:

$\{Resulting\ signal\}\bullet\{Code\}_A = \{6, -6, +6\}$
$\{Resulting\ signal\}\bullet\{Code\}_B = \{-6, -6, +6\}$

So, $d_A = \{1, -1, 1\}$ and $d_B = \{-1, -1, 1\}$ that shows A = (0, 1, 0) and B = (1, 1, 0) bitwise.

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12. Design your own orthogonal spreading code for two senders with a spreading factor of 8.

Only orthogonality in each time slot should be satisfied; like this:

$\{Code\text{-}Data\}_A = A_k = \{[00000000], [00110011], [01100110]\}$
$\{Code\text{-}Data\}_B = B_k = \{[00011110], [00101101], [01111000]\}$

(And then, in this case:
$\{Signal\}_A$ = {[++++++++], [--++--++], [+--++--+]} volts,
$\{Signal\}_B$ = {[---++++-], [--+-++-+], [+----+++]} volts
and: {Resulting Signal} = {[0, 0, 0, +2, +2, +2, +2, 0],
[-2, -2, +2, 0, 0, 0, 0, +2],
[+2, -2, -2, 0, 0, 0, 0, +2]})

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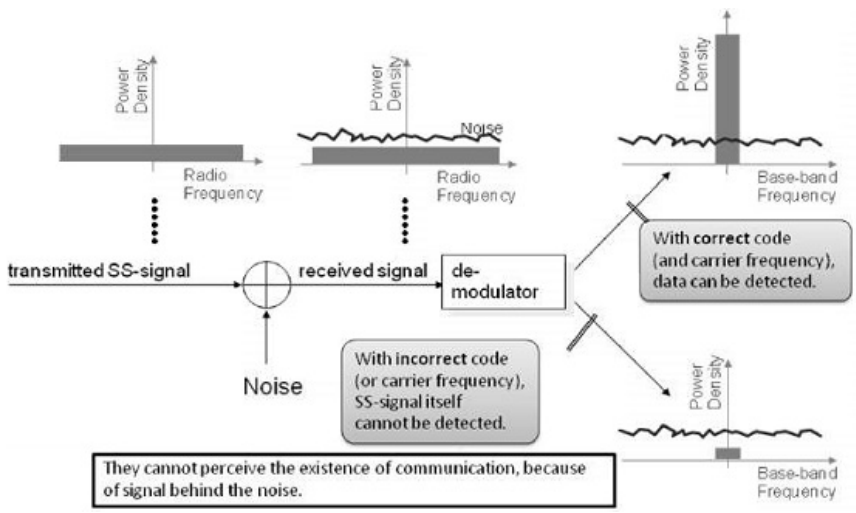
13. Suppose that the wireless channel from these two senders to the receiver can support a data rate of 48 Mbits/s. What is the maximum achievable data rate for a particular sender when your code is used?

We earn 1 bit information in every 8 chips; So:

$$User\ Bit\ Rate = \frac{48_{Mbps}}{8} = 6_{Mbps}$$

## MATLAB Section:

14. Generate a sequence of chips, the total length is number of chips per symbol times number of symbols. you only need to have two chip sequence supporting two transmitters(number of bits is yours to decide based on what you have learned about CDMA decoding). For each chip value, we generate a sequence of bits to be transmitted. Use a random number generator to pace your work. Use +1/-1 representation for both bits and chips as you have learned before in class. Spread the bit sequence into a chip sequence by proper multiplication. This gives the sequence of chips to transmit. Think about how you have to scale the magnitude of these values to reflect power density reduced by spreading. Explain your answer.




Power, in appropriate CDMA, could be under noise power level. So, the magnitude powered by 2, could be a number near SNR.

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15. Without any manipulation, unspread this chip sequence again: compute scalar product for each group of chips with the corresponding group of chipping keys, compare against zero, decide on the bit. You should get exactly the original data bits back (and your scalar products should be equal to +/- chipping sequence length). Also try to use the wrong key for users to see the obvious difference in result.

Remark: without effecting the generalization of problem, we assume 2 user here. The result is more general and easier to use in next parts.

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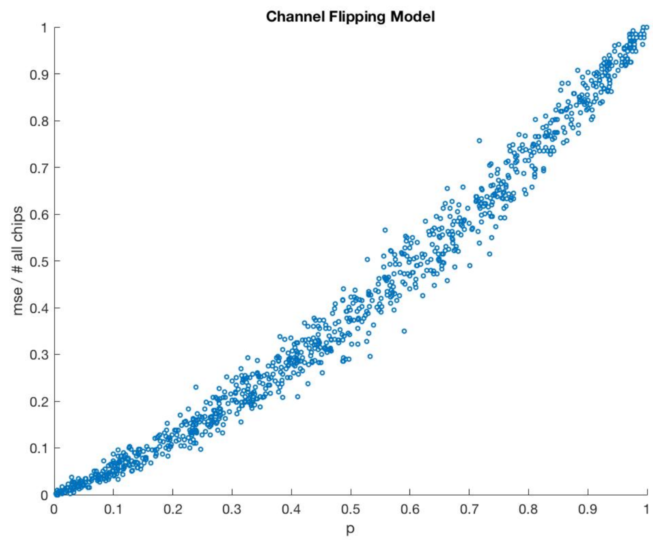
16. Now flip your chips(each bit which is going to be transmitted through the channel) with an error probability (Bernoulli model: all chip errors have identical probability, all error events are independent of each other). Unspread again, decide on bit value, compare against original bit. What do you observe? Calculate the MSE for different probabilities of Bernoulli model. Create a graph showing the relationship between the MSE and error probability.

In code, there is a section named "Channel" to do this job. But, to do this code repeatedly, a function named "mse_grapher" is declared. In general script graphing section is commented.
There is the result for 1000 running:

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17. introduce a second path: shift your sequence of chips by a certain value (thats the difference in propagation time along the two paths) and add the original and the shifted chip sequence together. Use this overlapped sum as input for despreading and bit decision. What do you observe? (Hint: Youll get interesting results if your shift value is not a multiple of a bit time.)

We consider two parameters for effect of Shifting: n_shift, as the number of chips in shift, and alpha, as the power ratio of this second path (because we know other paths are not as sharp as the main one).

We will get these results for a 10 bits data and codes 0000, with alpha=1, n_shift=1:

Data A = -1 -1 -1 -1 1 1 -1 -1 1 1
Decoded A = -1.50 -2.50 -1.50 0 -2.00 2.00 -1.00 -2.50 2.00 1.00

And for B with code 0011:

Data B = -1 1 1 -1 -1 1 -1 1 1
Decoded B = 1.50 -1.50 1.50 -1.00 1.00 -1.00 2.00 -1.50 1.00 -2.00

n_shift=2:

Data A = 1 -1 -1 1 -1 1 -1 -1 1 -1
Decoded A = -2 0 -3 1 -1 1 -1 -2 1 -2
Data B = -1 1 -1 1 1 1 1 1 1 -1
Decoded B = 0 0 -1 -1 1 -1 1 0 -1 0

n_shift=3:

Data A = -1 1 -1 -1 1 1 1 1 1 -1
Decoded A = -1.50 1.00 0.50 -0.50 0.50 1.00 2.50 1.50 2.00 -0.50
Data B = -1 1 1 -1 -1 -1 1 -1 -1 -1
Decoded B = -0.50 0 0.50 1.50 -1.50 -2.00 0.50 -0.50 -1.00 -0.50

n_shift=4:

Data A = 1 -1 -1 -1 1 -1 -1 1 1 1
Decoded A = 1 0 -2 -2 0 0 -1 0 2 1
Data B = -1 1 1 -1 -1 -1 1 1 1 -1
Decoded B = -1 0 2 0 -2 -2 -1 2 2 -1

Therefore, we understand the shape of the codes are important in result (for example here we had an even symmetry and we got integer numbers in even shifting).

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18. Use the knowledge of the size of the shift. Reverse this shift, feed this into despreading, decide on bits, compare. What do you observe? (Hint: as a little test, look what happens when you use a wrong value to undo the shifting; your error performance should be quite bad.)

We use 4 recursions in shift error correction:

```
% Error Correction:
m_shift = n_shift;
fine_signal = receiving_signal - alpha * [zeros(1,m_shift), receiving_signal(1:end-m_shift)] + ...
                                 alpha^2 * [zeros(1,2*m_shift), receiving_signal(1:end-2*m_shift)]-...
                                 alpha^3 * [zeros(1,3*m_shift), receiving_signal(1:end-3*m_shift)]+...
                                 alpha^4 * [zeros(1,4*m_shift), receiving_signal(1:end-4*m_shift)];
```

Results (in one run):

| | |
|---|---|
| No Error Correction: | mse = 14.5600 |
| Error Correction with well-known shifting: | mse = 6.8254 |
| Error Correction with wrong shifting: | mse = 18.0740 |

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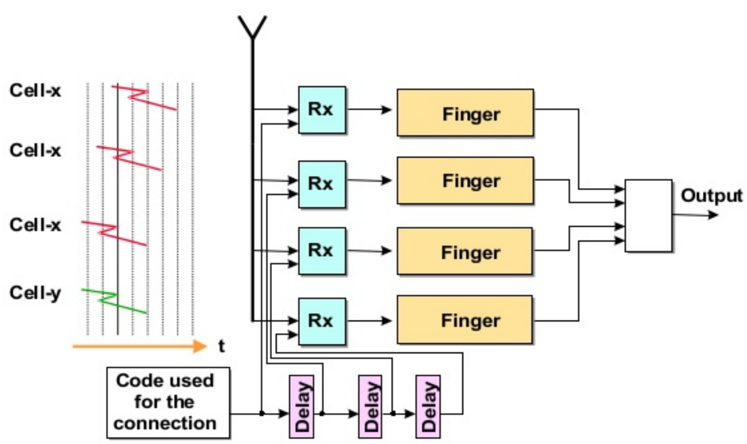
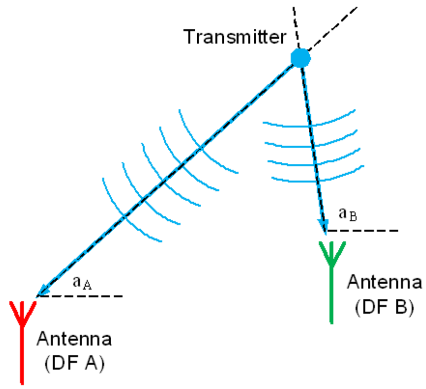
19. How can you make use of the information received along the two paths? What do you observe? For more information about this question please refer to Rake Receivers and their applications. How can a rake filter solve such a problem? Explain your answer.




Rake receiver is a well-known application to do this job.

As shown in figure, rake receiver uses some finger (like a fork) to see the signal from some different points of view. Paths will have different delays in different point of view; and this difference leads us to find the paths delay.

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20. Now consider your second transmitter. It has its own sequence of bits to transmit, its own sequence of pseudo-random chipping keys. Overlap the spreaded signals of both transmitters, unspread with the repsective keys, look at the error behavior. What do you observe?

It is shown in previous parts, too. In final code, mse is calculated the sum of two channels mse.

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- end of report -