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# OPTIMUM RANGES FOR DATA TRANSMISSION IN MOBILE COMMUNICATIONS

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**Abstract**—Mobile communications are the fastest growing communications technology in history. In the field of data transmission, Optimum data transmission is a key factor for mobile communication which can be easily defined from Throughput, means the number of bits per second correctly received. Mobile communication allows transmission of voice and multimedia data via a mobile device using wired and wireless links; here these data are represented by bits. The throughput of a data communications system depends on a number of variables including packet size, transmission rate, the number of overhead bits in each packet, received signal power, received noise power spectral density, Signal to noise ratio. The purpose of this work is to find out the optimum ranges by observing certain changing parameter such as transmission rate, packet length, signal-to-noise ratio (SNR) with throughput depending on the very nature of the channels(AWGN & Rayleigh fading Channel). Here I ignore Rician fading channel because this occurs one of the paths, typically a line of sight signal, is much stronger so error occurring possibilities are less than others.

**Index Terms**— Optimum, Throughput, AWGN, Rayleigh channel, Packet length, Transmission rate, Signal-to-Noise Ratio (SNR).

## 1 Introduction

In data transmission, throughput is the amount of data moved successfully from one place to another in a given time period. The throughput is usually measured in bits per second (bit/s or bps), and sometimes in data packets per second or data packets per time slot. Typically, throughputs are measured in kbps, Mbps and Gbps, the speed with which data can be transmitted from one device to another. Data rates are often measured in megabits (million bits) or megabytes (million bytes) per second. These are usually abbreviated as Mbps and MBps, respectively. Throughput is affected by the channel environment such as the distance between the transmitter and the receiver, the fading state of the channel, the noise and interference power characteristics, the packet size, the transmission rate, the number of overhead bits in each packet, the modulation technique, and the channel conditions. From these variables, we can calculate other important quantities such as the signal-to-noise ratio, the binary error rate, and the packet success rate. [1]

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In AWGN channel the thermal noise of the communication channels, the noise is additive means the received signal equals the transmit signal plus some noise, where the noise is statistically independent of the signal. The noise is white means the power spectral density is flat, so the autocorrelation of the noise in time domain is zero for any non-zero time offset and the noise samples have a Gaussian distribution. Mostly it is also assumed that the channel is Linear and Time Invariant. The most basic results further assume that it is also frequency non-selective.

In Rayleigh Fading Channel assume that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade, according to a Rayleigh distribution and the delays associated with different signal paths in a multipath fading channel change in an unpredictable manner and can only be characterized statistically. When there are a large number of paths, the central limit theorem can be applied to model the time-variant impulse response of the channel as a complex-valued Gaussian random process.

Here for finding optimum ranges for data transmission using throughput optimization for fixed packet length varying the value of the transmission rate , and for fixed transmission rate varying the value of the packet length and also throughput optimization as a function of SNR where both packet length & transmission rate varied. All these conditions are applied on two channels: Additive white Gaussian noise (AWGN) and Rayleigh fading channel.

## 2 Introductions To Throughput

### 2.1 Definitions

System throughput (T) is the number of payload bits which means the essential data that is being carried within a packet or transmission unit per second received correctly. If the payload transmission rate is (KR/L) and the packet success rate f($\gamma$) which defined as the probability of receiving a packet correctly .so it can be written in the terms of bits per second,

$$T = \frac{K}{L} R f(\gamma) \qquad (2.1)$$

This probability is a function of the signal-to-noise ratio which can be defined as

$$\gamma = \frac{E_b}{N_0} = \frac{P}{N_0 R} \qquad (2.2)$$

Here $E_b$ = P/R joules is the received energy per bit. We will look at maximizing the throughput in a Gaussian white noise channel and Rayleigh Fading Channel with respect to the transmission rate and packet length.

### 2.2 Throughput Analysis

The transmitter, operating at R b/s, sends data in packets. Each packet contains L bits including a payload of K bits and a cyclic redundancy check error-detecting code with C bits. A forward error correction encoder produces the remaining L-K-C bits in each packet. The channel adds white noise with power spectral density No watts/Hz and the signal arrives at the receiver at a power level of P watts. In this research paper I assume to be the sum of all noise and interference, which can be modeled as Gaussian white noise. The CRC decoder detects transmission errors and generates acknowledgments that cause packets with errors to be retransmitted. Table 1 displays a summary of the variables in our analysis and their unit, notation. [2]

Table 1: Variables in Analysis

| Quantity | Notation | Unit | Value |
|---|---|---|---|
| Signal to Noise Ratio | $\gamma$ | dB | 10/Varied with Transmission Rate |
| Received signal power | P | Watts | 5*$10^{-9}$ W |
| Receiver noise power spectral density | No | W/Hz | $10^{-15}$ W/Hz |
| Binary transmission rate | R | bits/s | Varied |
| Packet size | L | bits | Varied |
| Cyclic Redundancy Check | C | bits | 16 bits |

We have used some equations for optimizing throughput and simulated those in MATLAB and then observed the results in graphical representation in MATLAB window. By analyzing these graphical representations we will suggest optimal range for throughput in each channel on each condition.

### 2.3 Principles For This Work

This analysis includes the following simplifying Principles on which we analyze throughput & it's optimization:

◉◉The CRC decoder detects all errors in the output of the FEC decoder.

◉◉Transmission of acknowledgments from the receiver to the transmitter is error free and instantaneous.

◉◉In the presence of errors, the system performs selective repeat ARQ retransmissions.

◉◉The received signal power is P watts, either a constant or a random variable with a Rayleigh probability density function, representative of fading wireless channels.

## 3 Throughputs vs. Transmission Rate (Fixed Packet Length)

The AWGN channel model is used to approximate the way errors are introduced in a data stream when it is transmitted over a lossy medium. The model we may use in the Workshop is the Additive White Gaussian Noise channel (AWGN). This channel model is memory less, meaning that the distortion of one bit is independent of all other bits in the data stream. Here one noise is added with the original transmitted signal, called white noise.

Frequency flat, fast Rayleigh fading may be considered the most critical disturbance in a wireless communication system. In its most general form, it is modeled as a multiplicative time continuous random (zero mean complex Gaussian) distortion of the transmitted signal. In order to achieve an efficient communication here, each part of the communication link must be carefully designed based on the properties of the time continuous channel.

### 3.1 Equation Analysis

To find the transmission rate, R=R* b/s, that maximizes the throughput, we differentiate Equation (2.1) with respect to R to obtain:

$$\frac{dT}{dR} = (K/L)\, f(\gamma) + (K/L)\, R\, \frac{df(\gamma)}{d\gamma}\,\frac{d\gamma}{dR}$$

$$= (K/L)\left( f(\gamma) + R\frac{df(\gamma)}{d\gamma}(-P/N_0R^2)\right) \quad (3.1)$$

Next we set the derivative to zero:

$$f(\gamma) - (P/N_0R)\frac{df(\gamma)}{d\gamma} = f(\gamma)\gamma\ \frac{df(\gamma)}{d\gamma} = 0 \quad (3.2)$$

$$f(\gamma) = \gamma\ \frac{df(\gamma)}{d\gamma}. \quad (3.3)$$

We adopt the notation $\gamma = \gamma^*$ for a signal-to-noise ratio that satisfies Equation (3.3). The corresponding transmission rate is

$$R^* = \frac{P}{\gamma^* N_0} \quad (3.4)$$

A sufficient condition for a locally maximum throughput at R=R* is:

$$\left.\frac{d^2T}{dR^2}\right|_{R=R^*} < 0 \qquad (3.5)$$

The solution to Equation (3.3), $\gamma^*$, is the key to maximizing the throughput of a packet data transmission. To operate with maximum throughput, the system should set the transmission rate to R* in Equation (3.4). $\gamma^*$ is a property of the function, $f(\gamma)$, which is the relationship between packet success rate and signal to interference ratio. This function is a property of the transmission system including the modem, codecs, receiver structure and antennas. Each system has its own ideal signal-to-noise ratio, $\gamma^*$. Depending on the channel quality, reflected in the ratio P/No, the optimum transmission rate is R* in Equation (3.4).

For non-coherent FSK in a white Gaussian noise channel, the probability of a bit error is given by:

$$P(\gamma) = \frac{1}{2}e^{-\frac{\gamma}{2}}$$

For a model that corresponds to mobile radio communications, we can perform the same analysis for a fast fading Rayleigh channel. For non-coherent FSK in a Rayleigh fading channel, the probability of a bit error is given by:

$$\overline{P}(G) = \frac{1}{2+G}.$$

Here the G is the Signal to noise ratio and $\overline{P}(G)$ is the bit error rate for Rayleigh fading channel.[3]

### 3.2 Simulation For AWGN Channel

Here, I have taken simulation for different values of packet length (L) where transmission rate varies

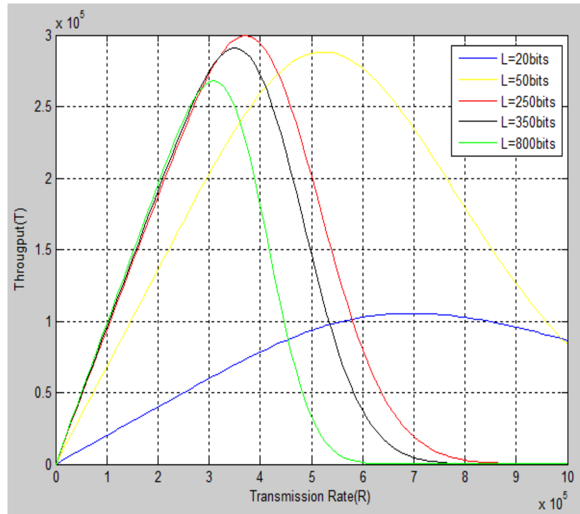


Figure 1: Throughput Vs Transmission Rate

with throughput.

In figure I have noticed that when the packet length size was small then the throughput has reached its highest peak with higher transmission rate and also has fallen in a wide range. But as soon as the packet length has kept higher, then the curve of throughput is stepper rather than flat and the throughput has reached its highest peak lower transmission rate. When we have increased our packet length size than before, then the throughput has reached the maximum peak at a very lower transmission rate and also has fallen down quite quickly.

### 3.3 Optimum Ranges

From the above analysis I have seen that if we keep our packet length less than 350 bits and greater

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than 50 bits, then we will be able to get the maximum throughput and the transmission rate shouldn't be so high which is in a range of 300kbps to 600kbps. So using the general equations for calculating throughput in respect of transmission rate and keeping the packet length fixed the throughput can be optimized in a certain range.

### 3.4 Simulation For Rayleigh Fading Channel

Here, I have also taken simulation for different values of packet length (L) where transmission rate varies with throughput. This graph also contains five assumptions.

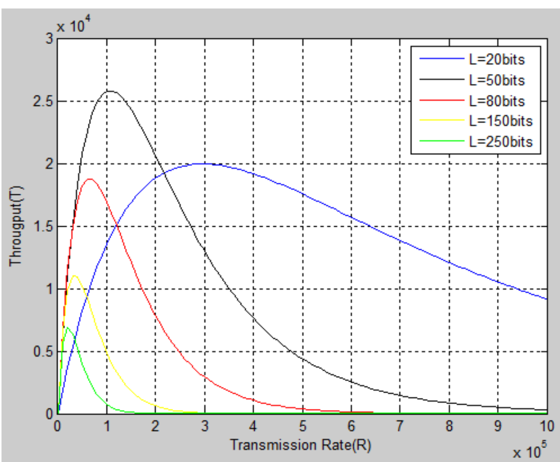


Figure 2: Throughput Vs Transmission Rate

In figure 2 I have noticed that this graph characteristic is behave almost like Figure 1. But here after certain packet length size, then the throughput has reached the maximum peak at a very lower transmission

### 3.5 Optimum Ranges

From the above representation of throughput with the function of transmission rate and fixed packet length, I have also observed that for transmission rate of 50kbps to 450 Kbps we have got the highest peak of throughput and the packet size was within 20bits to 80bits.

### 3.6 IN COMBINED FORM

For showing the comparison between two channels for optimum ranges with the function of transmission rate where fixed packet lengths are fixed in same graph. we will choose four readings whose are exist in the optimum ranges.

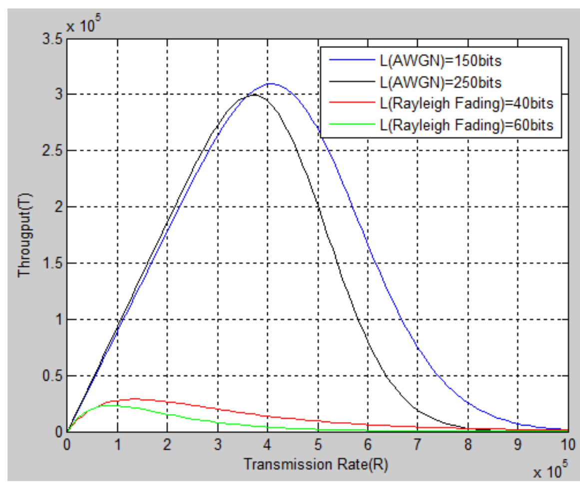


Figure 3 : Throughput (T) Vs Transmission Rate(R)

### 3.7 GRAPHICAL ANALYSIS

By observing the above figure I can say that in AWGN channel, data transmission ability is much more than Rayleigh Fading channel. But in AWGN channel, it takes more transmission rate to reach peak position than that of Rayleigh Fading channel.

## 4 Throughput (T) Vs Packet Length (L) (Fixed Transmission Rate)

The AWGN channel models the distortion incurred by transmission over a lossy medium as the addition of a zero-mean Gaussian random value to each bit. Decoders can take advantage of the added information of "how close" a received value is to a valid bit value (0 or 1 for our purposes). This type of decoding is called soft decision decoding.

In the Rayleigh fading channel a higher diversity order is obtained if the encoder output bits, instead of symbols, are interleaved. By also using codes of lower rates, the diversity is increased even further. To avoid bandwidth expansion here, the channel symbol constellation must be expanded accordingly. The resulting system is referred to as bit-interleaved channel symbol expansion diversity (CSED) and is the best low-complexity coded modulation scheme presented so far for the Rayleigh fading channel.

### 4.1 Equation Analysis

Each packet, of length L bits, is a combination of a payload (K bits) and overhead (L-K bits). Because the packet success rate $f(\gamma)$ is a decreasing function of L, there is an optimum packet length, L*. When L<L*, excessive overhead in each packet limits the throughput. When L>L*, packet errors limit the throughput. When there is no forward error correction coding, which we shall assume for the entirety of this chapter, (K=L-C, where C bits is the length of the cyclic redundancy check), there is a simple derivation of L*. In this case,

$$f(\gamma) = (1 - P(\gamma))^L, \qquad (4.1)$$

Where $P_e(\gamma)$ is the binary error rate of the modem. Therefore, in a system without FEC, the throughput as a function of L is

$$T = \frac{L-C}{L} R (1 - P_e(\gamma))^L \qquad (4.2)$$

To maximize T with respect to L, we consider L to be a continuous variable and differentiate Equation (4.2) to obtain

$$\frac{dT}{dL} = R\frac{L-C}{L}(1-P_e(\gamma))^L \ln(1-P_e(\gamma)) + R\frac{C}{L^2}(1-P(\gamma))^L \; (4.3)$$

Setting the derivative equal to zero produces a quadratic equation in L with the positive root:

$$L^* = \frac{1}{2}C + \frac{1}{2}\sqrt{C^2 - \frac{4C}{\ln(1-P_e(\gamma))}} \qquad (4.4)$$

As shown in Figure 4 and 5 (in which C=16), the optimum packet size is a decreasing function of $P_e(\gamma)$.

As the binary error rate goes to zero, the packet error rate also approaches zero and the optimum packet size increases without bound. Because

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$P_e(\gamma)$ decreases with $\gamma$, L* increases monotonically with signal-to-noise ratio. Better channels support longer packets. Of course, in practice L is an integer and the optimum number of bits in a packet is either the greatest integer less than L* or the smallest integer greater than L*.

Equations (3.3) and (4.4) can be viewed as a pair of simultaneous equations in variables L and $\gamma$. Their simultaneous solution produces the jointly optimum packet size and Signal - to- noise ratio of a particular transmission system. We will use the notation, L** and $\gamma$**, respectively for the jointly optimized variables.

For non-coherent FSK in a white Gaussian noise channel, the probability of a bit error is given by:

$$P(\gamma) = \frac{1}{2} e^{-\frac{\gamma}{2}}$$

For a model that corresponds to mobile radio communications, we can perform the same analysis for a fast fading Rayleigh channel. For non-coherent FSK in a Rayleigh fading channel, the probability of a bit error is given by:

$$\overline{P}(G) = \frac{1}{2+G}.$$

Here the G is the Signal to noise ratio and $\overline{P}(G)$ is the bit error rate for Rayleigh fading channel.[3]

### 4.2 Simulation For AWGN Channel:

For throughput optimization for fixed transmission rate varying the value of the packet length we have taken graphs based on transmission rate..The graph contains five assumptions where SNR will be changed with the value of R.

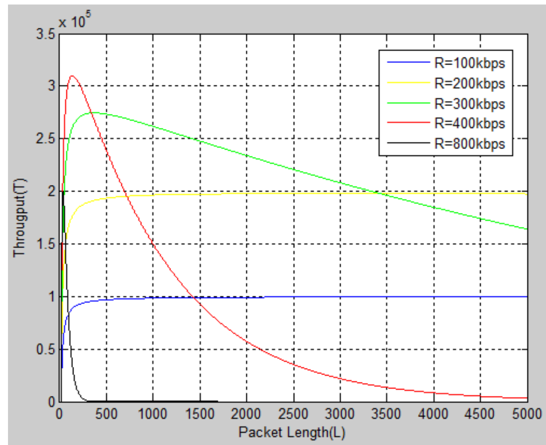

Figure 4 : Throughput (T) Vs Packet Length(L)

In the figure we see that first two readings throughputs are gone to the saturation after a certain packet length. Then two readings, peak throughputs are increased with the increase of transmission rate. But as soon as the transmission rate has kept higher, then the curve of throughput stepper rather than flat and the throughput has reached its highest with small packet size and has fallen down in a short range respectively.

### 4.3 Optimum Ranges

I have observed that if we keep our transmission rate in the range of 300kbps to 400kbps we will be able to get the maximum throughput. And for the maximum throughput the packet has come in the range of 50bits to 600 bits.

### 4.4 Simulation For Rayleigh Fading Channel

In the figure I have noticed that for the lower transmission rate the throughput has reached its highest peak with higher packet size and the highest peak which is fallen down in a wide range. The transmission rate has kept higher, then the curve of throughput is stepper than before. Then more transmission rate less will be the throughput and fallen down in a quite short range.

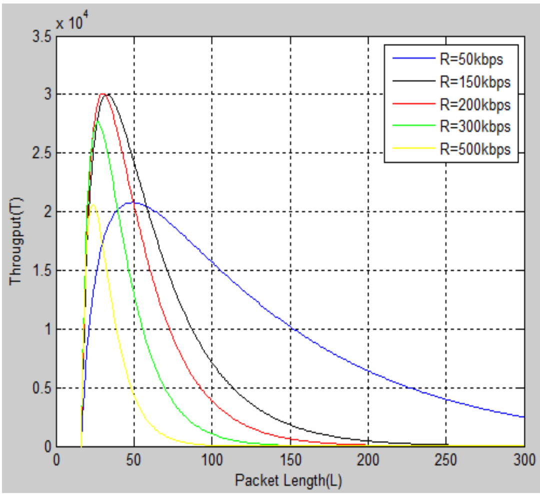


Figure 5: Throughput (T) Vs Packet Length (L)

#### 4.5 Optimum Ranges

From these graphs I have observed that for transmission rate of 150 Kbps to 300 kbps we have got the optimum throughput. But here we get maximum throughput at very small packet length within 20bits to 50 bits.

#### 4.6 IN COMBINED FORM

For showing the comparison between two channels for optimum ranges for this condition where transmission rates are fixed in same graph. we will choose four readings whose are exist in the optimum ranges.

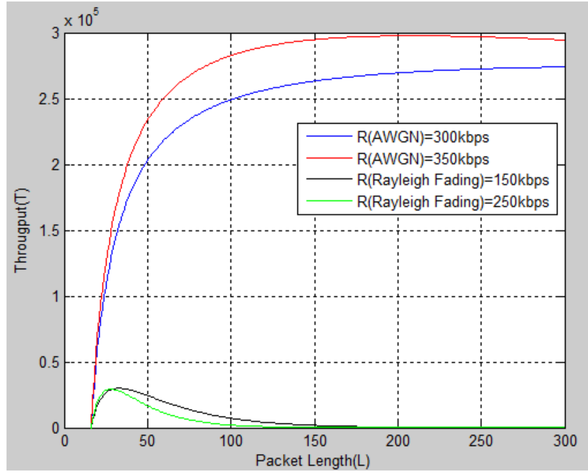


Figure 6: Throughput (T) Vs Packet Length (L)

#### 4.7 GRAPHICAL ANALYSIS

I have taken four readings for comparison. For the higher transmission rate the throughput increases with the increase of packet length in AWGN channel but in the Rayleigh fading channel we get peak throughput with little packet length which has fallen in a short range. So, the graphical representation is as like as before (condition).

## 5 Throughput (T) Vs SNR

## (Joint Optimization)

Some important conclusions can be drawn from the previous information for the channels. We first notice that at high SNR values (low transmission rates) the packet length used to maximize the throughput must be large. When the transmission rate increases and the SNR drops, the packet length to maximize the throughput must also decrease. Another observation we make is how the throughput curve behaves for increasing values of L when different SNR values are used. From previous figures we can see that at high bit rates (low SNR) the choice of packet size is more critical.

### 5.1 Joint Optimization

The following figure has shown the throughput optimization with respect to joint optimization in terms of SNR (Signal to Noise Ratio) in both channels. We have analyzed throughput with

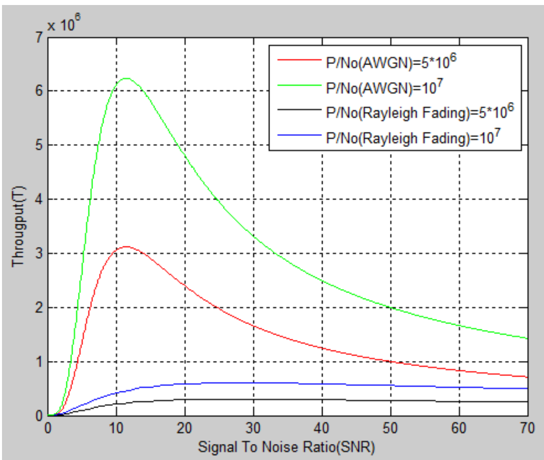


Figure7: Throughput (T) Vs SNR

respect to SNR and has kept some fixes values for P/ $N_0$. Here we have taken another value of $\frac{P}{N_0}$ that is $10^7$.

### 5.2 GRAPHICAL ANALYSIS

Observing the above figure I can say that throughput is maximized in this condition for both channels. But as like before throughput is maximized in AWGN channel. From the figure we see that the value of P/No is changed which is doubled. Then in both channels the peak throughput is doubled from the peak value where P/No is 5*10^6.

### 5.3 Optimum Ranges

From this optimum SNR, the optimum packet length and (given the received signal power over the noise power spectral density) the optimum transmission rate can be determined.

## 6 Conclusions

We obtained some important information from this work . We have learned that data throughput depends on a wide variety of variables. Given a modulation scheme, and the channel conditions, the optimum SNR at which to operate the system for maximum throughput can be derived. We have talked about many different variables and how changing certain parameters can yield better throughput performance. Implementing these concepts in real systems is not as easy as one might think. In order for a system to make parameter changes it must be able to make simple measurements in the system.

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