UNIT – V 4G NETWORKS

Introduction – 4G vision – 4G features and challenges - Applications of 4G – 4G Technologies: Multicarrier Modulation, Smart antenna techniques, OFDM-MIMO systems, Adaptive Modulation and coding with time slot scheduler, Cognitive Radio.

5.1 INTRODUCTION

4G stands for Forth Generation of Cellular Communications and is the next step in the evolution of mobile data. 4G provides high mobility with high speed data rates and also supports high capacity IP-based services and applications while it also maintains full backward compatibility.

It is also based on wireless communication that is IP based and is slated on Advanced MIMO technology. 4G technologies follow Multiple Input Multiple Output Technology that uses signal multiplexing between multiple transmitting antennas (space multiplex) and time or frequency.

Fourth generation (4G) technology will offer many advancements to the wireless market, including downlink data rates well over 100 megabits per second (Mbps), low latency, very efficient spectrum use and low-cost implementations.

4G enhancements promise to bring the wireless experience to an entirely new level with impressive user applications, such as sophisticated graphical user interfaces, high-end gaming, high-definition video and high-performance imaging.

5.2 4G VISION

The 4G systems are designed to provide a wide variety of new services, from high-quality voice to high definition video to high-data-rate wireless channels. The term 4G is used broadly to include several types of BWA communication systems, not only cellular systems. 4G is described as MAGIC — Mobile multimedia, anytime anywhere, Global mobility support, integrated wireless solution, and customizes personal service.

The 4G systems will not only support the next generation mobile services, but also will support the fixed wireless networks. The 4G systems are about seamlessly integrating terminals, networks, and applications to satisfy increasing user demands. Accessing information anywhere, anytime, with a seamless connection to a wide range of information and services, and receiving a large volume of information, data, pictures, video, and so on, are the keys of the 4G infrastructure.

The future 4G systems will consist of a set of various networks using IP as a common protocol. 4G systems will have broader bandwidth, higher data rate, and smoother and quicker handoff and will focus on ensuring seamless service across a multiple of wireless systems and networks.

The key is to integrate the 4Gcapabilities with all the existing mobile technologies through the advanced techniques of digital communications and networking.

Application adaptability and being highly dynamic are the main features of 4G services of interest to users. These features mean services can be delivered and be available to the personal preference of different users and support the users' traffic, air interfaces, radio environment, and quality of service.

Connection with the network applications can be transferred into various forms and levels correctly and efficiently. The following figure5.1 illustrates elements and techniques to support the adaptability of the 4G domain. The fourth generation will encompass all systems from various networks, public to private; operator-driven broadband networks to personal areas; and ad hoc networks. The 4G systems will interoperate with 2G and 3G systems, as well as with digital (broadband) broadcasting systems.

In addition, 4G systems will be fully IP-based wireless Internet. This all-encompassing integrated perspective shows the broad range of systems that the fourth generation intends to integrate, from satellite broadband to high altitude platform to cellular 3G and 3G systems to WLL (wireless local loop) and FWA (fixed wireless access) to WLAN (wireless local area network) and PAN (personal area network),all with IP as the integrating mechanism. With 4G, a range of new services and models will be available. These services and models need to be further examined for their interface with the design of 4G systems.

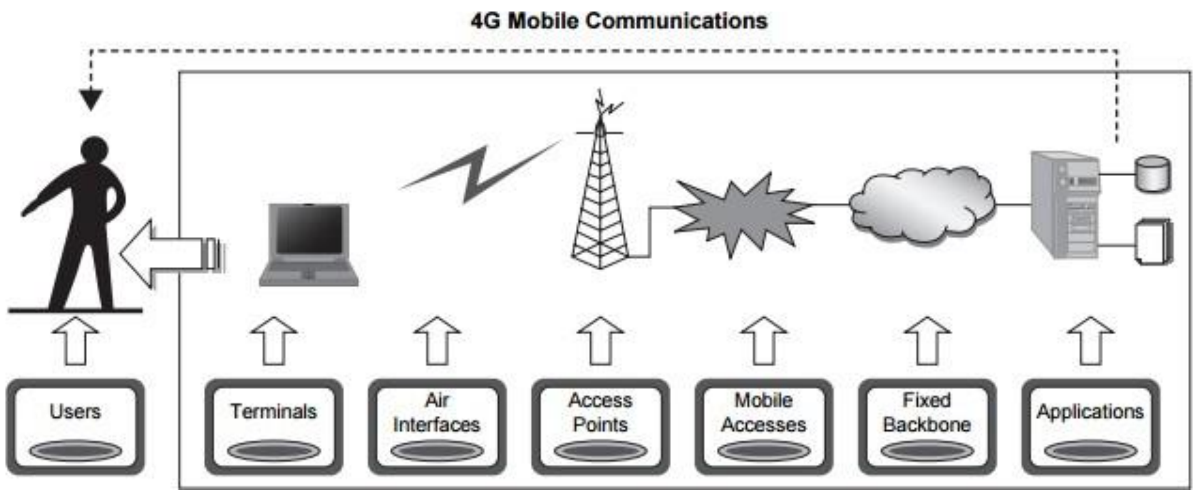


Figure 5.1 4G Mobile Communication Visions

Table 5.2 Comparison of key parameters of 4G with 3G.

Details	3G including 2.5G (EDGE)	4G
Major requirement driving Architecture	Predominantly voice driven, data was always add on	Converge data and voice over IP
Network architecture	Wide area cell-based	Hybrid-integration of WLAN (WiFi, Bluetooth) and wireless wide-area networks
Speeds	384 kbps to 2 Mbps	20 to 100 Mbps in mobile mode
Frequency band	Dependent on country or continent (1.8 to 2.4 GHz)	Higher frequency bands (2 to 8 GHz)
Bandwidth	5 to 20 MHz	100 MHz or more
Switching design basis	Circuit and packet	All digital with packetized
Access technologies	WCDMA, CDMA2000	OFDM and multicarrier

Forward error correction	Convolutional codes rate 1/2, 1/3	Concatenated coding
Component design	Optimized antenna design, multiband adapters	Smart antenna, software defined multiband and wideband radios
Internet protocol(IP)	Number of air link protocol including IPv5.0	All IP (IPv6.0)
Mobile top speed	200 km/h	200 km/h

4G will need to be highly dynamic in terms of support for:

- The users' traffic
- Air interfaces and terminal types
- Radio environments
- Quality-of-service types
- Mobility patterns

5.3 4G FEATURES AND CHALLENGES

4G FEATURES

Some key features of 4G mobile networks are as follows.

- High usability: anytime, anywhere, and with any technology
- Support for multimedia services at low transmission cost
- Personalization
- Integrated services
- Support for interactive multimedia, voice, streaming video, Internet, and
- other broadband services
- IP based mobile system
- High speed, high capacity, and low cost per bit
- Global access, service portability, and scalable mobile services
- Seamless switching, and a variety of Quality of Service driven services
- Better scheduling and call admission control techniques
- Ad hoc and multi hop networks
- Better spectral efficiency
- Seamless network of multiple protocols and air interfaces

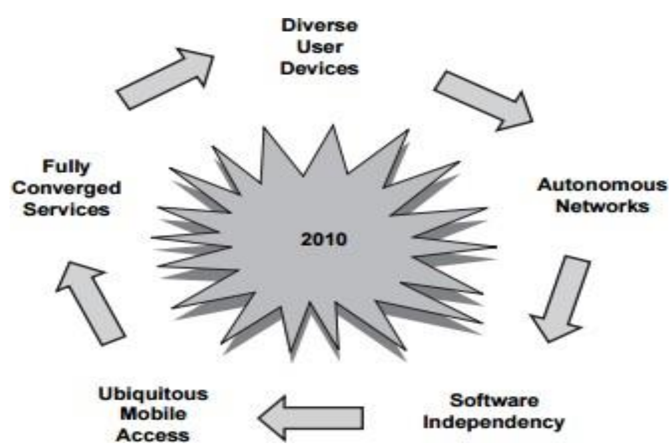


Fig 5.2 4G Features

4G networks will be all-IP-based heterogeneous networks that will allow users to use any system at anytime and anywhere.

Users carrying an integrated terminal can use a wide range of applications provided by multiple wireless networks.

4G systems will provide not only telecommunications services, but also data and multimedia services.

To support multimedia services, high-data-rate ser-vices with system reliability will be provided. At the same time, a low per-bit transmission cost will be maintained by an improved spectral efficiency of the system.

Personalized service will be provided by 4G networks. It is expected that when 4G services are launched, users in widely different locations, occupations, and economic classes will use the services.

4G CHALLENGES

While migrating from 3G to 4G, certain challenges have to be faced.

- **Multimode user terminal**: Multimode user terminal is a device operating in different modes supporting a large type of 4G services and wireless networks by reconfiguring themselves to adapt to different wireless networks. They encounter several design problems like limitations in the device cost, size, backward compatibility to systems and power consumption.
- **Wireless network discovery**: Availing 4G services need the multimode user terminal to find and select the required wireless network. Discovery of 4G systems will be much more challenging than 3G due to the heterogeneity of the networks and their access protocols.
- **Wireless network selection**: 4G will offer the users a option to select a wireless network providing optimized performance and high QoS for a specific place, time and desired service (communication, multimedia). But the parameters that define high QoS and optimized performance at specific instant must be clearly defined to form the network selection procedure efficient and transparent to the end user.
- **Terminal mobility:** Terminal mobility is an important characteristic to satisfy the “Anytime Anywhere” promise of 4G. It permits the mobile users to move across the geographic boundaries of wireless networks. Two important problems in terminal mobility are location and hand off management. Location management includes tracking the location of the mobile users and maintaining data like the authentication information, QoS capabilities, and the original and the current cell location. Handoff management is maintaining the continuing communication when the terminal roams.

- **Network infrastructure and QoS support**: Unlike previous generation networks such as 2G and 3G, 4G is an integration of IP and non-IP based system. Before 4G, QoS designs were made with a specific wireless system in mind. But in 4G systems QoS designs should consider the integration of various wireless networks to ensure QoS for the end-to end services.

- **Security:** Most of the security schemes and the encryption/decryption protocols of the present generation networks were designed only for specific services. They appear to be very inflexible to be used across the heterogeneous architecture of 4G that desires dynamically adaptive, reconfigurable and light-weight security mechanism.

- **Fault tolerance:** Wireless networks resemble a tree-like topology. Any failure in one of the levels will affect all the network elements at the levels below. This problem may become more complex because of the multiple tree topologies. Adequate research work is needed to devise a method for fault tolerance in wireless networks.

5.4 APPLICATIONS OF 4G

- **Virtual presence**: 4G will provide user services at all times, even if the user is off-site.
- **Virtual navigation**: 4G will provide users with virtual navigation through which a user can access a database of streets, buildings, etc., of a large city. This requires High-speed transmission.
- **Tele-medicine**: 4G will support the remote health monitoring of patients via video conference assistance for a doctor anytime and anywhere.
- **Tele-geo-processing applications**: 4G will combine geographical information systems (GIS) and global positioning systems (GPS) in which a user will get location querying.
- **Education:** 4G will provide a good opportunity to people anywhere in the world to continue their education on-line in a cost-effective manner.
- **Multimode Software Application Multimode software** is software that allows the user device to adapt itself to various wireless interfaces networks in order to provide constant net access with high data (packet based) rate. All the networks will be compatible once the switch is completed, eliminating roaming and areas where only one type of phone is supported. Once the voice and data networks are superposed there will suddenly be millions of new devices on the network cloud. This will require either reconstruction of the address space for the entire Internet or using different address spaces for the existing wireless networks. The multimode device architecture may improve call completion and expand effective coverage area.

- **Support for Multiple and Efficient Applications and Services-** 4G provides support for unicast, multicast and broadcast services and the applications that rely on them. Prompt enforcement of Service Level Agreements (SLA) along with privacy and other security features.
- **Quality of Service** -Consistent application of admission control and scheduling algorithms regardless of underlying infrastructure and operator diversity leads to an increased quality of service (Qos) to the users.
- **Network Detection Selection**: A mobile terminal that features multiple radio technologies or possibly uses software defined radios if economical, allows participation in multiple networks simultaneously, thereby connecting to the best network with the most appropriate service parameters (cost, QoS and capacity among others) for the application. This requires establishing a uniform process for defining eligibility of a terminal to attach to a network and to determine the validity of link layer configuration.
- **Handover and Service Continuity:** A base station‖ that features intra- and inter-technology handovers, assuring service continuity with zero or minimal interruption, without a noticeable loss in service quality. Support for this function requires continuous transparent maintenance of active service instances and inclusion of various access technologies, from Wi-Fi to OFDMA. Crisis Management Application: In the event of natural disasters where the entire communications infrastructure is in disarray, restoring communications quickly is essential. With wideband wireless mobile communications, limited and even total communication capability (including Internet and video services) could be set up within hours instead of days or even weeks required at present for restoration of wire line communications.

5.5 4G Technologies

5.5.1 Multicarrier Modulation:

Multi-carrier modulation (MCM) is a method of transmitting data by splitting it into several components, and sending each of these components over separate carrier signals. The individual carriers have narrow bandwidth , but the composite signal can have broad bandwidth.

The advantages of MCM include relative immunity to fading caused by transmission over more than one path at a time (multipath fading), less susceptibility than single-carrier systems to interference caused by impulse noise, and enhanced immunity to inter-symbol interference. Limitations include difficulty in synchronizing the carriers under marginal conditions, and a relatively strict requirement that amplification be linear.

Multicarrier modulation (MCM) is a derivative of frequency-division multiplexing. Forms of multicarrier systems are currently used in DSL modems and digital audio/video broadcast (DAB/DVB).

MCM is a baseband process that uses parallel equal bandwidth sub channels to transmit information and is normally implemented with fast Fourier transform (FFT) techniques. MCM's advantages are better performance in the inter symbol-interference environment and avoidance of single-frequency interferers. However, MCM increases the peak-to-average ratio of the signal, and to overcome inter symbol interference or guard band must be added to the data.

The difference, D, of the peak-to-average ratio between MCM and a single carrier system is a function of the number of subcarriers, N, as:

$$D(dB) = 10 \log N$$

Any increase in the peak-to-average ratio of a signal requires an increase in linearity of the system to reduce distortion. Linearization techniques can be used, but they increase the cost of the system.

If Lb is the original length of block and the channel's response is of length Lc, the cyclically extended symbol has a new length Lb + L c – 1. The new symbol of length Lb+ Lc– 1sampling periods has no inter symbol interference. The cost is an increase in energy and uncoded bits are added to the data.

At the MCM receiver, only Lb samples are processed and Lc–1 samples are discarded, resulting in a loss in signal-to-noise ratio (SNR) as:

$$(SNR)_{LOSS} = \frac{10 \log L_b + L_c - 1}{L_b} (dB)$$

Two different types of MCM multicarrier code division multiple access (MCCDMA) and orthogonal frequency-division multiplexing (OFDM) using time division multiple access (TDMA).
MC-CDMA is actually OFDM with a CDMA
overlay.

Similar to single-carrier CDMA systems, the users are multiplexed with orthogonal codes to distinguish users in MC-CDMA. However, in MC-CDMA, each user can be allocated several codes, where the data is spread in time or frequency. Either way, multiple users simultaneously access the system.

In OFDM with TDMA, the users are assigned time slots to transmit and receive data. Typically MC-CDMA uses quadrature phase shift keying (QPSK) for modulation, while OFDM with TDMA could use more high-level modulations, such as multilevel quadrature amplitude modulation (M-QAM.

In OFDM the subcarrier pulse shape is a square wave. The task of pulse forming and modulation is performed by a simple inverse FFT (IFFT) which can be implemented very efficiently. To decode the transmission, a receiver needs only to implement FFT.

The OFDM divides a broadband channel into many parallel sub channels. The OFDM receiver senses the channel and corrects distortion on each sub channel before the transmitted data can be extracted. In OFDM, each of the frequencies is an integer multiple of a fundamental frequency. This ensures that even though sub channels overlap, they do not interfere with each other.

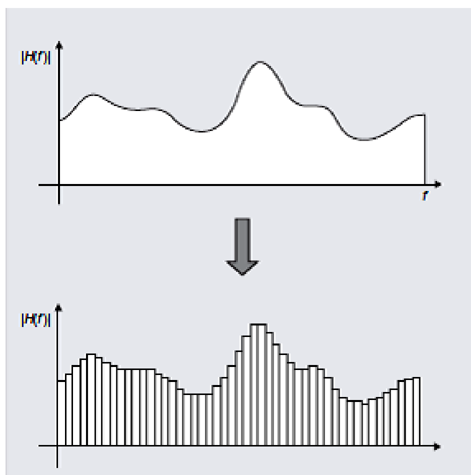


Fig. 5.3 A broadband channel divided into many parallel narrowband channels.

<u>5.5.2</u> <u>SMART ANTENNA TECHNIQUES:</u>

Smart antenna techniques, such as multiple-input multiple-output (MIMO) systems, can extend the capabilities of the 3G and 4G systems to provide customers with increased data throughput for mobile high-speed data applications. MIMO systems use multiple antennas at both the transmitter and the receiver to increase the capacity of the wireless. With MIMO systems, it may be possible to provide in excess of 1 Mbps for 2.5G wireless TDMA EDGE and as high as 20 Mbps for 4G systems.

With MIMO, different signals are transmitted out of each antenna simultaneously in the same bandwidth and then separated at the receiver.
With four antennas at the transmitter and receiver, this has the potential to provide four times the data rate of a single antenna system without an increase in transmit power or bandwidth.

MIMO techniques can support multiple independent channels in the same bandwidth, provided the multipath environment is rich enough. The number of transmitting antennas is M, and the number of receiving antennas is N, where N ≥M.

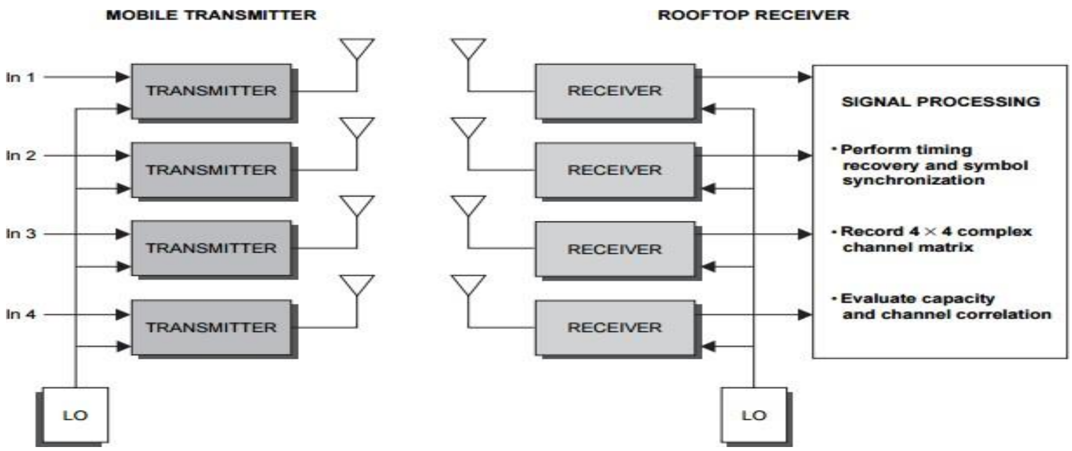


Fig. 5.4 Smart Antenna

There are four cases:

- Single-input, single-output (SISO)
- Single-input, multiple-output (SIMO)
- Multiple-input, single-output (MISO)
- Multiple-input, multiple-output(MIMO)

SISO (Single Input Single Output):

The simplest form of radio link can be defined in MIMO terms as SISO – Single Input Single Output. This is effectively a standard radio channel – this transmitter operates with one antenna as does the receiver. There is no diversity and no additional processing required.

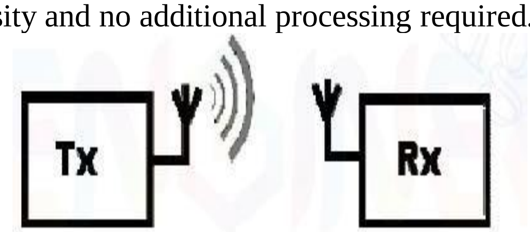


Fig. 5.5 SISO (Single Input Single Output)

The channel bandwidth is B, the transmitter power is Pt, the signal at the receiver has an average signal-to-noise ratio of SNR0, then the Shannon limit on channel capacity C is

$$C = B \log2 (1 - SNR_0)$$

SIMO (Single Input Multiple Output):

The SIMO or Single Input Multiple Output version of MIMO occurs where the transmitter has a single antenna and the receiver has multiple antennas. This is also known as receiving diversity. It is often used to enable a receiver system that receives signals from a number of independent sources to struggle the effects of fading.

SIMO has the advantage that it is relatively easy to implement. The use of SIMO may be quite acceptable in many applications, but where the receiver is located in a mobile device such as a cell phone handset, the levels of processing may be limited by size, cost and battery drain.

Fig. 5.6 SIMO (Single Input Multiple Output)

There are N antennas at the receiver. If the signals received on the antennas have on average the same amplitude, then they can be added coherently to produce an N^2 increase in signal power. There are N sets of noise sources that are added coherently and result in an N –fold increase in noise power. Hence, the overall increase in SNR will be:

$$SNR \approx \frac{N^2 * signal\ power}{N * (noise)} = N * SNR_0$$

The capacity for this channel is approximately equal to

$$C \approx B \log2 (1 + N \times SNR_0)$$

MISO(Multiple Input Single Output):

Multiple Input Single Output (MISO) is also termed transmit diversity. In this case, the same data is transmitted redundantly from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to receive extract the required data.

The advantage of using MISO is that the multiple antennas and the redundancy coding / processing is moved from the receiver to the transmitter. This has a positive impact on size, cost and battery life as the lower level of processing requires less battery consumption.

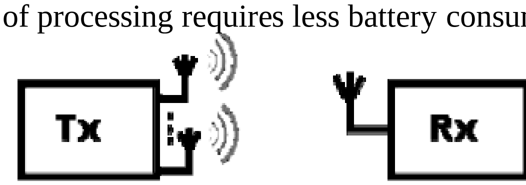


Fig. 5.7 MISO (Multiple Input Single Output)

It has M transmitting antennas. The total power is divided into M transmitter branches. If the signals add coherently at the receiving antenna, we get an M - fold increase in SNR as compared to SISO. Because there is only one receiving antenna, the noise level is the same as SISO. The overall increase in SNR is approximately.

$$SNR \approx \frac{M^2 * signal\ power/M}{noise} = M * SNR_0$$

MIMO (Multiple Input Multiple Output):

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.

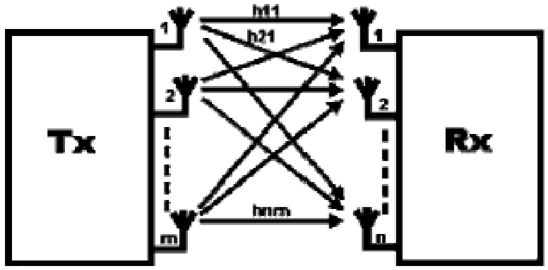


Fig. 5.8 MIMO (Multiple Input Multiple Output)

MIMO systems can be viewed as a combination of MISO and SIMO channels. In this case, it is possible to achieve approximately an MN-fold increase in the average SNR0 giving a channel capacity equal to

$$C = B \log_2 (1 + M \times N \times SNR_0)$$

Assuming N ≥ M, we can send different signals using the same bandwidth and still be able to decode correctly at the receiver. Thus, we are creating a channel for each one of the transmitters. The capacity of each one of these channels is roughly equal to

$$C = B \ \log(1 + \frac{N}{M} \times SNR_0)$$

Since we have M of these channels (M transmitting antennas), the total capacity of the system is

$$C = MB \log(1 + \frac{N}{M} \ \times SNR0)$$

We get a linear increase in capacity with respect to the transmitting antennas.

5.5.3 OFDM-MIMO SYSTEMS:

OFDM and MIMO techniques can be combined to achieve high spectral efficiency and increased throughput. The OFDM-MIMO system transmits independent OFDM modulated data from multiple antennas simultaneously. At the receiver, after OFDM demodulation, MIMO decodes each subchannel to extract data from all transmits antennas on all the subchannels.

Multiple-input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (MIMO-OFDM) is an air interface solution for next-generation wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and fourth-generation mobile cellular wireless systems. OFDM and MIMO techniques can be combined to achieve high spectral efficiency and increased throughput.

For high-data rate transmissions, the MIMO channel is frequency selective (multipath). OFDM can transform such channel into a set of parallel frequency flat channels (reduce Rx complexity).

a. MIMO-OFDM Transmitter:

The Source bit stream is encoded by the FEC encoder and the coded bit stream mapped to a constellation by digital modulator, and encoded by the MIMO encoder. Each of the parallel output symbol streams are corresponding to a certain Transmitting antenna follows the same Transmitting process:

- Insertion of pilot symbols (synchronization)
- Modulation by inverse FFT
- Attachment of CP and Preamble

Finally, the data frame is transferred to IF/RF stage for Transmitter

b. MIMO-OFDM Receiver

The received symbol stream from different Receiving antennas is fist synchronized Preambles and CPs must be extracted from Received symbol stream. The Remaining OFDM symbols demodulated by FFT. Frequency pilots are extracted from the demodulated OFDM symbols, and are used for channel estimation. Estimated channel matrix aids the MIMO decoder and the estimated Transmitted symbols are demodulated and then decoded. All MIMO-OFDM receivers must perform time synchronization; frequency offset estimation, and correction and parameter estimation. This is generally carried out using a preamble consisting of one or more training sequences. Once the acquisition phase is over, receiver goes into the tracking mode.

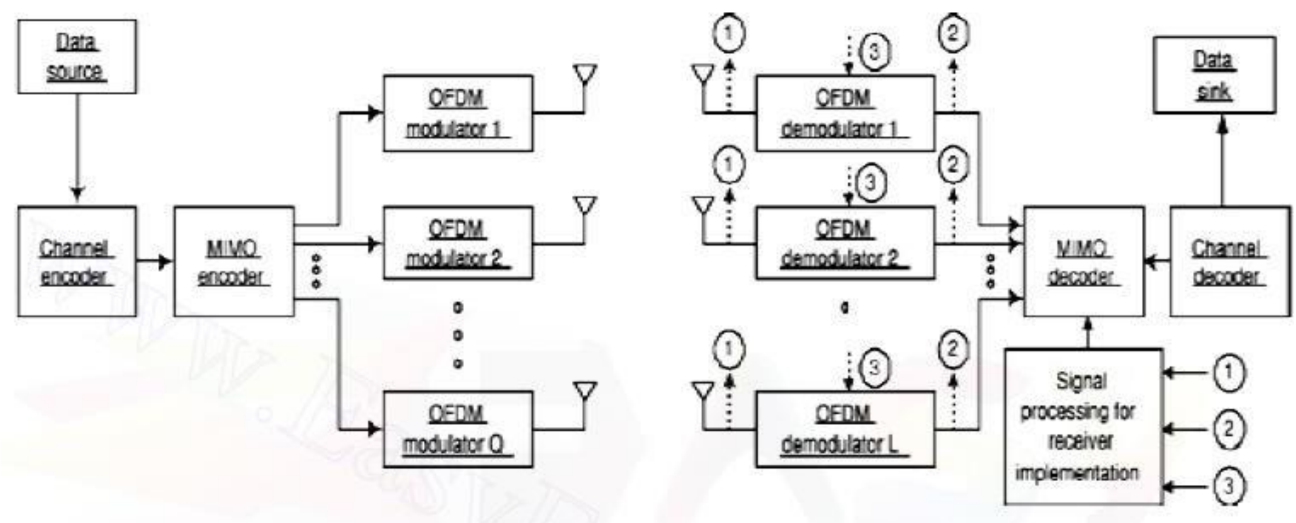


Fig 5.9 Block Diagram of MIMO-OFDM

Advantage of OFDM – MIMO systems is:

1. High spectral efficiency& capacity
2. Simple implementation by FFT (fast Fourier transform);
3. Low receiver complexity;
4. Robustability for high-data-rate transmission over multipath fading channel
5. High flexibility in terms of link adaptation
6. Low complexity multiple access schemes such as orthogonal frequency division multiple access.

Applications of OFDM – MIMO systems are:

- Wireless network
- Next generation network(4G)
- Wi-Fi, Wi-MAX, W – MAN
- Digital TV
- Power line control
- Digital audio and video broadcasting
- Discrete Multitone systems

5.5.4 ADAPTIVE MODULATION AND CODING WITH TIME SLOT SCHEDULER

Adaptive modulation or link adaptation is used to improve the spectral efficiency particularly over wireless fading channels. Adaptive modulation offers parameters such as data rate, transmit power, instantaneous BER, symbol rate, and channel code rate to be adjusted relative to the channel fading, by exploiting the channel information that is present at the transmitter.

AMC is one of the most important RRM mechanisms that have been used to improve system capacity. AMC adapts the modulation and coding scheme (MCS) according to the channel condition. The channel condition can be reported back by the UE by using Channel Quality Indicator (CQI).

In general, TCP/IP is designed for a highly reliable transmission medium in wired networks where packet losses are seldom and are interpreted as congestion in the network.

On the other hand, a wireless network uses a time varying channel where packet losses may be common due to severe fading.

This is misinterpreted by TCP as congestion which leads to inefficient utilization of the available radio link capacity. This results in significant degradation of the wireless system performance.

There is a need for a system with efficient packet data transmission using TCP in 4G. This can be achieved by using a suitable automatic repeat request (ARQ) scheme combined with an adaptive modulation and coding sys-tem, and a time-slot scheduler that uses channel predictions.

This way, the lower layers are adapted to channel conditions while still providing some robustness through retransmission. The time-slot scheduler shares the spectrum efficiently between users while satisfying the QoS requirements.

If the channel quality for each radio link can be predicted for a short duration (say about 10 ms) into the future and accessible by the link layer, then ARQ along with an adaptive modulation and coding system can be selected for each user to satisfy the bit error rate (BER) requirement and provide high through-put.

The scheduler uses this information about individual data streams (along with predicted values of different radio links and selected modulation and coding systems by the link layer) and distributes the time slots among the users.

The planning is done so that the desired QoS and associated priority to different users are guaranteed while channel spectrum is efficiently utilized.

Table 5.3 Comparison of channel capacity for different channel types.

Channel type	Capacity (Mbps)	Normalized capacity with respect to SISO
SISO	3.45 B	1.0
SIMO	5.66 B	1.64
MISO	5.35 B	1.55
MIMO (with same input)	7.64 B	2.21
MIMO (with different input)	15 B	4.35

a. SYSTEM MODEL

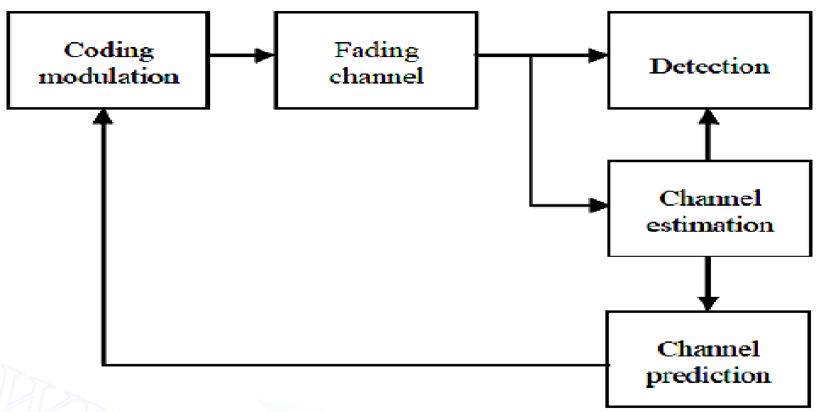
Adaptive modulation systems invariably require some Channel State Information (CSI) at the transmitter. This can be achieved by estimating and predicting the channel conditions at the receiver and fed back to the transmitter, so that the transmission scheme can be adapted relative to the channel characteristics.

During each transmission, the modulation scheme is adjusted to maximize the spectral efficiency, under BER and average power constraints, based on the instantaneous predicted SINR. The various modulation techniques such as QPSK and M-ary Quadrature Amplitude Modulation (M-QAM) schemes with different constellation sizes are provided at the transmitter.

The link adaptation can employ QPSK for noisy channels, which are more robust and can tolerate higher levels of interference but has lower transmission bitrate. M-QAMis adapted for clearer channels, and has twice higher bit rate but is more prone to errors due to interference and noise. To improve the quality of the wireless link the transmitter uses some form of channel coding. The coding can either be in the traditional form of coding followed by modulation (each done independent of the other) or joint coding and modulation.

Coding adds redundant bits to the data bits which can correct errors in the received bits. The degree of coding is determined by its rate, which are the proportion ofdata bits to coded bits. This typically varies from 1/8 to 4/5.

Block diagram for Adaptive Modulation &



Coding

Fig 5.10 Block diagram for Adaptive Modulation & Coding

If the channel quality for each radio link can be predicted for a short duration (say about 10 ms) into the future and accessible by the link layer, then ARQ along with an adaptive modulation and coding system can be selected for each user to satisfy the bit error rate (BER) requirement and provide high throughput.

The scheduler uses this information about individual data streams (along with predicted values of different radio links and modulation and coding systems by the link layer) and distributes the time slots among the users. The planning is done so that the desired QoS and associated priority to different users are guaranteed while channel spectrum is efficiently utilized.

5.5.5 COGNITIVE RADIO

Cognitive radio (CR) is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. CR is a hybrid technology involving software defined radio (SDR) as applied to spread spectrum communications.

Possible functions of cognitive radio include the ability of a transceiver to determine its geographic location, identify and authorize its user, encrypt or decrypt signals, sense neighboring wireless devices in operation, and adjust output power and modulation characteristics.

There are two main types of cognitive radio,

1. Full cognitive radio and
2. Spectrum-sensing cognitive radio.

Full cognitive radio takes into account all parameters that a wireless node or network can be aware of. Spectrum-sensing cognitive radio is used to detect channels in the radio frequency spectrum. Cognitive radio can able to monitor sense and detect the conditions of their operating environment, and reconfigure their own characteristics dynamically to match those conditions.

The CR can be viewed as an enabling technology that will benefit several types of users by introducing new communications and networking models for the whole wireless world, creating better business opportunities for the operators and new technical dimensions for smaller operators, and helping shape an overall more efficient approach regarding spectrum requirements and usage in the next generation of wireless networks.

The primary objectives of the cognitive radio are to provide highly reliable communications whenever and wherever needed and to utilize the radio spectrum efficiently. The key issues in the cognitive radio are awareness, intelligence, learning, adaptability, reliability, and efficiency.

The three major tasks of the cognitive radio include:

(1) Radio-scene analysis,
(2) Channel identification, and
(3) Dynamic spectrum management and transmit-power control.

The radio-scene analysis includes the detection of spectrum holes by for example sensing the radio frequency spectrum. The channel identification includes estimation of the channel state information which is needed at the receiver for coherent detection.

The transmitter power control and dynamic spectrum management select the transmission power levels and frequency holes for transmission based on the results of radio scene analysis and channel identification. The first two tasks are carried out in the receiver (RX) while the third task is carried out in the transmitter (TX), which requires some form of feedback between RX and TX.

a. FUNCTIONS OF CR

The main functions of Cognitive Radios are:

- **Spectrum Sensing**: It detects the unused spectrum and sharing it without harmful interference with other users.
- Spectrum sensing techniques can be classified into three categories:
  - **Transmitter detection**: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum, there are several approaches proposed: matched filter detection energy detection
  - **Match filter detection** is obtained by correlating a known signal, or template, with an unknown signal to detect the presence of the template in the unknown signal.
  - **Cooperative detection** refers to spectrum sensing methods where information from multiple Cognitive radio users is incorporated for primary user detection.