Performance Analysis of Communication Systems

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Abstract

In this project, several simplified binary communication schemes are studied. In particular, all these schemes are simulated and the results are compared with theoretical values. For this study, an additive white Gaussian noise(AWGN) channel with binary antipodal signaling(binary phase shift keying), on-off signaling, and quadrature phase shift keying(QPSK) schemes are considered.

1 Introduction and Theory

The general problem in communication systems is to transmit the symbols generated by source over a channel. The symbols can be binary ("0"s and "1"s), or M-ary (M different symbols, say 0,1,2,...,M-1), where M is usually taken to be power of 2. The symbols are assumed to be equally likely, and independent of each other. That is, in the binary case, "0" and "1" is transmitted with equal probability (with probability 1/2 each), and in the M-ary case, each symbol is transmitted with equal probability (with probability 1/M each). Obviously, each symbol of an M-ary signal corresponds to $log_2 M$ bits, that is, we can transmit $log_2 M$ bits by using one M-ary symbol.

In binary phase shift keying (BPSK) modulation and on-off signaling, we are concerned with the transmission of binary symbols, "0"s or "1"s. The equivalent model for the BPSK and on-off signaling over an additive white Gaussian noise channel is as follows: In BPSK modulation, in order to transmit the bit "1", we transmit a "1" and in order to transmit the bit"0", we transmit a "-1". In a real digital communication system, transmission of 1's correspond to transmission of certain waveforms, but here we are considering the equivalent discrete-time model. In on-off signaling, in order to transmit the bit "1", we transmit a "1", and in order to transmit the bit "0" we transmit "0".

The receiver can only observe the transmitted signals corrupted with some noise. In an AWGN channel, the observation is a random variable, Y = X + Z, where the random variable X is the discrete random variable denoting the signal transmitted, and Z is the additive zero-mean Gaussian noise term with variance N0/2. Obviously, in a real communication system, the noise is a random process, as opposed to a random variable. However, we again emphasize that we are talking about the equivalent discrete time model in this project. The quantity is defined as the signal to noise ratio (SNR) [1].

$$\lambda = \frac{E[X^2]}{N_0} \tag{1}$$

For instance, the signal to noise ratio per bit for BPSK is $1/N_0$. Similarly, for SNR per bit for OOK is $1/2N_0$.

The receiver observes Y , and tries to make a decision about which symbol was transmitted. Since the transmission of each symbol is independent of each other, the receiver can make a symbol-by-symbol decision. The optimal decision on the current symbol is obtained through binary hypothesis testing (Bayesian detection) with equal priors. The hypothesis in each case can be given as:

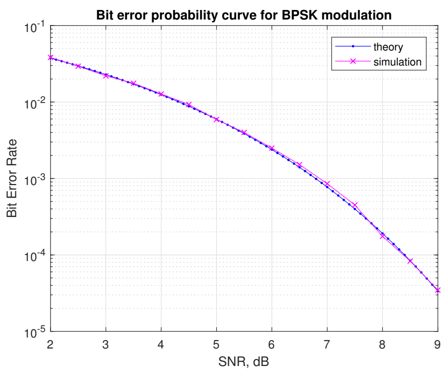
$$H_k : Y \sim \mathcal{N}(s_k, \mathbf{C}_n) \tag{2}$$

where s_k is obtained from signal constellation, $\mathbf{C}_n$=$\sigma_n^2 I_n$ is the covariance matrix of noise, with σ_n^2 determined from the SNR value. The optimal decision rule for BPSK modulation: if $y < 0$, then decide X=-1 (or, m=0), and if $y > 0$ then decide X=+1. For on-off signaling: if $y < 1/2$, then decide X=-1 (or, m=0), and if $y > 1/2$ then decide X=+1.

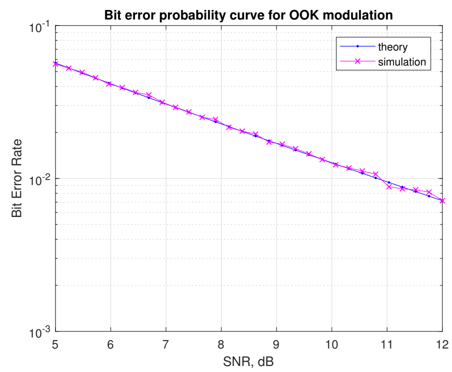
To compare all the schemes, BPSK,OOK, and QPSK are simulated over an additive white Gaussian noise channel for various signal to noise ratios in Matlab. 100,000 transmissions are considered for simulation. 2-9 dB signal to noise ratio are considered for simulating and estimating probability of error (Bit error rate(BER)). The matlab code for all the simulations are listed in the Appendix. The theoretical BER for BPSK and QPSK are same, which is $P_e = Q(\sqrt{\frac{2}{N_0}})$. The BER for OOK is $P_e = Q(\sqrt{\frac{1}{2N_0}})$.

2 Results and Discussion

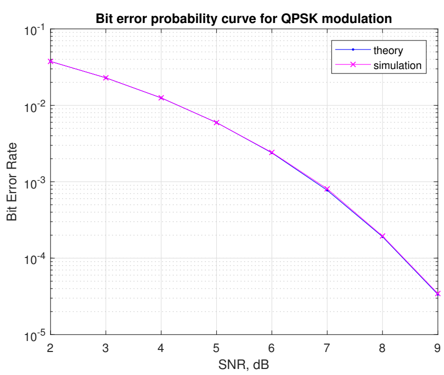
All the results from simulation are grouped together in figure 1. BER of BPSK over AWGN of 2-9 dB SNR's is given in figure 1(a). BER of OOK over AWGN of 5-12 dB SNR's is given in 1(b). BER of QPSK over AWGN of 2-9 dB SNR's is given in 1(c). BER of BPSK,OOK, and QPSK schemes are plotted in figure 1(d) for comparing the performance of communication schemes.



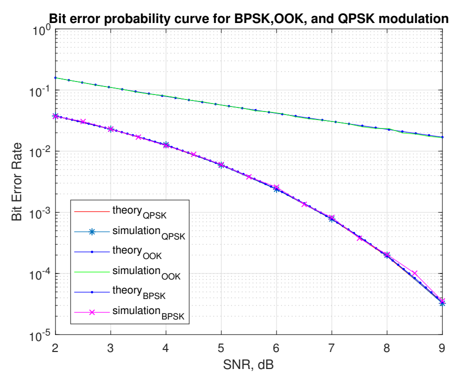
(a) BER of BPSK



(b) BER of OOK



(c) BER of QPSK



(d) BER of BPSK,OOK, and OPSK

Figure 1: The BER of BPSK,OOK, and QPSK are simulated and compared with theoretical values and plotted altogether. .

In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors. The bit error rate (BER) is the number of bit errors per unit time. In other words, the bit error ratio (also BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval [2]. Usually, the SNR depends upon the noise over the channel. Greater the noise variance, lower is the SNR and vice versa. BER depends on the SNR. The greater the SNR, the lower the BER, and vice versa. Well, from figure 1(a), It is obvious that the simulated BER of BPSK concurs well with theoretical BER. Similarly, it is shown for OOK and QPSK in figure 1(b) and 1(c). Hence, we can see that as the SNR increases, the BER for all communication schemes reduces. The SNR and BER share almost linear relationship with each other. As the SNR increases, the BER decreases. The rate of decrease BER for BPSK and QPSK are same over same range of SNRs. However, the BER decreases at a lower rate for on-off keying communication scheme.

In figure 1(d), BPSK,OOK, and QPSK schemes are plotted together over SNR 2-9 dB. Careful observation reveals that about 9 dB of SNR is necessary to achieve a BER of close to 10^{-5} for BPSK and QPSK. However, for OOK, It is observed that BER of 10^{-2} is achieved for a SNR of 9 dB. It is clear, the BPSK and QPSK have same BER over same range of SNRs. However, BER for OOK is high for same range of SNRS. It can also be inferred that BER will almost always be a function of the SNR.

3 Conclusions

In conclusion, the BER of BPSK, OOK, and QPSK schemes are analyzed. It is observed that BPSK and QPSK share same BER-SNR characteristics. It is because QPSK modulation consists of two BPSK modulation on in-phase and quadrature components of the signal [3]. The BER performance of OOK is poor relative to BPSK and QPSK communication scheme.

The BER for QPSK modulation is almost the same as the BER that can be achieved using BPSK modulation. So, to summarize, for a given data rate and a given channel condition (SNR), QPSK is good as BPSK in terms of error performance while it requires half the transmission bandwidth needed for BPSK modulation. This is very important in wireless communications and is a major reason why QPSK is widely favored in digital satellite communications and other terrestrial systems.

References

[1] Simon, M.K. and Alouini, M.S., 2005. Digital communication over fading channels (Vol. 95). John Wiley & Sons.

[2] Meyr, H., Moeneclaey, M. and Fechtel, S.A., 1998. Digital communication receivers: synchronization, channel estimation, and signal processing (pp. 212-213). New York: Wiley.

[3] Bosco, G., Curri, V., Carena, A., Poggiolini, P. and Forghieri, F., 2011. On the performance of Nyquist-WDM terabit superchannels based on PM-BPSK, PM-QPSK, PM-8QAM or PM-16QAM subcarriers. Journal of Lightwave Technology, 29(1), pp.53-61.

Appendix

Matlab Code For BPSK Simulation

```
% %% BPSK transmission over AWGN channel
%BPSK BER
clc
clear

const=[1 -1];
size=100000;
iter_max=1000;
SNR_min=2;
SNR_max=9;
nSNR = 10; % number of signal to noise ratio values to use

SNR_BPSK=[];BER_BPSK=[];
for EbN0 = SNR_min:0.5:SNR_max
EbN0_lin=10.^(0.1*EbN0);
noise_var=0.5/(EbN0_lin); % s^2=N0/2
iter = 0;
err = 0;
while (iter <iter_max && err <100)
bits=randsrc(1,size,[0 1]);
s=const(bits+1);
x = s + sqrt(noise_var)*randn(1,size);
bit_hat=(-sign(x)+1)/2;
err = err + sum(bits ≠ bit_hat);
iter = iter + 1;
end
SNR_BPSK =[SNR_BPSK EbN0];
BER_BPSK = [BER_BPSK err/(size*iter)];
end
SNR_dB_BPSK=[2:(1/nSNR):9];
theoryBer_BPSK = 0.5*erfc(sqrt(10.^(SNR_dB_BPSK/10))); % theoretical ber

% plot
close all
figure
semilogy(SNR_dB_BPSK,theoryBer_BPSK,'b.-');
hold on
semilogy(SNR_BPSK,BER_BPSK,'mx-');
grid on
legend('theory', 'simulation');
xlabel('SNR, dB');
ylabel('Bit Error Rate');
title('Bit error probability curve for BPSK modulation');
```

Matlab Code For OOK Simulation

```matlab
clear, clc
% set up
nSymb = 2; % number of points in constellation
N = 10^5; % number of symbols transmitted
nSNR = 30; % number of signal to noise ratio values to use
errorRate = comm.ErrorRate; %enable error rate stats

% define SNR
SNRmin = 2; %min SNR (dB) value
SNRmax = 9; %max SNR (dB) value
SNRdB_OOK = linspace(SNRmin,SNRmax,nSNR); % SNR in dB matrix

% signal and noise power
sigAmp = 1;
sigP = sigAmp^2; % signal power
noiseP = 1./SNRdB_OOK; % noise power = variance of white noise

for n = 1:nSNR % for each SNR value ... compute a BER
    data = randi([0 nSymb-1],N,1);  %define the PRBS
    const = [0 1];  %configure OOK, BPSK, QPSK
    modSignal = genqammod(data,const);

    % Introduce noise on top of channel
    added_noise = sqrt(noiseP(n)/2)*randn(N,1); % noise only in one ...
        dimension
    noisy_signal = modSignal+added_noise;
%     snrAct(n) = 1/(1*var(added_noise)); % convert SNR measurement ...
    from dB to linear

    %demod with ook
    demodData_matlab = genqamdemod(noisy_signal,const);

    % Compute BER.
    reset(errorRate);  %reset error stats each iteration through loop
    errorStats = errorRate(data,demodData_matlab);  %error stats such ...
        as BER
    ber_OOK(n) = errorStats(1);  %BER

end

theory_OOK =qfunc(sqrt(0.5./noiseP));

figure
semilogy(SNRdB_OOK,theory_OOK,'b.-');
hold on;
grid
semilogy(SNRdB_OOK,ber_OOK,'mx-');
legend('theory', 'simulation');
xlabel('SNR, dB');
ylabel('Bit Error Rate');
```

```
title('Bit error probability curve for OOK modulation');
```

Matlab Code For QPSK Simulation

```
clc
clear
M = 4; % Alphabet size
EbN0_min=2;EbN0_max=9;step=1;
SNR_QPSK=[];BER_QPSK=[];
for EbN0 = EbN0_min:step:EbN0_max
SNR_dB_QPSK=EbN0 + 3; %for QPSK Eb/N0=0.5*Es/N0=0.5*SNR
x = randi(M,1000000,1)-1;
y=qammod(x,M);
ynoisy = awgn(y,SNR_dB_QPSK,'measured');
z=qamdemod(ynoisy,M);
[num,rt]= biterr(x,z);
SNR_QPSK=[SNR_QPSK EbN0];
BER_QPSK=[BER_QPSK rt];
end

SNR_dB_QPSK=[2:1:9];
theoryBer_QPSK = 0.5*erfc(sqrt(10.^(SNR_dB_QPSK/10))); % theoretical ber
close all
figure
semilogy(SNR_dB_QPSK,theoryBer_QPSK,'b.-');
hold on
semilogy(SNR_QPSK,BER_QPSK,'mx-');
grid on
legend('theory', 'simulation');
xlabel('SNR, dB');
ylabel('Bit Error Rate');
title('Bit error probability curve for QPSK modulation');
```

Matlab Code For Comparing Simulations

```
load('QPSK');
load('OOK');
load('BPSK');
figure
semilogy(SNR_dB_QPSK,theoryBer_QPSK,'r-');
hold on
semilogy(SNR_QPSK,BER_QPSK,'*-');
hold on
semilogy(SNRdB_OOK,theory_OOK,'b.-');
hold on;
grid on
semilogy(SNRdB_OOK,ber_OOK,'g-');
hold on
semilogy(SNR_dB_BPSK,theoryBer_BPSK,'b.-');
hold on
semilogy(SNR_BPSK,BER_BPSK,'mx-');
grid on
legend('theory_{QPSK}', ...
    'simulation_{QPSK}','theory_{OOK}','simulation_{OOK}','theory_{BPSK}','simulation_{B
xlabel('SNR, dB');
ylabel('Bit Error Rate');
title('Bit error probability curve for BPSK,OOK, and QPSK modulation');
```