USN										

Sub:	Wireless and Cellular Communication					Sub Code: 18EC81
Date:	18/06/2022	Duration:	90 Minutes	Max Marks:	50	Sem / Sec:

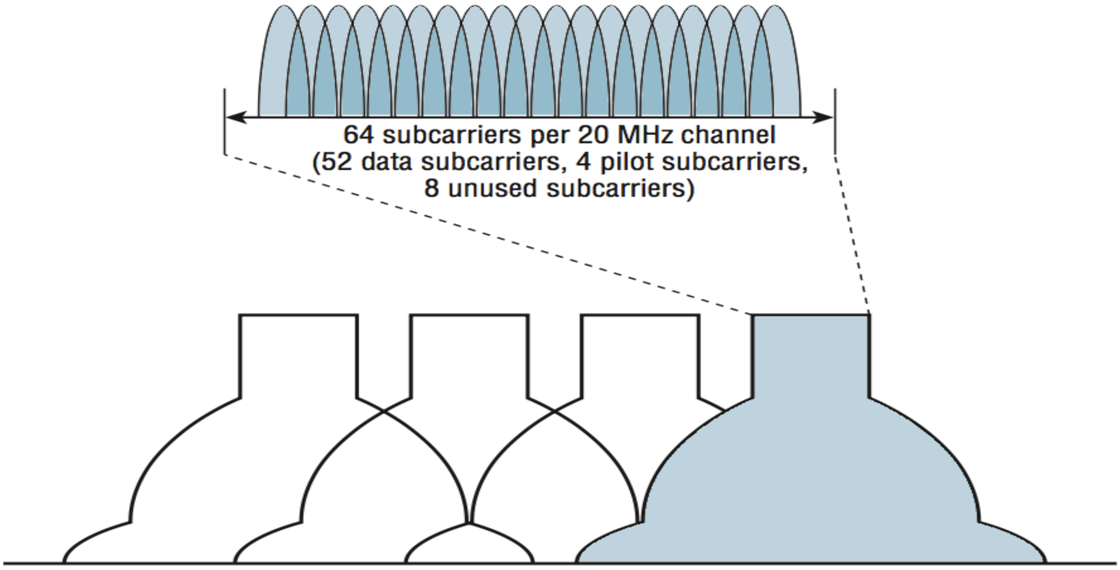
1 Explain OFDM with neat figure. Explain the advantages of OFDM leading to its selection for LTE. 10

ANS:

OFDM:

- Orthogonal frequency-division multiplexing is a method of data transmission where a single information stream is split among several closely spaced narrowband subchannel frequencies instead of a single Wideband channel frequency. It is mostly used in wireless data transmission but may be employed in wired and fiber optic communication as well.

- In a traditional single-channel modulation scheme, each data bit is sent serially or sequentially one after another. In OFDM, several bits can be sent in parallel, or at the same time, in separate substream channels. This enables each substream's data rate to be lower than would be required by a single stream of similar bandwidth. This makes the system less susceptible to interference and enables more efficient data bandwidth.



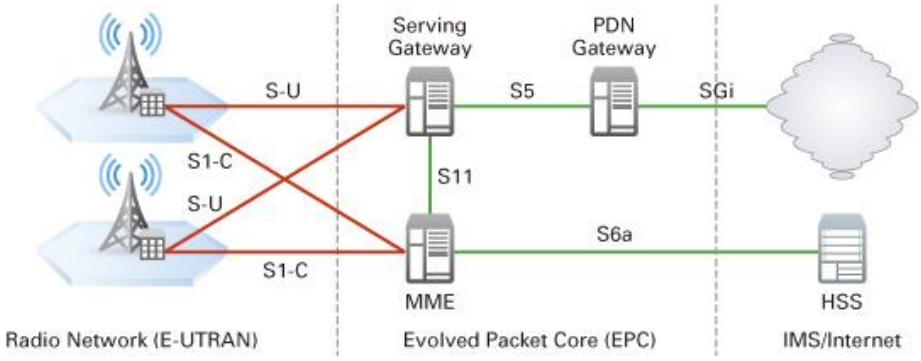
Advantages:

OFDM advantages and disadvantages
Elegant solution to multipath interference
■ Reduced computational complexity
■ Graceful degradation of performance under excess delay
■ Exploitation of frequency diversity
■ Enables efficient multi-access scheme
■ Robust against narrowband interference
■ Suitable for coherent demodulation
■ Facilitates use of MIMO
■ Efficient support of broadcast services

2 Explain flat LTE SAE architecture with a neat diagram. Explain how 3 GPP network evolved towards flat LTE- SAE architecture 10

ANS:

System Architecture Evolution (SAE) is a new network architecture designed to simplify LTE networks and establish a flat architecture similar to other IP based communications networks. SAE uses an eNB and Access Gateway (aGW) and removes the RNC and SGSN from the equivalent 3G network architecture to create a simpler mobile network. This allows the network to be built with an "All-IP" based network architecture. SAE also includes entities to allow full inter-working with other related wireless technology (WCDMA, WiMAX, WLAN, etc.). These entities can specifically manage and permit the non-3GPP technologies to interface directly with the network and be managed from within the same network.



The architecture consists of following modules:

MME (Mobility Management Entity): The MME is an important controller node in the LTE network. It is responsible for:

- Idle mode UE (User Equipment) tracking
- Paging procedure such as re-transmissions
- Bearer activation and deactivation process
- S-GW selection for a UE at the initial attach
- Intra-LTE handover with Core Network node relocation
- User authentication with HSS

SGW (Serving Gateway): The main function of the Serving Gateway is routing and forwarding of user data packets. It is also responsible for inter-eNB handovers in the U-plane and provides mobility between LTE and other types of networks, such as between 2G/3G and P-GW. The DL data from the UEs in idle state is terminated at the SGW, and arrival of DL data triggers paging for the UE. The SGW keeps context information such as parameters of the IP bearer and routing information, and stores the UE contexts when paging happens. It is also responsible for replicating user traffic for lawful interception.

PGW (PDN Gateway): The PDN Gateway is the connecting node between UEs and external networks. It is the entry point of data traffic for UEs. In order to access multiple PDNs, UEs can connect to several PGWs at the same time. The functions of the PGW include:

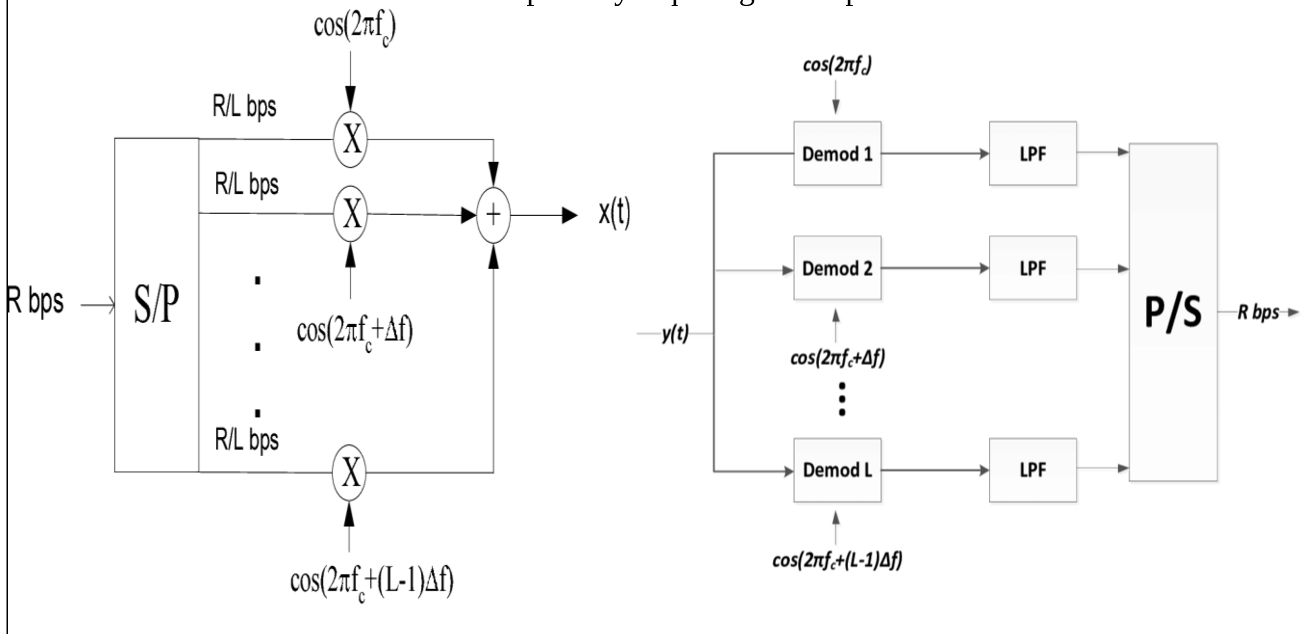
- Policy enforcement
- Packet filtering
- Charging support
- Lawful interception
- Packet screening

3 Explain the basic multicarrier transmitter and receiver with neat block diagram. 10

ANS:

Multicarrier modulation: rather than fighting the time - dispersive ISI channel why not utilize its diversity.
Large no. of subcarriers L are used in parallel, so that the symbol time of each goes from T to LT.
Instead of sending a single signal with data rate R and BW B, L no. of signals are sent with data rate R/L and BW B/L.
If B/L << Bc – each of the signal will undergo flat fading and the time dispersion for each signal will be negligible.
As long as no. of subcarriers L is large B/L << Bc condition for flat fading can be met.
This is the basic principle of OFDM

Transmitter - A high rate stream of R bps is broken into L parallel streams each with rate R/L and then multiplied by a different carrier frequency.
Receiver – each subcarrier is decoded separately requiring L independent Rx.



Transmitter Receiver

4 Compare OFDM system and SC-FDE system. 10

ANS:

- SC-FDE is a single-carrier (SC) modulation combined with frequency-domain equalization (FDE) and is an alternative approach to inter symbol interference (ISI) mitigation.
- SC-FDMA also called linearly pre-coded OFDMA, is employed in LTE uplink.
- SC-FDMA is similar to OFDMA - requires IFFT operation at the Tx to separate users.
- It has an additional DFT processing step preceding the conventional OFDMA processing.

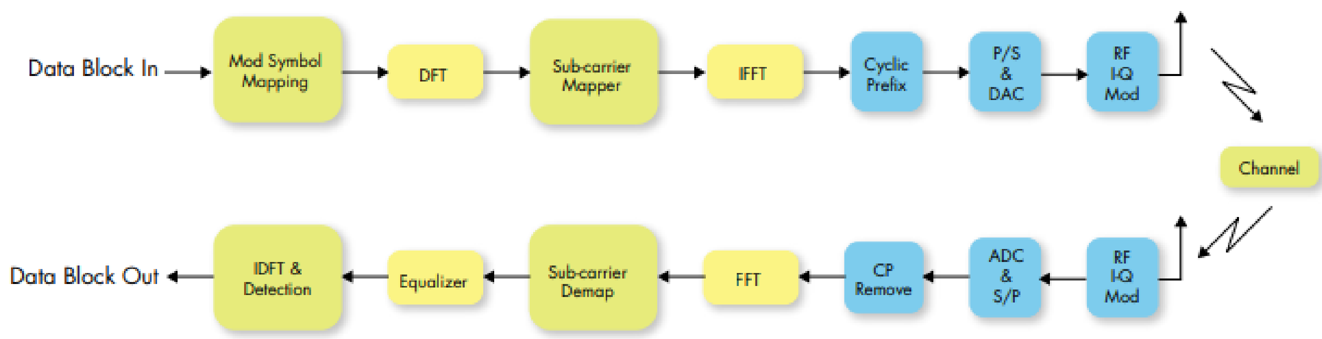
- Goal of SC-FDMA is to take the low PAR properties of SC-FDE and implement in an OFDMA system.
- SC-FDMA also reduces the transmit power and also the cost of power amplifiers.
- SC_FDMA is employed in uplink and has become an alternative approach to OFDMA specially in uplink transmission
- Equalization is done in frequency domain.
- Advantage is lower PAPR
- In OFDMA the symbol is mapped with one subcarrier but in SCFDMA allows symbol to be transmitted in parts over multiple subcarrier for-example in OFDMA one subcarrier occupies one subcarrier of 15khz but in SC-FDMA same symbol is distributed over multiple subcarriers of 15khz.
- In short SC-FDMA behaves like a single carrier system with short symbol duration compared to OFDMA
- TO achieve this SC-FDMA has an N point FFT block added right after S/P converter in the OFDMA structure.
- The FFT block converts parallel sequence of symbols from time domain to frequency domain (i.e. over different frequency points).

5 With a neat diagram, explain SC-FDMA. List out the advantages and disadvantages of SC-FDM

ANS:

SC-FDMA is a new multiple access technique that utilizes single carrier modulation, DFT spread orthogonal frequency multiplexing, and frequency domain equalization. It has a similar structure and performance as OFDM. SC-FDMA is currently adopted as the uplink multiple access scheme for 3GPP LTE.

Transmitter and receiver structure for SC-FDMA and OFDM are given in Figures 4 and 5. It is evident from the figures that SC-FDMA transceiver has similar structure as a typical OFDM system except the addition of a new DFT block before subcarrier mapping. Hence, SC-FDMA can be considered as an OFDM system with a DFT mapper. DC-FDMA transmitter and receiver is shown in the figure below



Advantages of SC-FDMA

- Lowers the inter symbol interference (Equalization isn't required).
- An SC-FDMA system is often easily implemented, system is often configured so, the improvements in terms of speech encoder and bit rate reduction could even be easily incorporated.
- Simple to implement, from a hardware standpoint.
- Fairly efficient with a little base population and when traffic is constant.
- SC-FDMA includes its applicability to both analog and digital transmission systems, the actual fact that no special coding is required, the allocation of capacity is simple, no network synchronization or timing is required, which the baseband signal is often recovered using simple

and cheap receiver equipment.

- Reducing the knowledge bit rate and using efficient digital codes can obtain capacity increases.

Disadvantages

- Due to the simultaneous transmission of a large number of frequencies, there is a possibility of inter modulation distortion at the transponder.
- Storage, enhancement of signals is not possible.
- The large bandwidth requirement for transponders.
- Guard bands may waste capacity.
- It requires RF (Radio Frequency) filters to meet stringent adjacent channel rejection specifications. This may increase the cost of the system.
- Network planning is cumbersome and time-critical.
- There is not much flexibility so, need to slowly change already assigned traffic patterns.
- The carrying capacity of traffic is relatively low.

6 Explain briefly about opportunistic scheduling approaches for OFDMA 10

4.4.3 Maximum Sum Rate Algorithm

The objective of the maximum sum rate (MSR) algorithm, as the name indicates, is to maximize the sum rate of all users, given a total transmit power constraint [59]. This algorithm is optimal if the goal is to get as much data as possible through the system. The drawback of the MSR algorithm is that it is likely that a few users that are close to the base station (and hence have excellent channels) will be allocated all the system resources. We will now briefly characterize the SINR, data rate, and power and subcarrier allocation that is achieved by the MSR algorithm.

Let $P_{k,l}$ denote user k's transmit power in subcarrier l. The signal-to-interference-plus-noise ratio for user k in subcarrier l, denoted as $\text{SINR}_{k,l}$, can be expressed as

$$\text{SINR}_{k,l} = \frac{P_{k,l} h_{k,l}^2}{\sum_{j=1, j \neq k}^{K} P_{j,l} h_{k,l}^2 + \sigma^2 \frac{B}{L}}. \quad (4.3)$$

Using the Shannon capacity formula as the throughput measure,[5] the MSR algorithm maximizes the following quantity:

$$\max_{P_{k,l}} \sum_{k=1}^{K} \sum_{l=1}^{L} \frac{B}{L} \log\left(1 + \text{SINR}_{k,l}\right) \quad (4.4)$$

with the total power constraint

$$\sum_{k=1}^{K} \sum_{l=1}^{L} P_{k,l} \leq P_{tot}.$$

The sum capacity is maximized if the total throughput in each subcarrier is maximized. Hence, the max sum capacity optimization problem can be decoupled into L simpler problems, one for each subcarrier. Further, the sum capacity in subcarrier l, denoted as C_l, can be written as

$$C_l = \sum_{k=1}^{K} \log \left(1 + \frac{P_{k,l}}{P_{tot,l} - P_{k,l} + \frac{\sigma^2}{h_{k,l}^2} \frac{B}{L}} \right), \quad (4.5)$$

where $P_{tot,l} - P_{k,l}$ denotes other users' interference to user k in subcarrier l. It is easy to show that C_l is maximized when all available power $P_{tot,l}$ is assigned to just the single user with the largest channel gain in subcarrier l. This result agrees with intuition: give each channel to the user with the best gain in that channel. This is sometimes referred to as a "greedy" optimization. The optimal power allocation proceeds according to a rich-get-richer "waterfilling" solution [14, 16] or more realistically for the multiuser scenario with QAM, "mercury waterfilling" [34]. The total sum capacity is readily determined by adding up the rate on each of the subcarriers.

4.4.4 Maximum Fairness Algorithm

Although the total throughput is maximized by the MSR algorithm, in a cellular system like LTE where the path loss attenuation will vary by several orders of magnitude between users, some users will be extremely underserved by an MSR-based scheduling procedure. At the alternate extreme, the maximum fairness algorithm [41] aims to allocate the subcarriers and power such that the *minimum* user's data rate is maximized. This essentially corresponds to equalizing the data rates of all users, hence the name "Maximum Fairness."

The maximum fairness algorithm can be referred to as a *Max-Min* problem, since the goal is to maximize the minimum data rate. The optimum subcarrier and power allocation is considerably more difficult to determine than in the MSR case because the objective function is not concave. It is particularly difficult (NP-hard) to simultaneously find the optimum subcarrier and power allocation. Therefore, low-complexity suboptimal algorithms are necessary, in which the subcarrier and power allocation are done separately.

A common approach is to assume initially that equal power is allocated to each subcarrier, and then to iteratively assign each available subcarrier to a low-rate user with the best channel on it [41, 54]. Once this generally suboptimal subcarrier allocation is completed, an optimum (waterfilling) power allocation can be performed. It is typical for this suboptimal approximation to be very close to the performance obtained with an exhaustive search for the best joint subcarrier-power allocation, both in terms of the fairness achieved and the total throughput.

4.4.5 Proportional Rate Constraints Algorithm

A weakness of the Maximum Fairness algorithm is that the rate distribution among users is not flexible. Further, the total throughput is largely limited by the user with the worst SINR, as most of the resources are allocated to that user, which is clearly suboptimal. In a wireless broadband network, it is likely that different users require application-specific data rates that vary substantially. A generalization of the Maximum Fairness algorithm is the Proportional Rate Constraints (PRC) algorithm, whose objective is to maximize the sum throughput, with the additional constraint that each user's data rate is proportional to a set of pre-determined system parameters $\{\beta_k\}_{k=1}^{K}$. Mathematically, the proportional data rate's constraint can be expressed as

$$\frac{R_1}{\beta_1} = \frac{R_2}{\beta_2} = \cdots = \frac{R_K}{\beta_K} \tag{4.6}$$

where each user's achieved data rate R_k is

$$R_k = \sum_{l=1}^{L} \frac{\rho_{k,l} B}{L} \log_2\left(1 + \frac{P_{k,l} h_{k,l}^2}{\sigma^2 \frac{B}{L}}\right), \tag{4.7}$$

and $\rho_{k,l}$ can only be the value of either 1 or 0, indicating whether subcarrier l is used by user k or not. Clearly, this is the same setup as the Maximum Fairness algorithm if $\beta_k = 1$ for each user. The advantage is that any arbitrary data rates can be achieved by varying the β_k values.

The PRC optimization problem is also generally very difficult to solve directly, since it involves both continuous variables $P_{k,l}$ and binary variables $\rho_{k,l}$ and the feasible set is not convex. As for the Maximum Fairness case, the prudent approach is to separate the subcarrier and power allocation, and to settle for a near-optimal subcarrier and power allocation that can be achieved with manageable complexity. The near optimal approach is derived and outlined in [45,46] and a low-complexity implementation

...tion developed in [54].

4.4.6 Proportional Fairness Scheduling

The three algorithms we have discussed thus far attempt to *instantaneously* achieve an objective such as the total sum throughput (MSR algorithm), maximum fairness (equal data rates among all users), or pre-set proportional rates for each user. Alternatively, one could attempt to achieve such objectives over time, which provides significant additional flexibility to the scheduling algorithms. In this case, in addition to throughput and fairness, a third element enters the tradeoff, which is *latency*. In an extreme case of latency tolerance, the scheduler could simply just wait for the user to get close to the base station before transmitting. In fact, the MSR algorithm achieves both fairness and maximum throughput if the users are assumed to have the same average channels in the long term (on the order of minutes, hours, or more), and there is no constraint with regard to latency. Since latencies even on the order of seconds are generally unacceptable, scheduling algorithms that balance latency and throughput and achieve some degree of fairness are needed. The most popular framework for this type of scheduling is Proportional Fairness (PF) scheduling [49, 50, 52].

The PF scheduler is designed to take advantage of multiuser diversity, while maintaining comparable long-term throughput for all users. Let $R_k(t)$ denote the instantaneous data rate that user k can achieve at time t, and $T_k(t)$ be the average throughput for user k up to time slot t. The Proportional Fairness scheduler selects the user, denoted as k^*, with the highest $R_k(t)/T_k(t)$ for transmission. In the long-term, this is equivalent to selecting the user with the highest instantaneous rate relative to its mean rate. The average throughput $T_k(t)$ for all users is then updated according to

$$T_k(t+1) = \begin{cases} \left(1 - \frac{1}{t_c}\right) T_k(t) + \frac{1}{t_c} R_k(t) & k = k^* \\ \left(1 - \frac{1}{t_c}\right) T_k(t) & k \neq k^*. \end{cases} \tag{4.8}$$

Since the Proportional Fairness scheduler selects the user with the largest instantaneous data rate relative to its average throughput, "bad" channels for each user are unlikely to be selected. On the other hand, users that have been consistently underserved receive scheduling priority, which promotes fairness. The parameter t_c controls the latency of the system. If t_c is large, then the latency increases, with the benefit of higher sum throughput. If t_c is small, the latency decreases since the average throughput values change more quickly, at the expense of some throughput. The Proportional

$$T_k(t+1) = \left(1 - \frac{1}{t_c}\right) T_k(t) + \frac{1}{t_c} \sum_{n \in \Omega_k(t)} R_k(t, n) \tag{4.9}$$

for $k = 1, 2, \ldots, K$. Other weighted adaptations and evolutions of PF scheduling of OFDMA are certainly possible.