EI - IV Wireless Communication

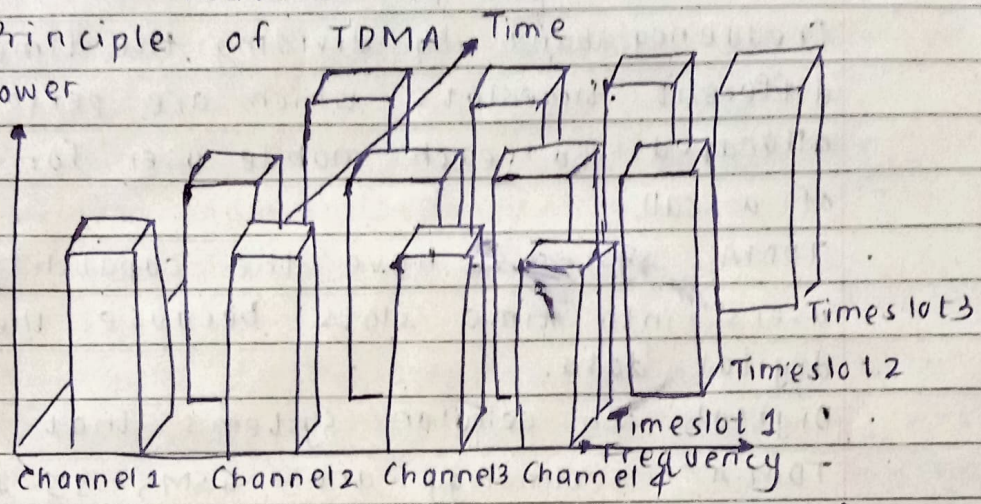
Unit III Multiple Access Techniques

Nov Dec - 2022

Q. 1.a) Explain the Principle of TDMA. What are different features of TDMA?

Ans

Principle of TDMA



Time Division Multiple Access (TDMA) is a channel-access method in which multiple users share the same frequency channel by dividing the signal into different time slots. Each user is assigned a specific time slot during which they can transmit or receive data.

- How TDMA Works

The system has several frequency channels (Channel 1, Channel 2, Channel 3, Channel 4)

- Each channel is divided into time slots (Timeslot 1, Timeslot 2, Timeslot 3).
- Users are assigned unique time slots within a channel, avoiding overlap.
- No two users transmit during the same times slot on the same frequency.
- Number of users supported = Channels x Time slots per channel

Basically, multiple users share a single carrier frequency, but at different times - time sharing.

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- In digital systems, continuous transmission is not required because users do not use the allotted bandwidth all the time.
- It allows several users to share the same frequency band by dividing the timescale into different timeslots which are periodically allocated to each mobile user for the duration of a call.
- TDMA systems have the capability to split users into time slots because they transfer digital data.
- Digital 2G cellular systems that used the TDMA technology are GSM, IS-136.
- TDMA systems divide the radio spectrum into time slots and each user is allowed to either transmit or receive in each time slots (i.e., different users can use the same frequency in the same cell but at different times).
- TDMA multiplexes three signals over a single channel.
- The evolved TDMA standard for cellular divides a single channel into six time slots, with each signal using two slots.
- In TDMA, when the caller presses the push-to-talk (PTT) switch, a control channel registers the radio to the closest base station. During registration, the base station assigns the user an available pair of channels, one to transmit and the other to receive.
- However, unlike an FDMA system registration, a TDMA system registration also assigns an available time-slot within the channel.

The user can only send or receive information at that time, regardless of availability of other time-slots.

- Information flow is not continuous for any user, but rather is sent and received in bursts.
- The bursts are re-assembled at the receiving end and appear to provide continuous sound because the process is very fast.
- In figure, each row represents a single channel and divided into three time-slots. Calls in a TDMA system start in analogue format and are sampled, transforming the call into a digital format. After the call is converted into digital format, the TDMA system places the call into an assigned slot.

Number of users supported by the TDMA system = Number of Channels in the frequency spectrum × Time slots/channel

- Advantages
- Data Transmission is in discrete bursts
  - Extended battery life over FDMA
  - Handoff process is simpler, since it is able to listen for other base stations during idle time slots.
- More efficient use of spectrum, compared to FDMA
  - Will accomodate more users in the same spectrum space than an FDMA system which improves capacity in high-traffic areas, such as large metropolitan areas.

- Efficient utilization of hierarchical cell structures - pico, micro, and macro cells.

- Disadvantages

- TDMA requires synchronization. If the time slot synchronization is lost, the channels may collide with each other.
- Network and spectrum planning are intensive.
- Dropped calls are possible when users switch in and out of different cells.
- Higher costs due to greater equipment sophistication.
- Equalization is required, since transmission rates are generally very high as compared to FDMA channels.

* Features / Characteristics of TDMA

1. Time-division multiplexing
   - Transmission is organized in repetitive frames divided into time slots.
   - Each user gets one time slot per frame.
2. Higher Capacity
   - More users can be supported because time is efficiently shared.
3. No overlapping transmissions
   - Eliminates interference between users on the same frequency since they transmit at different times.
4. Requires synchronization
   - TDMA systems need precise time synchronizatio so users transmit exactly in their slots.
5. Variable data rates
   - Users can be assigned multiple time slots for higher throughput.

6. Reduced power consumption
- Devices transmit only during their allocated time slots, allowing idle periods → saves battery.

7. Flexibility
- Allows dynamic allocation of time slots based on network load.

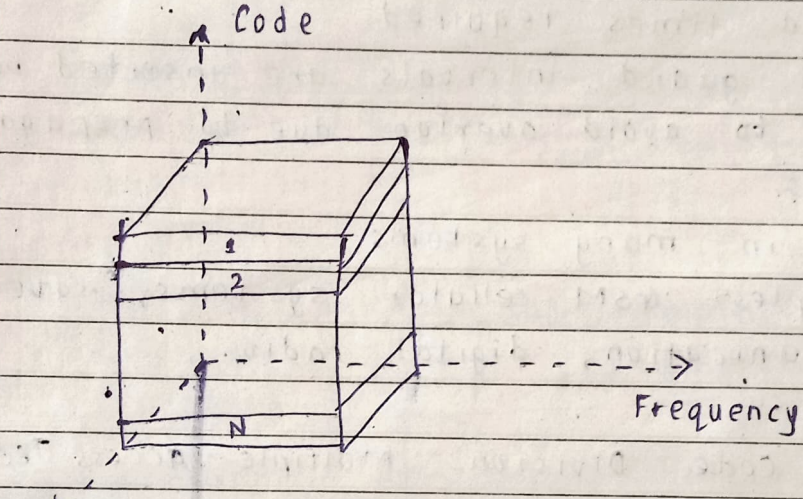
8. Guard times required
- Small guard intervals are inserted between slots to avoid overlap due to propagation delays.

9. Used in many systems,
- Examples: GSM cellular systems, satellite communication, digital radio.

Q.1 b) How Code Division Multiple-Access Technique is implanted while accessing a channel for multiple users? support your theory with example.

Ans. CDMA allows transmissions to occupy the entire bandwidth at the same time without interference.
- A spread-spectrum signal is a signal that has an extra modulation that expands the signal bandwidth beyond what is required by the underlying data modulation.
- CDMA cellular technology is originally known as IS-95, which ~~comple~~ competes with GSM technology for dominance in the cellular world.
- CDMA cellular systems operate in the 800 MHz and 1.9 GHz PCS brands.
- QUALCOMM is the developer of the CDMA air interface used in cellular systems.

- Compared to GSM cellular systems, CDMA requires fewer cellular towers and provides up to five times the calling capacity.
- CDMA also provides more than 10 times the voice traffic of earlier analogue system (AMPS) and is the basis for 3G data transmission for GSM carriers.



CDMA users access entire spectrum

- CDMA uses unique spreading codes to spread the data before transmission.
- CDMA assigns to each user a unique code sequence that is used to code data before transmission. If a receiver knows the code sequence related to a user, it is able to decode the received data.
- The codes are shared by the mobile phone and the base station. The codes are called pseudorandom code sequences.
- All the users can access the entire spectrum allocation all of the time.
- A user's unique code separates the call from all other calls.
- The signal is transmitted in a channel, which is below noise level.

- The receiver then uses a correlator to despread and will not pass through the filter.
- Codes take the form of a carefully designed one/zero sequence produced at a much higher rate than that of the base band data.
- The rate of a spreading code is referred to as chip rate rather than bit rate.
- To eliminate the noise, CDMA mobile phones and base stations use the minimum amount of power required to communicate with each other.
- By decreasing a user's transmission power, the mobile phone has added battery life, increased talktime, and smaller batteries.

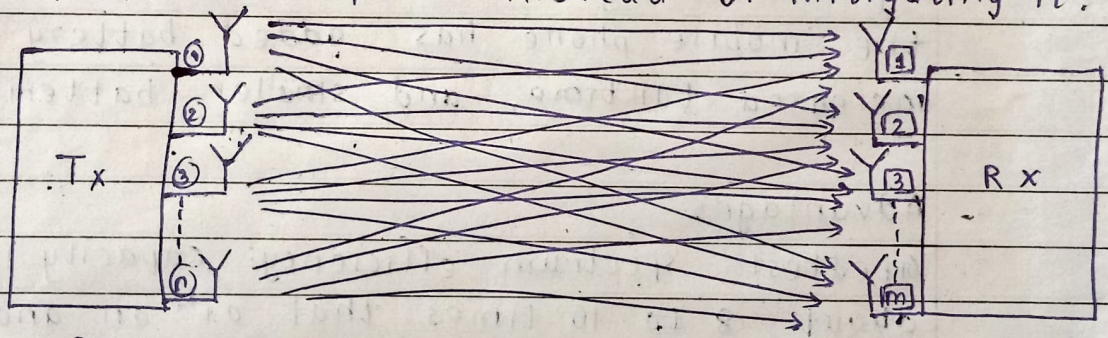
- Advantages
- Greatest spectrum efficiency: capacity increases about 8 to 10 times that of an analogue system and 4 to 5 times that of other digital systems, which makes it most useful in high traffic areas with a large number of users and limited spectrum.
- CDMA improves call quality by filtering out background noise, crosstalk, and interference.
- Simplified frequency planning: all users on a CDMA system use the same radio frequency spectrum.
  - frequency plans are not necessary.
  - Frequency re-tunes for expansion are eliminated
  - Fewer cells are required for quality coverage.
- Random walsh codes enhance user privacy.
- Precise power control increases talk time and battery life for mobile phones.

- Disadvantages
- Backwards compatibility techniques are costly.
- Equipments are expensive.
- Low traffic areas lead to inefficient use of spectrum and equipment resources.

Q.2 a) What is MIMO? Explain two formats of MIMO

Ans. A MIMO system consists of several antenna elements, plus adaptive signal processing, at both transmitter and receiver.

- First introduced at stanford University (1994) and Lucent (1996)
- Exploit multipath instead of mitigating it.



Basic structure of a MIMO system

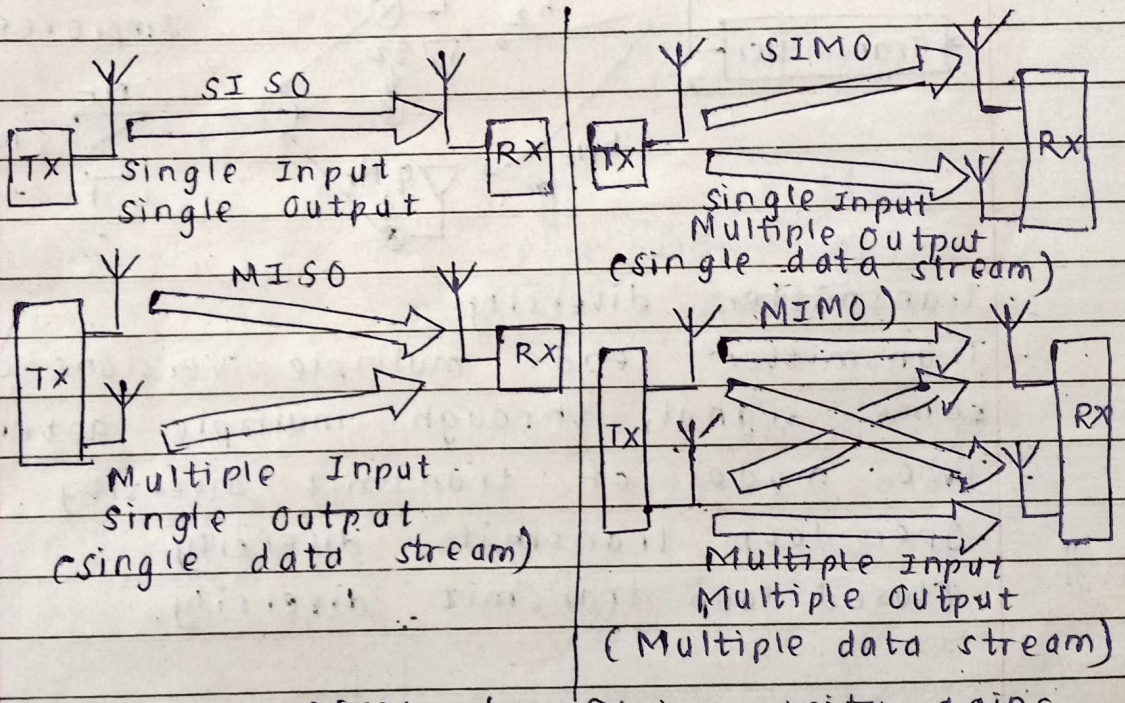
Multiple-Input Multiple-Output abbreviated as MIMO, is a wireless technology that increases the data capacity of a RF radio by using multiple transmitting and receiving antennas.

- In a MIMO system, same data is transmitted through multiple antennas over the same path in the same bandwidth.
- Because of this each signal reaches the receiving antenna through a different path, resulting in more retiable data.
- The data rate also increases by a factor determined by the number of transmit and receive antennas.

. The receiver is designed to take into account the slight time difference between receptions of each signal as they travel through different paths, any additional noise or interference, and even lost signals.

* Single-user MIMO

. Basic communication modes

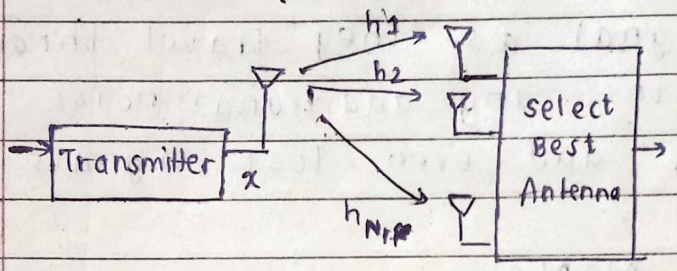


Single-user MIMO benefits: capacity gains

. Diversity gain
- Receiver diversity
- Transmit diversity

. Receiver diversity
- Receiver coherently combines signals received by multiple antennas
- Asymptotic gain: Increasing SNR proportionally to Nr (# of receive antennas)
. Intuition: received signal power adds up

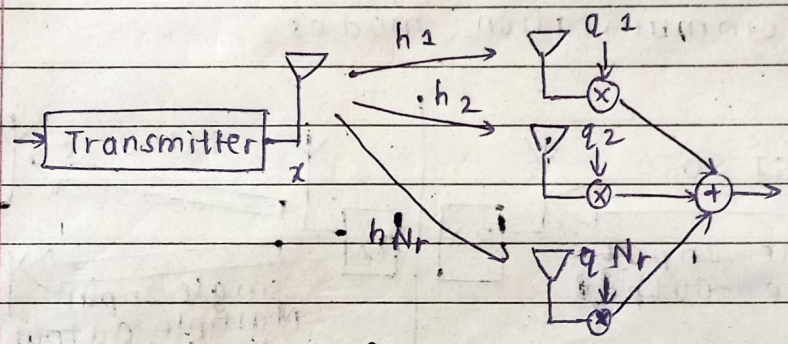
Implementing receiver diversity



* selection combining

Improves SNR to

avg SNR · $(1 + \frac{1}{2} + \ldots + \frac{1}{N_r})$



* Maximum Ratio combining

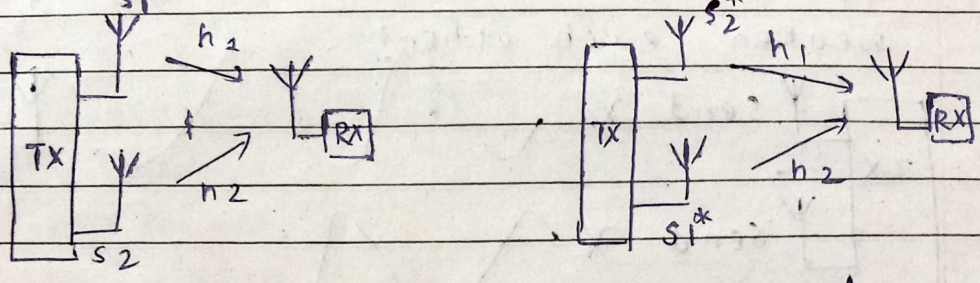
Improves SNR to

$\sum_{i=1}^{N_r} SNR_i$

- Transmitter diversity
- Transmitter sends multiple versions of the same signal, through multiple antennas
- Two modes of transmit diversity
  - Open-loop transmit diversity
  - Closed-loop transmit diversity

Open-loop transmit diversity

- Principle
- Send redundant versions of the same signa (symbol), over multiple time slots, and throug multiple antennas
- Encode the symbols differently for differen time slots and TX antenna
- Example: 2 TX antenna STBC
- Send two data ~~signal~~ symbols, s_1 and s_2

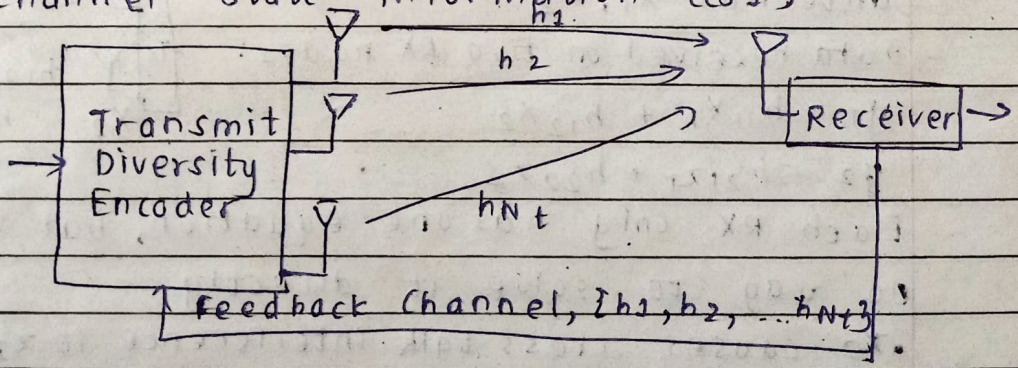


- Received signals:

$$r(t_1) = h_1 s_1 + h_2 s_2$$
$$r(t_2) = h_1 s_2^* + h_2 s_1^*$$

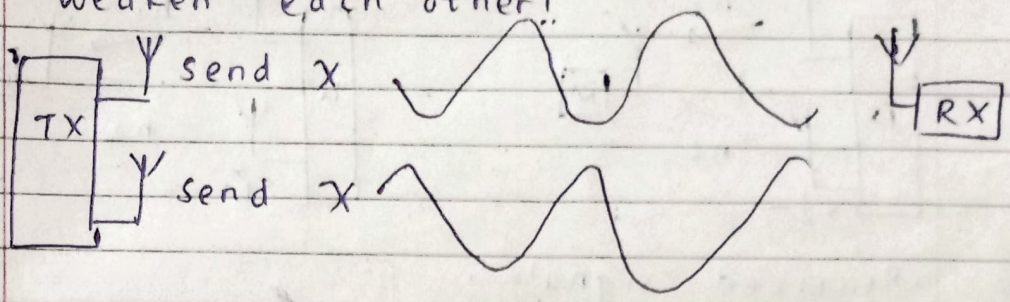
Closed-loop transmit diversity

- Principle
- Send redundant versions of the same signal (symbol), over the same time slot.
- Encode the symbols differently for different TX antennas
  - i.e., weight the symbols on different antennas, following a precoding algorithm
  - Precoding design requires feedback of channel state information (CSI)



- Why precoding?
- Signals from different antennas need to sync (align) in their phases.
- But the different channels (between TX antennas and RX antenna) distort ~~angle~~ signals differently, causing phase offset.
  - e.g. both TX antennas sends $x = e^{j2\pi ft}$, RX may receive $e^{j2\pi ft}$ one TX antenna,

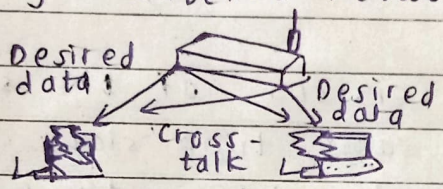
but $e^{j(2\pi f t + \varphi)}$ from the other, which weaken each other!



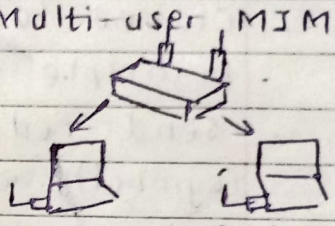
Multi-user MIMO

Concept of Multi-user MIMO (MU-MIMO)

- Single-antenna network



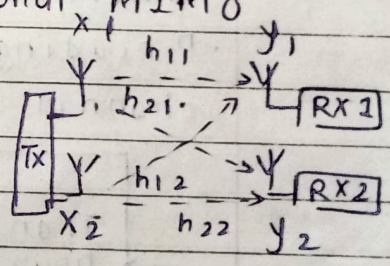
Multi-user MIMO



MU-MIMO enables multiple streams of data to be sent to different users in parallel, without cross-talk interference.

MU-MIMO differs from traditional MIMO

- Data to be sent over two TX antennas: x_1, x_2
- Data received on two RX nodes:



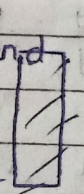
$y_1 = h_{11}x_1 + h_{12}x_2$

$y_2 = h_{21}x_1 + h_{22}x_2$

- Each RX only has one equation, but two variable no way to solve it directly
- x_2 causes cross-talk interference to x_1, & vice versa.

How to remove cross-talk?

- Send a weighted mix of x1 and x2



TX antenna1 sends: $w_{11}x_1 + w_{12}x_2$

TX antenna2 sends: $w_{21}x_1 + w_{22}x_2$

- Data received on RX1:

$y_1 = h_{11}(w_{11}x_1 + w_{12}x_2) + h_{12}(w_{21}x_1 + w_{22}x_2)$

$= (h_{11}w_{11} + h_{12}w_{21})x_1 + (h_{11}w_{12} + h_{12}w_{22})x_2$

- RX1 only wants x_1, so ideally, we should have $(h_{11}w_{12} + h_{12}w_{22}) = 0$

Q 2-b) What is OFDM technique? Also explain OFDMA transmitter and receiver.

Ans. Orthogonal Frequency Division Multiplexing

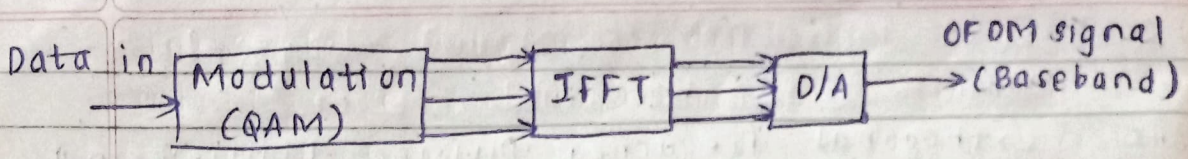
- In OFDM, a single user gets all the ~~carrier~~ subcarriers.
- In OFDMA, multiple users are assigned different sets of subcarriers at the same time.
- Many users can transmit simultaneously without interfering, as long as each is on a different set of orthogonal subcarriers.
- How it works:
  1. The available bandwidth is divided into many narrowband subcarriers. (all orthogonal)
  2. Each user gets a subset of these subcarriers.
  3. Resource allocation can be dynamic (depends on channel quality, data rate needs, etc.)

Example:

- Suppase system bandwidth = 20 MHz → split into 1024 subcarriers.
- User A → subcarriers 1-256.
- User B → subcarriers 257-512.
- User C → subcarriers 513-768.
- User D → subcarriers 769-1024.
- All four users transmit at the same time, on the same total bandwidth, but on different subcarriers.

OFDMA Transmitter

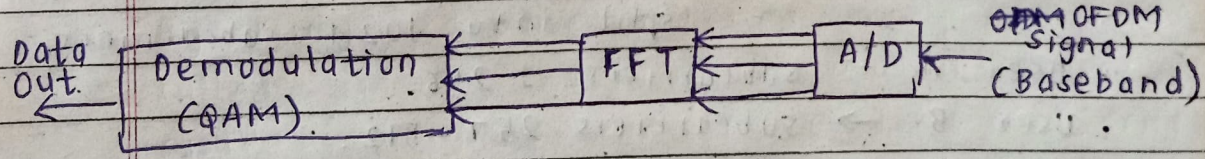
The OFDMA transmitter performs the same initial steps as an OFDM transmitter, but with an added layer of resource allocation:



1. User Data Preparation: Data streams from multiple ~~peop~~ users are prepared.
2. Resource Allocation/Mapping: A crucial step in OFDMA where the system decides which specific groups of subcarriers (sometimes called resource blocks) are assigned to which users based on their needs and channel conditions.
3. Modulation and IFFT: The data for all users is modulated onto their assigned subcarriers and combined using a single IFFT operation into one composite signal for broadcast.
4. Transmission: The combined signal is upconverted and transmitted wirelessly.

OFDMA Receiver:

The OFDMA receiver is designed to separate the shared signal back into individual user data streams:



1. Demodulation and FFT: The receiver ~~receives~~ captures the signal, downconverts it, and uses a Fast Fourier Transform (FFT) to break the signal back down into its individual subcarriers.
2. De-mapping/De-allocation: Based on the resource allocation information shared with the transmitter, the receiver extracts only the subcarriers designated for that specific user.
3. Demodulation and Parallel-to-Serial Conversion: The extracted data is demodulated and

reassembled into original high-speed data stream for that user.

May-Jun 2023

Q.2-a) What is SDMA? Explain in detail Space Division Multiple Access Technique.

Ans. In addition to frequency, time, and code domains, the spacial dimension can also be used for multiplexing of different data streams by transmitting the data streams over different, non-overlapping transmission channels. The use of space division multiplexing for multiple access is termed SDMA

- SDMA enables users to share simultaneously the same bandwidth in different geographical locations.
- SDMA solves capacity problem of wireless communication systems by exploitation of the spacial dimension which makes it possible to identify the individual users, even when they are in the same time/frequency/code domains.
- SDMA can be achieved using beam forming or sectorization.

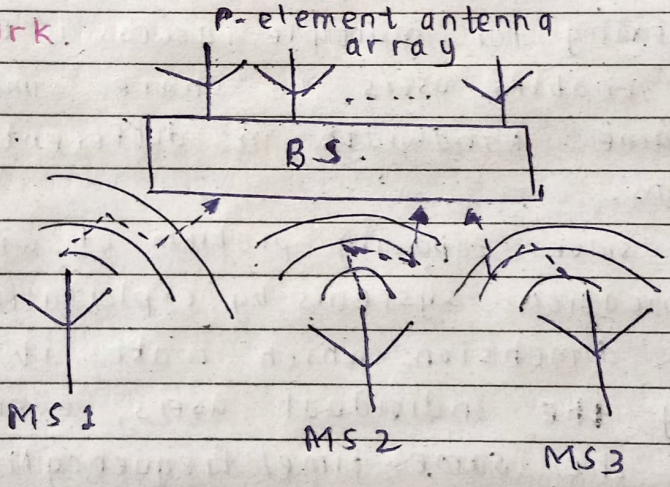
Omnidirectional antenna-based traditional cellular networks

In traditional mobile cellular network systems, the base stations have no information on the position of the mobile units within the cell, and base stations radiate the signal in all directions within the cell in order to provide radio coverage. These result in wasting power on re-transmissions when there are no mobile

units to reach, in addition to causing interference for adjacent cells using the same frequency, so called co-channel cells.

- In the same way, in reception, the antenna receives signals coming from all directions including noise and interference.
- These considerations have led to the development of the SDMA technique, which is based on deriving and exploiting information on the spacial position of mobile terminals.

Adaptive antenna or SDMA-based cellular network.



SDMA concept, employing a p-element antenna array for supporting 3 mobile users.

- By using adaptive antenna arrays, sometimes called smart antennas in mobile radio systems, signals can be received and sent only from and into a limited angular range, following the directional nature of multipath.
- This improves coverage or link quality in noise-limited situations and enhances capacity in interference-limited situations.
- Each user exploiting a single-transmitter-antenna-aided mobile station simultaneously communicates with the base station equipped with an array of receiver antennas.

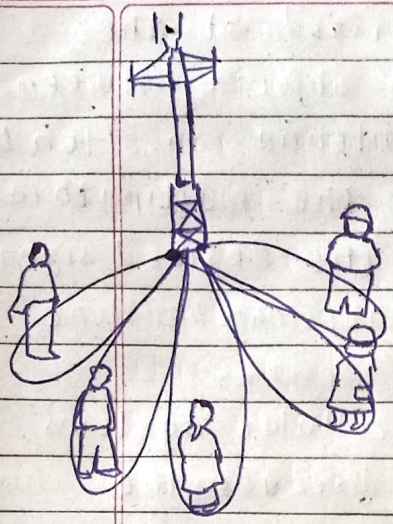


Figure 1 Multiple users belonging to the same cell use the same channel

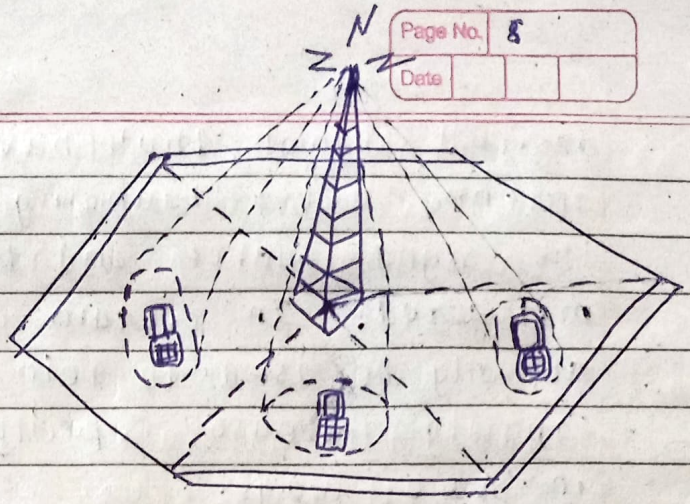


Figure 2 Intra-cell SDMA

Figure 2 shows spacially filtered base station antenna serving different users by using spot beams.

- SDMA controls the radiated energy to each user in space (figure 1) by using adaptive antenna array patterns.
- These different areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system).
- Sectorized antennas may be thought of as a primitive application of SDMA.

Advantages

- Range extension: When a system is constructed using SDMA, the number of cells required to cover a given area can be substantially reduced.
- Interference suppression: Interference from other systems and from users in other cells is significantly reduced by exploiting the desired user's unique channel impulse responses. In "noisy" areas where range is limited by interference, spacially selective transmission and reception result in range extension.
- Multipath effect elimination: The copies of the

desired signal that have arrived at the antenna after bouncing from objects between the signal source and the antenna can often be mitigated. In certain cases, the multipath can actually be used to reinforce the desired signal.

Capacity Increase: Capacity increase can be done in two ways:

Channel reuse patterns in cellular systems can be significantly tighter because the
- average interference resulting from co-channel signals in other cells is markedly reduced (e.g., moving from a 7-cell to a 4-cell reuse pattern nearly doubles capacity).
- Separate spacial channels can be created in each cell on the same conventional channel. In other words, intercellular reuse of conventional channels is possible (fig.2)

Compatibility: SDMA is compatible with most of the existing modulation schemes, carrier frequencies and other specifications.

Nov-Dec 2023

Q.1 b) Elaborate on usefulness of MIMO (Multiple Input Multiple Output) technique in multiple access environment

Ans. In multiple access environment, MIMO techniques significantly boost performance by increasing network capacity, improving spectral efficiency, and enhancing user experience. MIMO achieves this by using multiple antennas at both the transmitter and receiver to send and receive multiple data streams simultaneously over the same radio channel, which allows for more users and higher data rates even under heavy load.

It also mitigates the effects of fading and interference, leading to more reliable and higher-quality connections.

Benefits of MIMO in multiple access environments

- Increased capacity: By transmitting multiple data streams at once, MIMO increases overall throughput of the network. For example, an 8x8 MIMO router can support multiple high-bandwidth streams simultaneously to different devices (like video streaming to a TV and online gaming to a laptop)
- Higher spectral efficiency: MIMO allows for a more efficient use of the limited radio spectrum by serving more users or providing higher data rates within the same bandwidth.
- Improved reliability: MIMO utilizes multiple antennas to combat fading, which is when a signal is weakened or distorted by reflections. It can process signal fragments from different paths to reconstruct the original data, ensuring a more reliable ~~comm~~ connection and better signal quality.
- Enhanced coverage: MIMO's ability to explcit multipath propagation can improve signal quality over a wider area, extending network coverage and providing more consistent performance for users in various locations, such as within a crowded university campus or office building.
- Support for more users: By boosting capacity and spectral efficiency, MIMO allows a single base station or access point to handle a larger number of connected devices without a significant drop in performance.

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Q.2.a) How would you differentiate between CDMA (Code Division Multiple Access) and SDMA (Space Division Multiple Access)?

Ans.

	CDMA	SDMA
Idea	Spread the spectrum using orthogonal codes.	Segment space into cells/sectors.
Terminals	All terminals can be active at the same place at the same moment, uninterrupted.	Only one terminal can be active in one cell/one sector.
Signal separation	Code plus special receivers	Cell structure directed antennas
Advantages	Flexible, less planning needed, soft handover	very simple, increases capacity per km^2
Disadvantages	Complex receivers, needs more complicated power control for senders	Inflexible antennas typically fixed
Comment	Used in many 3G systems higher complexity, lowered expectations; integrated with TDMA/FDMA	Only combination with TDMA, FDMA, or CDMA useful

Q.2.b) What do you understand by IDMA (Interleave Division Multiple Access)? Discuss in detail.

Ans. Interleave Division Multiple Access (IDMA)

- In CDMA, users are separated by unique codes.
- In IDMA, users are separated by different interleavers (bit-level scrambling patterns).
- All users can transmit at the same frequency

SDMA uses beamforming to direct signals

and same time, but the receiver can separate them based on their interleaving patterns.

How IDMA works

- Each user's data bits are passed through a unique interleaver (a permutation device that changes the order of bits).
- Interleaved signals are transmitted simultaneously over the same channel.
- At the receiver:
  - A de-interleaver reorders bits
  - An iterative multi-user detector (MUD) separates the users' signals.

Working Principles:

- Data Symbol Generation: The data symbols are generated by the transmitter.
- Interleaving: The data symbols are interleaved using a unique interleaver sequence assigned to each user.
- Mapping: The interleaved data symbols are mapped onto the available time slots.
- Transmission: The mapped data symbols are transmitted over the wireless channel.

Example:

- User A → interleaver pattern [2, 4, 1, 3]
- User B → interleaver pattern [3, 1, 4, 2]
- User C → interleaver pattern [4, 3, 2, 1]
- Even though all users transmit together, the receiver can separate them using their unique interleavers.

Features of IDMA

- Low transmitter complexity → only interleaving (much simpler than coding).
- Higher receiver complexity → requires iterative detection.
- Supports large number of users (scalable).

- Good performance in multi-user interference environments.
- Works well ~~with~~ in uplink (multiple users to base station).

Real-world Applications: Mobile, satellite, sensor network communication.

- Proposed for 4G and 5G uplink communication.
- Suitable where many users need simultaneous access (e.g., IoT, sensor networks).
- Imagine three students writing in one common notebook at the same time.
- To avoid mixing:
  - Student A writes only on odd-numbered pages.
  - Student B writes only on even-numbered pages.
  - Student C writes in reverse order pages
  - when reading, the reader can easily separate each student's work by their unique writing pattern

Advantages

- Improved Spectral Efficiency: IDMA can provide higher spectral efficiency than other multiple access schemes, such as CDMA and TDMA, by efficiently utilizing the available frequency spectrum and time slots.
- Improved Error Performance: IDMA can provide improved error performance by reducing the effects of multipath fading and interference.
- Low Complexity: IDMA is a simple and efficient multiple access scheme that requires less complex hardware and processing than other schemes, such as CDMA.
- Flexibility: IDMA is a flexible multiple scheme that can be easily adapted to different wireless communication environments and applications

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Security: IDMA can provide improved security by using unique interleaver sequences for each user, making it difficult for unauthorized access.

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Q.1 a) What are advantages of OFDM technique? Explain in detail OFDM technique.

Ans. OFDM is main advantages include resistance to multipath fading and high spectral efficiency. It achieves this by dividing a high-speed data stream into multiple, slower, parallel streams on narrowband sub-channels, which makes the system robust against fading and simplifies equalization. Other benefits include high data rates, making it suitable for modern applications, and immunity to narrowband interference by allowing affected sub-carriers to be disabled.

Robustness against channel impairments

- Combats multipath fading: OFDM splits a wideband into many narrow sub-channels. Each sub-channel experiences a flatter fading profile, making it much easir to handle than a single, heavily distorted wideband channel.
- Simplifies equalization: Because each sub-channel is narrowband, the equalization required is significantly simpler than in single-carrier systems. Equalization can be performed on each sub-channel independently, and a simple one-tap ~~fried~~ frequency-domain equalizer can be used.
- Resists narrowband interference: In cases of narrowband interference, the interference only affects a few sub-channels. These affected

sub-channels can be ignored or disabled without losing the entire data stream, which makes the system more resilient to interference.

Performance and efficiency

- High data rates: By using multiple sub-carriers, OFDM can achieve very high data transmission rates, making it ideal for modern broadband applications like Wi-Fi, LTE, and WiMAX.
- High spectral efficiency: The sub-carriers in OFDM are allowed to overlap and are orthogonal, meaning they don't interfere with each other. This allows for very close spacing of the sub-carriers, leading to a highly efficient use of the available spectrum compared to systems with guard ~~bea~~-bands.
- Simplified timing recovery: The use of a cyclic prefix and the nature of its design make timing recovery and phase/channel estimation in time-varying environments much more straightforward.