Lecture 11: Modulation Techniques for Mobile Radio

Cellular systems transmit information signals (audio signals or digital data signals) that are generally baseband signals occupying a band that is located around zero frequency. An audio signal, for example, occupies frequencies that generally occupy the spectrum from 0 Hz to around 4 kHz. Digital data may have different rates (and therefore occupy different frequency bands) ranging from few kbits/s to several Mbits/s. Such signals occupy bandwidths from few kHz to few MHz depending on the method of transmission. Regardless of whither we are talking about the transmission of speech or digital data, these signals cannot be transmitted directly as they contain frequency components that have very low frequencies that are not suitable for transmission over the air in addition to the fact that all similar signals of the same nature occupy the same frequency band and therefore would interfere with each other if all of them are transmitted as they are. Therefore, modulation is needed to shift the frequency of the signal from being around zero (baseband signal) to some high frequency (passband signal). This makes the signal suitable for transmission over the air as a radio signal and allows the use of different frequency bands for transmission of different signals. The process of bringing the modulated signal back from the high frequency used during transmission back to the original baseband frequency range is called demodulation.

Analog vs. Digital Modulation Techniques

There exists analog modulation techniques as well as digital modulation techniques. In most cases, these modulation techniques are closely related, although the names may be different. For example, the famous analog modulation techniques are Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Modulation (PM), while the corresponding digital modulation techniques are called Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK). We will start discussing analog modulation techniques and then switch to frequency modulation techniques later.

Analog Modulation Techniques: Amplitude Modulation vs. Frequency (or Phase) Modulation

Amplitude, Frequency, and Phase modulation techniques are the three mostly used types of modulation. Each of these techniques transmits the information contained in the message signal by changing on of the three parameters of the a sinusoid (Amplitude A_c, Frequency f_c, and Phase θ_c). In amplitude modulation the amplitude of the carrier signal is modified such that $A_c(t) \propto m(t)$, in frequency modulation the frequency of the carrier signal is modified such that $f_c(t) \propto m(t)$, and finally in phase modulation the phase of the carrier signal is modified such that $\theta_c(t) \propto m(t)$. For mobile and cellular phones, FREQUENCY MODULATION is the most widely used to its features (especially when compared to amplitude modulation).

Comparison between Amplitude and Frequency Modulations

Feature	AM	FM (or PM)
Spread of Usage	Limited Usage	Widely Usage
Amplitude of Modulated Signal	A function of the message signal	Constant
Frequency (or Phase) of Modulated Signal	Constant	A function of the message signal
Information is carried over	The amplitude of the signal	The frequency (or phase) of the signal
Linearity of the Modulation	Linear (adding two signals and then modulating them gives same result as modulating the two signals and then addition the modulated signals)	Non linear (adding two signals and then modulating them is not the same as modulating the two signals and then addition the modulated signals)
Quality of Reception	Directly proportional to SNR or (SIR)	Rapid Improvement in quality once a minimum SNR or SIR is reached (called FM Threshold)
Noise Immunity (Effect of Burst and Impulse Noise)	Low (Burst and Impulse noise directly affect amplitude of received signal which directly appears in demodulated signal)	High (Burst and impulse noise have little effect on phase/frequency of modulated signal if it has sufficiently high power and therefore mostly do not appear in demodulated signal)
Performance in Fading Channels	Bad (Fading affects amplitude of modulated signal which is related to message signal, so reception is directly affected)	Very good (Fading affects amplitude of modulated signal which is constant, so reception is indirectly affected)
Bandwidth of Modulated Signal	Constant – relatively low (Only affected by bandwidth of message signal)	Variable – relatively high (Can be modified by modifying the modulation index)
Can Performance be Improved (Tradeoff between Bandwidth and Performance)	No (No tradeoff can be done)	Yes (Bandwidth and quality of Received signal can be traded off. Each doubling of bandwidth gives approximately 6 dB improvement in reception quality. **This is one of the most important features that make FM preferred over AM in many systems including cellular systems**)
Use of In-Band Pilot Tone	Needed (to improve performance in fading channels or channels with rapidly varying amplitude responses. Receiver monitors the pilot tone and adjusts receiver gain according to	No needed (because amplitude of signal is constant)

	amplitude or pilot tone to compensate for fluctuations in amplitude)	
Transmitted Power	Variable (Depends on message signal)	Constant (Is independent of message signal)
Type of RF Power Amplifiers Used	Inefficient (Linear Type A or Type AB with efficiency < 40%)	Efficient (Type C with efficiency > 70%. Non-linearity of power amplifier has no effect)
Battery Life of Handheld Devices	Low (because of low efficiency of power amplifiers used)	High (because of high efficiency of power amplifiers used)
Capture Effect	Does not exist	Exists (because of rapid improvement in reception quality as SNR improves)
Resistance to Co-Channel Interference	Low (All signals existing at the same reception frequency band appear in demodulated signal with same amplitude ratios as received)	High (Capture effect allows it to receive the strong signal and reject the weak co-channel interferes
Bandwidth Usage	Low (very bandwidth efficient)	High (bandwidth inefficient. But high bandwidth must be used to obtain capture effect and immunity to noise advantages of FM
System Complexity	Low	High
Performance in low SNR	Relatively good	Relatively bad