ELC5693-GENERAL COMMUNICATION THEORY
6B07112 Electronic and Electrical Engineering

СӘТБАЕВ УНИВЕРСИТЕТІ
SATBAYEV UNIVERSITY

Lecture 10: Noise and Distortions in Communication Channels

Dosbayev Zhandos Makhsutuly, senior lecturer
E-mail: zh.dosbayev@satbayev.university

Outline

Noise and Distortions in Communication Channels

Types of Noise

Sources of Distortion

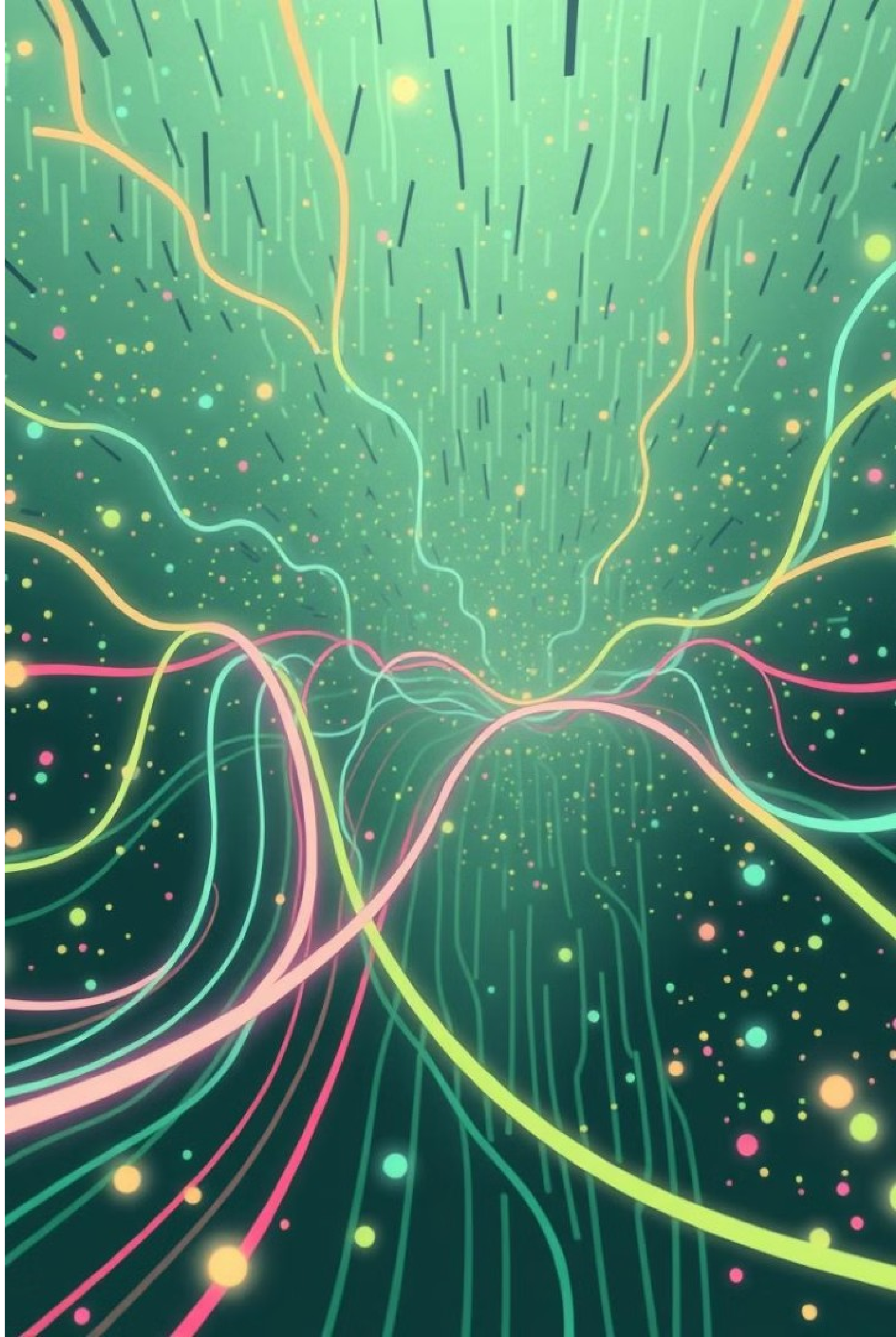
Signal-to-Noise Ratio (SNR)

Techniques for Noise Reduction: Filtering, Equalisation, Error Coding

Noise and Distortions in Communication Channels

Welcome to Lecture 10, where we delve into the fascinating world of noise and distortions in communication channels. In this comprehensive exploration, we'll uncover the various types of interference that plague our communication systems, from the microscopic jitters of electrons to the grand-scale disruptions in satellite transmissions.

As we navigate through this complex terrain, we'll examine the sources of these disruptions, their effects on signal integrity, and the ingenious techniques engineers have developed to combat them. By the end of this lecture, you'll have a profound understanding of how modern communication systems triumph over the cacophony of the universe to deliver clear, reliable signals across vast distances.



Introduction to Noise and Distortions in Communication Channels

In the realm of communication systems, noise and distortions are the archenemies of clear signal transmission. These unwanted perturbations can significantly degrade the quality of information being transmitted, leading to errors, misinterpretations, and in severe cases, complete loss of data.

Noise, in its essence, refers to random fluctuations that interfere with the desired signal. Distortions, on the other hand, are predictable alterations to the signal's shape or timing. Both can arise from a myriad of sources, ranging from the fundamental physics of electronic components to environmental factors like electromagnetic interference.

1. **Signal Generation**

   The pristine signal is created at the source, carrying the intended information.

2. **Channel Transmission**

   As the signal travels through the channel, it encounters various forms of noise and distortions.

3. **Signal Reception**

   The received signal is a combination of the original signal plus accumulated noise and distortions.

4. **Signal Processing**

   Advanced techniques are employed to mitigate the effects of noise and distortions, recovering the original signal.

Types of Noise: Thermal Noise, Shot Noise, Flicker Noise

In the microscopic world of electronic circuits, several types of noise conspire to muddy our signals. Thermal noise, also known as Johnson-Nyquist noise, arises from the random thermal motion of charge carriers in a conductor. This omnipresent noise sets a fundamental limit on the sensitivity of electronic systems and increases with temperature.

Shot noise, on the other hand, is a consequence of the discrete nature of electric charge. As electrons flow across a barrier, such as in semiconductor junctions, their arrival times fluctuate, causing small current variations. This type of noise is particularly significant in low-current systems.

Thermal Noise

Caused by random thermal agitation of charge carriers. Its power spectral density is uniform, earning it the moniker "white noise". It sets the noise floor in many systems.

Shot Noise

Results from the quantized nature of electric charge. It becomes prominent in systems with low current levels, such as photodetectors and tunnel junctions.

Flicker Noise

Also known as 1/f noise, it has a power spectral density that decreases with frequency. It's prevalent in semiconductor devices and can dominate at low frequencies.

Sources of Distortion: Non-linearity, Inter-symbol Interference

Distortions in communication channels can significantly alter the shape and timing of signals, leading to misinterpretation at the receiver. Non-linearity, a common source of distortion, occurs when the output of a system is not directly proportional to its input. This can result in harmonic distortion, where new frequency components are introduced, or intermodulation distortion, where different frequency components interact.

Inter-symbol interference (ISI) is another crucial form of distortion, particularly in digital communication systems. ISI occurs when symbols in a transmission interfere with each other, often due to multipath propagation or bandwidth limitations. This can cause symbols to "smear" into adjacent time slots, making it difficult for the receiver to accurately decode the transmitted information.

Non-linearity

Caused by components with non-linear transfer characteristics. Can introduce harmonics and intermodulation products, distorting the signal spectrum.

Inter-symbol Interference

Results from temporal spreading of transmitted symbols. Can lead to increased bit error rates in digital systems if not properly mitigated.

Amplitude Distortion

Occurs when different frequency components experience unequal gain. Can alter the shape of transmitted pulses.

Phase Distortion

Happens when different frequency components experience unequal phase shifts. Can cause timing errors in digital systems.

Additive White Gaussian Noise (AWGN) Model

The Additive White Gaussian Noise (AWGN) model is a cornerstone in the analysis of communication systems. This model provides a simplified yet powerful representation of the noise encountered in many real-world scenarios. In the AWGN model, the noise is assumed to be statistically independent of the signal and additive in nature, meaning it's simply added to the signal.

The "white" aspect of AWGN refers to its uniform power spectral density across all frequencies, analogous to white light containing all colours. The "Gaussian" part describes the probability distribution of the noise amplitude, which follows a normal or Gaussian distribution. This model is particularly useful because it closely approximates many physical noise sources and allows for tractable mathematical analysis.

1

Signal Generation

The original signal is created with specific characteristics.

2

Noise Addition

AWGN is added to the signal, simulating channel effects.

3

Signal Reception

The noisy signal is received and processed.

4

Performance Analysis

System performance is evaluated under various noise levels.

Signal-to-Noise Ratio (SNR) and its Importance

The Signal-to-Noise Ratio (SNR) is a critical metric in communication systems, quantifying the relationship between the desired signal and the background noise. Expressed in decibels (dB), SNR provides a measure of signal quality and is fundamental in determining the performance limits of communication systems. A higher SNR indicates a stronger signal relative to the noise, generally resulting in better system performance.

In digital communications, SNR directly influences the bit error rate (BER), a key performance indicator. As SNR increases, the BER typically decreases, allowing for more reliable data transmission. SNR also plays a crucial role in determining the channel capacity, as described by Shannon's theorem, which sets the theoretical maximum data rate for a given channel.

SNR (dB)	Signal Quality	Typical Application
0-10	Poor	Minimum for digital communication
10-20	Moderate	Voice communication
20-30	Good	High-quality digital transmission
30+	Excellent	High-definition video, scientific instruments

Bandwidth and its Effect on Noise Performance

Bandwidth, the range of frequencies over which a system operates, plays a crucial role in determining noise performance. In general, increasing bandwidth allows for higher data rates but also admits more noise into the system. This fundamental trade-off is at the heart of many design decisions in communication systems.

The relationship between bandwidth and noise is governed by the concept of noise power spectral density. As bandwidth increases, the total noise power also increases, potentially degrading the signal-to-noise ratio. However, wider bandwidth can also allow for more sophisticated modulation schemes and coding techniques that can compensate for the increased noise.

Bandwidth

Determines the range of frequencies used for transmission. Wider bandwidth allows for higher data rates but potentially more noise.

Noise Power

Increases with bandwidth. The total noise power is proportional to the bandwidth of the system.

Data Rate

Generally increases with bandwidth, allowing for faster communication at the cost of potentially lower SNR.

Filtering

Bandwidth limitation through filtering can reduce noise but may also introduce inter-symbol interference.

Modulation Schemes and their Resilience to Noise

Modulation schemes play a pivotal role in determining a communication system's resilience to noise. Different modulation techniques offer varying trade-offs between spectral efficiency, power efficiency, and robustness against noise and interference. Understanding these trade-offs is crucial for designing systems that perform optimally under specific channel conditions.

Amplitude Modulation (AM) and Frequency Modulation (FM) are classic analog modulation schemes. AM is simple but highly susceptible to noise, while FM offers better noise immunity at the cost of increased bandwidth. In the digital domain, Phase-Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) are widely used. PSK is robust against amplitude noise but sensitive to phase noise, while QAM offers high spectral efficiency but requires a higher SNR to maintain reliability.

Amplitude Modulation (AM)

Simple implementation but highly susceptible to noise. Useful in applications where simplicity is prioritised over noise immunity.

Frequency Modulation (FM)

Offers better noise immunity than AM, especially for analog signals. Widely used in radio broadcasting.

Phase-Shift Keying (PSK)

Good noise resilience for digital signals. Binary PSK (BPSK) is particularly robust, while higher-order PSK schemes offer increased data rates at the cost of noise sensitivity.

Techniques for Noise Reduction: Filtering, Equalisation, Error Coding

Combating noise and distortions in communication systems requires a multi-faceted approach. Filtering is often the first line of defence, removing out-of-band noise and limiting the system's exposure to interference. Low-pass, band-pass, and high-pass filters can be employed depending on the signal and noise characteristics. Advanced adaptive filtering techniques can dynamically adjust to changing noise conditions.

Equalisation techniques address inter-symbol interference and channel distortions. Adaptive equalisers can compensate for unknown and time-varying channel characteristics, crucial in mobile communication systems. Error coding adds redundancy to the transmitted data, allowing for detection and correction of errors at the receiver. Techniques like Forward Error Correction (FEC) can significantly improve system performance in noisy environments.

1. **Filtering**

   Removes out-of-band noise and limits interference. Can be implemented in analog or digital domains. Adaptive filters can dynamically adjust to changing noise conditions.

2. **Equalisation**

   Compensates for channel distortions and inter-symbol interference. Adaptive equalisers can handle unknown and time-varying channel characteristics.

3. **Error Coding**

   Adds redundancy to transmitted data for error detection and correction. Techniques like Turbo codes and Low-Density Parity-Check (LDPC) codes offer near-Shannon limit performance.

4. **Spread Spectrum**

   Spreads signal over a wide bandwidth, providing resistance to narrow-band interference and improving security.

Case Studies: Examples of Noise and Distortions in Real-World Systems

Real-world communication systems face a myriad of challenges from noise and distortions. In satellite communications, thermal noise from the Earth and cosmic background radiation can significantly impact signal quality. The vast distances involved also lead to signal attenuation, requiring sophisticated error correction techniques and high-gain antennas.

Mobile phone networks contend with multipath fading, where signals reflect off buildings and terrain, arriving at the receiver at different times. This causes inter-symbol interference and requires advanced equalisation techniques. In underwater acoustic communications, used in oceanography and offshore oil industries, the channel is highly dispersive and time-varying, necessitating adaptive signal processing techniques.

Satellite Communication

Deals with extreme path loss, cosmic radiation, and atmospheric effects. Requires high-gain antennas and powerful error correction.

Mobile Networks

Face challenges from multipath fading, interference from other users, and rapidly changing channel conditions as users move.

Underwater Acoustics

Contend with highly dispersive channels, time-varying conditions, and low propagation speed of sound in water.