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Answer Sheet

Answer Question 1

(a) Given that the car is far away from the base station, but moving directly at the transmitter (i.e., assumes $\theta = 0$, so $\cos(\theta) = 1$), find the received Doppler shifted carrier frequency as the car moves toward the base station. Solution: We begin by noting $\cos(\theta)$ and $\cos(\theta)$ because $\Delta L = v \theta \lambda \Delta t = f \cos(\theta)$ in Hz We begin by noting f , then we can write, $f = \frac{v}{\lambda} \cos(\theta)$ We begin with 1,850 MHz. Therefore, the wavelength is $\lambda = \frac{3 \times 10^8 \text{ m/sec}}{1850 \times 10^6 \text{ sec}} = 0.162 \text{ meter}$ The vehicle speed is $75 \text{ mph} = 33.528 \text{ m/sec}$ When the car is moving toward the base station, the Doppler shift is positive, hence, $33.528 \text{ m/sec} \times \frac{1,850,000,207 \text{ Hz}}{0.162 \text{ m}}$ Doppler

(b) Now the car is moving away from the transmitter (again assumes $\theta = 0$, so $\cos(\theta) = 1$), find the received Doppler shifted carrier frequency as the car moves away from the base station.

(c) In this case 90 degrees; thus, $\cos(\theta) = 0$. There is no Doppler shift in the case where the car is directly under the base station antennas. But the cell phone may not receive a signal unless the antennas emit a signal downward.

Answer Question 2(a)

Modulation:

Transmission of information by communication systems over large distances is quite a feat of human ingenuity. We can talk, video chat and text anyone on this planet! The communication system uses a very clever technique called Modulation to increase the reach of the signals. Two signals are involved in this process.

We live in a digitally advanced era where the need for wires is no longer a necessity to be connected to everyone. Messages, information and signals are sent from one part of the world to another within minutes. The process of modulation plays a major role in the fast transmission of signals. Below, we have mentioned a few of its importance in the communication system.

Frequency-division multiplexing:

In frequency-division multiplexing (FDM), the available bandwidth of a communications channel is shared among multiple users by frequency translating, or modulating, each of the individual users onto a different carrier frequency. Assuming sufficient frequency separation of the carrier frequencies that the modulated signals do not overlap, recovery of each of the FDM signals is possible at the receiving end. In order to prevent overlap of the signals and to simplify filtering, each of the modulated signals is separated by a guard band, which consists of an unused portion of the available frequency spectrum. Each user is assigned a given frequency band for all time.

While each user's information signal may be either analog or digital, the combined FDM signal is inherently an analog waveform. Therefore, an FDM signal must be transmitted over an analog channel. Examples of FDM are found in some of the old long-distance telephone transmission systems, including the American N- and L-carrier coaxial cable systems and analog point-to-point microwave systems. In the L-carrier system a hierarchical combining structure is employed in which 12 voiceband signals are frequency-division multiplexed to form a group signal in the frequency range of 60 to 108 kilohertz. Five group signals are multiplexed to form a supergroup signal in the frequency range of 312 to 552 kilohertz, corresponding to 60 voiceband signals, and 10 supergroup signals are multiplexed to form a master group signal. In the L1 carrier system, deployed in the 1940s, the master group was transmitted directly over coaxial cable. For microwave systems, it was frequency modulated onto a microwave carrier frequency for point-to-point transmission. In the L4 system, developed in the 1960s, six master groups were combined to form a jumbo group signal of 3,600 voiceband signals.

Time-division multiplexing:

Multiplexing also may be conducted through the interleaving of time segments from different signals onto a single transmission path—a process known as time-division multiplexing (TDM). Time-division multiplexing of multiple signals is possible only when the available data rate of the channel exceeds the data rate of the total number of users. While TDM may be applied to either digital or analog signals, in practice it is applied almost always to digital signals. The resulting composite signal is thus also a digital signal.

In a representative TDM system, data from multiple users are presented to a time-division multiplexer. A scanning switch then selects data from each of the users in sequence to form a composite TDM signal consisting of the interleaved data signals. Each user's data path is assumed to be time-aligned or synchronized to each of the other users' data paths and to the scanning mechanism. If only one bit were selected from each of the data sources, then the scanning mechanism would select the value of the arriving bit from each of the multiple data sources. In practice, however, the scanning mechanism usually selects a slot of data consisting of multiple bits of each user's data; the scanner switch is then advanced to the next user to select another slot, and so on. Each user is assigned a given time slot for all time.

Most modern telecommunications systems employ some form of TDM for transmission over long-distance routes. The multiplexed signal may be sent directly over cable systems, or it may be modulated onto a carrier signal for transmission via radio wave. Examples of such systems include the North American T carriers as well as digital point-to-point microwave systems. In T1 systems, introduced in 1962, 24 voiceband signals (or the digital equivalent) are time-division multiplexed together. The voiceband signal is a 64-kilobit-per-second data stream consisting of 8-bit symbols transmitted at a rate of 8,000 symbols per second. The TDM process interleaves 24 8-bit time slots together, along with a single frame-synchronization bit, to form a 193-bit frame. The 193-bit frames are formed at the rate of 8,000 frames per second, resulting in an overall data rate of 1.544 megabits per second. For transmission over more recent T-

carrier systems, T1 signals are often further multiplexed to form higher-data-rate signals again using a hierarchical scheme.

Answer Question 2(b)

Large scale fading and small-scale fading. Large scale-fading represents the average signal-power attenuation or path loss due to motion over large areas and it is impacted by terrain configuration between the transmitter and receiver, and over a very long distance (several hundreds or thousands of meters), there is a steady decrease in power. Examination of the power over such a distance reveals that the power fluctuates around a mean value and these fluctuations have a rather long period. The statistics of large-scale fading, described in terms of a mean-path loss (n^{th} -power law) and a log-normally distributed variation about the mean, can lead to an estimate of path loss as a function of distance.

Small-scale fading refers to the rapid changes of the amplitude and phase of a radio signal over a short period of time (on the order of seconds) or a short distance (a few wavelengths). In small-scale fading, the instantaneous received signal power may vary as much as 30 to 40 dB when the receiver is moved by only a fraction of a wavelength. In a mobile-radio environment, each path has its own Doppler shift, time delay, and path attenuation, and multipath propagation results in a time-varying signal as the mobile moves position. Such a channel is linear, but time-varying. Small-scale fading is also called Rayleigh fading because when the number of versions of the transmitted signal which arrive at slightly different times is large, the envelope of the received signal is statistically described by a Rayleigh distribution if there is no line-of-sight component. If there is a line-of-sight component, it is then described by a Rician distribution.

Small-scale fading depends on the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters, such as the bandwidth and the symbol period, on the one hand, and the channel parameters, such as the coherence time, Doppler spread, coherence bandwidth and delay spread, on the other hand, different transmitted signals will experience different types of fading. Delay spread leads to time dispersion and frequency-selective fading. Doppler spread leads to frequency dispersion and time-selective fading. Time dispersion and frequency dispersion are caused by independent propagation mechanisms.

Answer Question 3(1)

OFDM is a form of multicarrier modulation. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period.

This acts as a bank of demodulators, translating each carrier down to DC. The resulting signal is integrated over the symbol period to regenerate the data from that

carrier. The same demodulator also demodulates the other carriers. As the carrier spacing equal to the reciprocal of the symbol period means that they will have a whole number of cycles in the symbol period and their contribution will sum to zero - in other words there is no interference contribution.

One requirement of the OFDM transmitting and receiving systems is that they must be linear. Any non-linearity will cause interference between the carriers as a result of inter-modulation distortion. This will introduce unwanted signals that would cause interference and impair the orthogonality of the transmission.

In terms of the equipment to be used the high peak to average ratio of multi-carrier systems such as OFDM requires the RF final amplifier on the output of the transmitter to be able to handle the peaks whilst the average power is much lower and this leads to inefficiency. In some systems the peaks are limited. Although this introduces distortion that results in a higher level of data errors, the system can rely on the error correction to remove them.

The traditional format for sending data over a radio channel is to send it serially, one bit after another. This relies on a single channel and any interference on that single frequency can disrupt the whole transmission.

OFDM adopts a different approach. The data is transmitted in parallel across the various carriers within the overall OFDM signal. Being split into a number of parallel "substreams" the overall data rate is that of the original stream, but that of each of the substreams is much lower, and the symbols are spaced further apart in time.

This reduces interference among symbols and makes it easier to receive each symbol accurately while maintaining the same throughput.

The lower data rate in each stream means that the interference from reflections is much less critical. This is achieved by adding a guard band time or guard interval into the system. This ensures that the data is only sampled when the signal is stable and no new delayed signals arrive that would alter the timing and phase of the signal. This can be achieved far more effectively within a low data rate substream.

OFDM advantages:

- Immunity to selective fading: One of the main advantages of OFDM is that it is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.
- Resilience to interference: Interference appearing on a channel may be bandwidth limited and in this way will not affect all the sub-channels. This means that not all the data is lost.
- Spectrum efficiency: Using close-spaced overlapping sub-carriers, a significant OFDM advantage is that it makes efficient use of the available spectrum.
- Resilient to ISI: Another advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.

- Resilient to narrow-band effects: Using adequate channel coding and interleaving it is possible to recover symbols lost due to the frequency selectivity of the channel and narrow band interference. Not all the data is lost.
- Simpler channel equalisation: One of the issues with CDMA systems was the complexity of the channel equalisation which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler.

Answer Question 3(2)

it's important to first know about transmit beamforming (TxBF). Unlike MIMO, which sends a different spatial stream on each antenna, transmit beamforming sends the same stream on multiple antennas with deliberate timing offsets to increase range. The phase of each data stream is transmitted by all antennas at different times, so that these different signals constructively interfere at a point in space (i.e. the location of the receiver), thereby enhancing the signal strength at that location. When using omni-directional antennas, pattern created becomes effectively directional. Transmit Beamforming can therefore only work if the transmitter can derive the location of the Receiver via the use of sounding frames.

MU-MIMO takes this process one step further. By adding even more radio chains/antennas, an AP can control the phased antenna pattern to control where the signal is the strongest and where the signal is the weakest. With enough antennas and knowledge about the relative positions of all associated client devices, an AP can create a phased pattern to talk to multiple clients both independently and simultaneously. Therefore, for the very first time, by using multi-user multiple-input, multiple-output (MU-MIMO) technology, a wireless Access Point can transmit to multiple Wi-Fi client devices at the same time.

MIMO systems can be configured to provide spatial diversity by transmitting the same symbol through different antennas, or increase the total transmission rate by transmitting independent information streams through different antennas. Can we achieve both of these two advantages simultaneously? While traditional design focused on maximizing either the spatial diversity or the transmission rate Their result shows that both of the two advantages mentioned above can be achieved simultaneously, but there is a tradeoff between them. In other words, having more spatial diversity results in less transmission rate, and vice versa. From a diversity-multiplexing tradeoff (DMT)'s point of view, we say a coding (transmission) scheme has a spatial multiplexing gain r and a diversity gain d , if the transmission rate scales like $r \log \text{SNR}$ and the average error probability decays like SNR^{-d} . The essential result of the paper is the characterization of the optimal diversity-multiplexing tradeoff for a MIMO system under independent and identically distributed (i.i.d) Rayleigh fading channel. It was proved that the optimal diversity gain $d(r)$ is a simple piecewise linear function of multiplexing gain r .