Comparing Probability of Error and Outage Probability of Different Channels

Riya Vardhan

Department of Electronics and Communication

Section: B, Roll No: 16

Registration No: 200907110

Thaejus Surya M T

Department of Electronics and Communication

Section: B, Roll No: 14

Registration No: 200907102

Sagnnik Biswas

Department of Electronics and Communication

Section: B, Roll No: 13

Registration No: 200907098

Virupaaksh

Department of Electronics and Communication

Section: B, Roll No: 1

Registration No: 190907234

***Abstract* – The objective of this study is to compare the various results in three different channel systems, namely the single channel system, the three-channel system, and the time-varying channel system. The aim is to determine the probability of error in the received signal and the outage probability, which checks if the received signal strength falls below a minimum threshold power. The comparative analysis of the three signal channels is aided by MATLAB software.**

***Keywords* – Error, Probability, Bit-Error-Rate(BER), Outage-Probability, Communication, Single-channel, Three-Channel, Fading, Performance**

I. Introduction

Study of wireless communication starts from probability theory because wireless communications deal with uncertainty. If there are no channel impairments by nature, the transmitted messages can be received without distortion, and no need to care about probability theory. But in reality, channel fading, shadowing, and multipath loss are seen during the transmission and receiving of signals. Therefore, it may be necessary to use techniques such as channel coding, modulation schemes, and error correction to improve the system performance and reduce the error rates.

II. Theory

A. Probability of Error

In a wireless channel, the probability of error (Pe) is the likelihood that a transmitted bit is received incorrectly due to noise or interference in the communication channel. It is a measure of the accuracy of the transmission and reception of the signal. Pe is calculated by dividing the total number of incorrectly received bits by the total number of transmitted bits. The probability of error is affected by various factors, such as the distance between the transmitter and receiver, the transmission power, the channel bandwidth, the modulation scheme used, and the presence of interference or noise in the communication channel. A lower probability of error indicates better transmission quality and higher accuracy in the transmission and reception of data. Assuming a noise follows a Gaussian distribution and the channel is subject to Rayleigh fading, the probability of error for a given modulation scheme can be calculated using the Bit Error Rate (BER) formula:

$$Bit\ Error\ Rate\ (BER) = 0.5 \times erfc(\sqrt{SNR})$$

where, $erfc$ is the complementary error function and SNR is the signal-to-noise ratio.

B. Outage Probability

The outage probability can be defined as the probability that the received signal-to-noise ratio (SNR) falls below a certain threshold, which is required to maintain a certain quality of service (QoS) at the receiver. The QoS can be defined as the bit error rate (BER), data rate, or other performance metrics. For example, suppose the outage threshold for a particular QoS level is SNRth. In that case, the outage probability can be calculated as

$$P_{out} = P(SNR < SNR_{th})$$

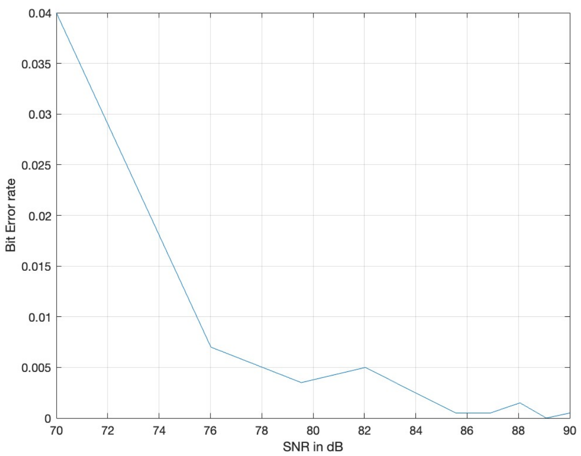
The outage probability can be estimated using various models, depending on the channel and propagation conditions, such as the log-normal model, the Rayleigh fading model, or the Nakagami-m model. The outage probability can be reduced using power control, adaptive modulation and coding, diversity techniques, and interference management. By reducing the outage probability, the overall system performance and reliability can be improved, especially in the presence of fading and interference.

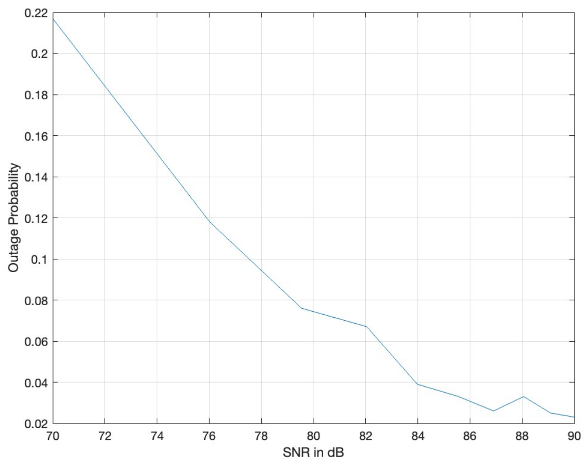
III. Wireless Communication Channels

Wireless communication channels is the medium through which signal is transmitted from the sender to the receiver in a particular bandwidth.

A. Single Channel

A single-channel wireless communication system refers to a system that uses a single channel for both the transmission and reception of data. This means that the same frequency band is used to send and receive data. One advantage of a single-channel system is that it is simple and cost-effective, requiring less hardware and power consumption than multi-channel systems. However, a single-channel system can be more susceptible to interference, noise, and other impairments, which can degrade the system's performance and reliability.





Results and Conclusions: As can be seen from the plot, the BER decreases as the SNR increases. This is because as the SNR increases, the received signal power becomes stronger relative to the noise, which reduces the probability of bit errors. However, as the SNR continues to decrease, the communication system may eventually become limited by other factors such as interference, fading, or power constraints, which cause the outage probability to decrease.

As the SNR increases, the probability of bit errors decreases. The knee of the curve represents the threshold where the BER begins to decrease at a slower rate, and this point can be used to determine the maximum achievable data rate for the wireless communication system. The BER curve can also be used to compare the performance of different modulation and coding schemes, and to optimize the design of the wireless communication system to meet the desired quality-of-service requirements.

In a single channel wireless communication system, the outage probability versus SNR curve can exhibit a sharp transition from high to low outage probability as SNR increases. This is because the system is highly susceptible to interference and other impairments that can cause an outage event to occur.

In a single channel wireless communication channel, the BER v/s SNR curve typically follows a smooth monotonic curve, where the BER decreases as the SNR increases. However, at a certain SNR threshold, the BER curve may experience a sharp transition and become asymptotic to a minimum BER level.

B. Three Channels

In a three channel wireless communication system, the received signal is a combination of three independent channels, each with its own noise and fading characteristics. With modified SNR values that account for the combined effects of the three channels, the outage probability and bit error rate can be calculated using the same equations as in a single channel system.

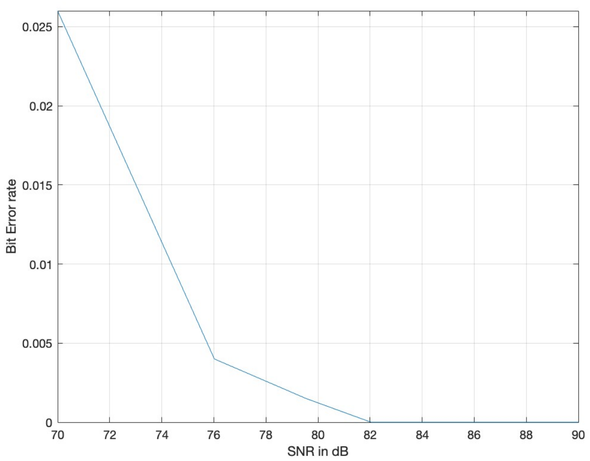
In Three channel transmission, the data is divided into three parts and transmitted over three independent channels, which reduces the effect of fading and noise on the transmitted signal. Therefore, the probability of bit errors and outages is lower in three channel transmission systems compared to single channel transmission systems.

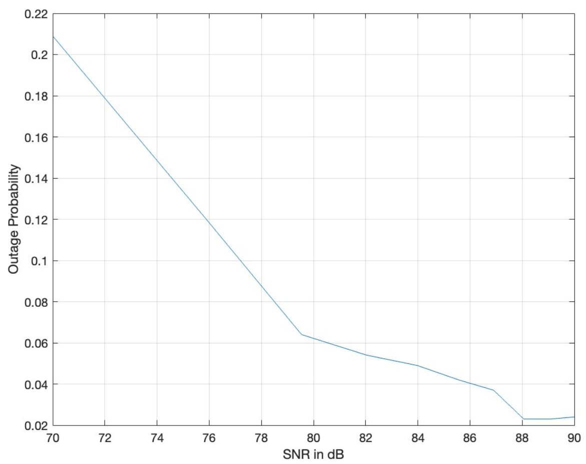
Results and Conclusions: As can be seen from the plot, the BER and outage probability curves exhibit similar trends to those in a single channel system, but with more fluctuations due to the combined effects of the three channels. The BER decreases as the SNR increases, while the outage probability initially decreases, then levels off and eventually increases again. However, the fluctuations in the curves can be larger in a three channel system, as the noise and fading characteristics of each channel can vary independently. In a three channel wireless communication channel, the BER v/s SNR curve can exhibit a staircase-like pattern, with multiple steps in the curve corresponding to the different SNRs of each channel. As, the

SNR increases, the BER transitions from one step to the next, resulting in an overall decrease in the BER.

In a three-channel wireless communication system, the outage probability versus SNR curve can exhibit a more gradual transition as SNR increases, compared to a single channel system. This is because the use of multiple channels provides redundancy and diversity, allowing the receiver to potentially recover from channel impairments in one or more of the channels.

Three channel transmission systems provide better BER and outage performance compared to single channel transmission systems.





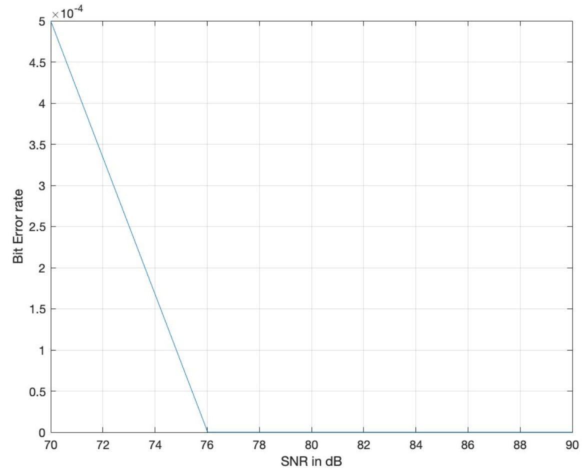
C. Time-Diversity Channel

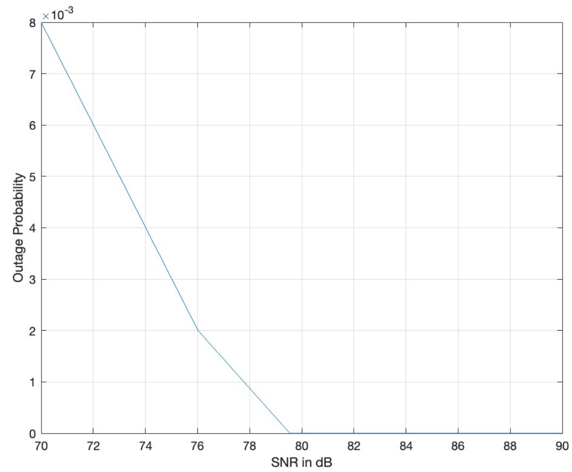
At low SNR, the probability of error and outage probability are high, because the received signal is weak compared to the noise and interference. As the SNR increases, the probability of error decreases and the outage probability also decreases.

As the number of time slots over which the signal is transmitted and received increases, the probability of error and outage probability decreases significantly, even at lower SNR levels. This is due to the fact that the receiver can combine the signals from multiple time slots to improve the overall signal quality.

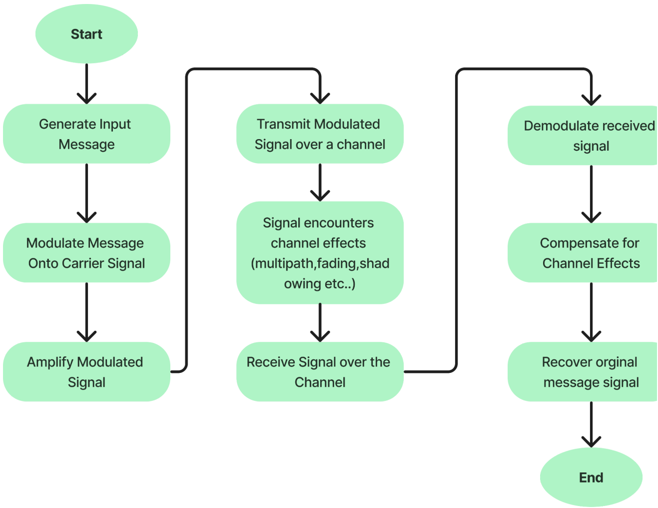
Result and Conclusion: Thus, the graph of probability of error and outage probability vs SNR in a time diversity channel will show a significant improvement in performance compared to a non-diversity channel, particularly at lower SNR levels. The slope of the graph will also be less steep, indicating a more gradual decrease in probability of error and outage probability with increasing SNR.

In a time diversity wireless communication system, the outage probability versus SNR curve can exhibit a similar gradual decrease as SNR increases, due to the use of multiple time slots and redundancy in the system. The receiver can potentially recover from channel impairments in each individual time slot, reducing the likelihood of an outage event occurring.





IV. Flow Chart



V. Conclusion

The graphical outputs of BER versus SNR (in dB) differ mainly due to the underlying communication systems. The graphical outputs of BER v/s SNR and outage probability v/s SNR for different wireless communication channels can provide insights into the performance of the systems under different conditions, and can inform the design and optimization of wireless communication systems for specific applications.

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