BER Performance Evaluation of GMSK for Fading Mobile Channels

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Abstract— **Digital modulation plays a significant role in efficient wireless communication. It allows the transmission of digital data via air on high frequency carrier waves. The worst case communication channel is usually in the urban environment where there are many obstacles. Due to the obstacles and reflectors, the transmitted signal arrives at the receiver from various directions over a multiplicity of paths. Such a phenomenon is called multipath. Mobile radio propagation is characterized by three main aspects: fading, shadowing and path loss. A major concern in a cellular mobile radio system is the co-channel interference. Therefore, the reduction of co-channel interference becomes a main thrust for the system design engineers. GMSK is studied and identified as an effective digital modulation technique suitable for power and band-limited mobile radio. This paper evaluates the BER performance of GMSK system under different channel models i.e. AWGN, Rayleigh and Rician fading channels. Subsequently, a comparative study is carried out to obtain the BER performance for BPSK and QPSK under fading mobile channels. The comparative study showed that BER for BPSK and QPSK are similar and they give the lowest BER under multipath fading. Though BPSK and QPSK give slightly better BER performance than GMSK, the spectral efficiency and hence power efficiency advantages of GMSK make it the preferred choice of modulation in fading mobile channels.**

Keywords— **Digital modulation, GMSK, Co-channel interference, Fading, Spectrum Manipulation, BER.**

I. INTRODUCTION

In the early days of mobile radio, it was possible to allocate a new channel to each new radio system installed so that co-channel interference did not occur. When there were no channels left to allocate, the channel spacing was reduced. In addition, channels were reused in different parts of the country, but far enough apart to ensure that throughout the service area of each base station, signals from the distant co-channel transmitters were below the front end noise level of the receivers [1]. Currently, the demand for mobile radio has reached the point where channels must be reused at distances that will produce significant co-channel interference, and the service area of a base station will become limited by co-channel interference rather than by front end noise [1]. Also, channel spacing cannot be reduced further without abandoning high deviation FM and tuning to narrow-band modulation techniques [1].

In the VHF/ UHF bands, mobile radio propagation is characterized by three main aspects: fading, shadowing and path loss. *Fading* due to multipath propagation causes rapid fluctuations of the received signal. It is well known that several branches of diversity are quite effective in mitigating multipath fading. *Shadowing* of the radio signal by buildings and hills leads to gradual changes in the local mean level, and is shown to be lognormally distributed. The third aspect of propagation is the prediction of the area mean signal level as a function of range. A commonly used approximation is that received power is inversely proportional to the fourth power of the range, and the approximation will be used here [2]. In order to mitigate the impairments, GMSK modulation technique with superior properties is described in this paper.

II. MOBILE RADIO ENVIRONMENT

A. *Fading and Shadowing*

A mobile radio signal *r(t)* illustrated in Fig. 1 can be characterized by two components *m(t)* and $r_o(t)$ based on natural physical occurrences [3].

$$r(t) = m(t)\cdot r_o(t) \tag{1}$$

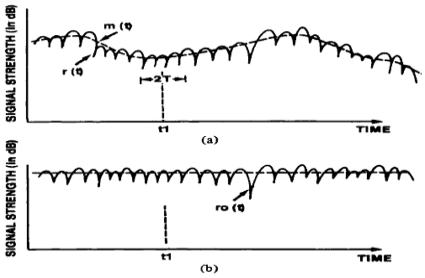

Fig. 1 A mobile radio signal fading representation.
(a) A mobile radio signal fading. (b) A short-term signal fading

m(t) is called local mean, long-term fading, or log-normal fading which is due to the terrain contour between the base station and the mobile unit. r_o is called multipath fading, short-term fading or Rayleigh fading which is due to the waves reflected from the surrounding buildings and man-made structures.

The long-term fading *m(t) can* be obtained from the following:

$$m(t_1) = \int_{t1-T}^{t1+T} r(t)dt \qquad (2)$$

where *2T* is the time interval for averaging *r(t). T* can be determined based on the fading rate of *r(t);* usually 20 to 40 fades [3]. Therefore *m(t)* is the envelope of *r(t)* as shown in Fig. 1(a). *m(t)* is also found to be a log-normal distribution based on its characteristics caused by the terrain contour. The short-term fading r_o is obtained by

$$ro\ (dB) = r(t) - m(t) \quad (dB) \qquad (3)$$

as shown in Fig. 1(b). *ro(t)* follows a Rayleigh distribution assuming that only reflected waves from local surroundings are the ones received [3]. Therefore the term Rayleigh fading is often used.

Another aspect of mobile radio propagation is shadowing. Shadowing of the radio signal by buildings and hills leads to gradual changes in local mean level as the vehicle moves, with the result that the local mean is lognormally distributed within an area, which is at roughly constant distance from the transmitter [1].

B. *Co-channel Interference*

Frequency reuse concept is the core of the cellular mobile radio system. In this frequency reuse system, users in different geographical locations may simultaneously use the same frequency channel. If the system is not properly planned, this arrangement can cause interference to occur. Interference due to the common use of the same channel is called co-channel interference.

Consider a mobile radio which receives a signal of envelope s_1 from its base station and an unwanted signal envelope s_2 from a distant station. The mobile suffers interference whenever s_1 does not exceed s_2 by the protection ratio *r* and the probability of co-channel interference is defined as the probability that

$$\mathrm{s}_1 \leq \mathrm{r.s}_2 \qquad (4)$$

In a plane area free of fading and shadowing, s_1 and s_2 can be found from a simple propagation law, which with some geometry shows a single interference area around the unwanted transmitter [1]. In a practical situation where the signals fluctuate greatly due to fading and shadowing, there are many small areas of interference.

C. *Probability of Co-channel Interference with Fading and Shadowing*

Co-channel interference occurs when $\mathrm{s}_1 \leq \mathrm{r.s}_2$, the probability of this happening is given by the following expression [1]

$$P(s_1 \leq r \cdot s_2) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{\exp(-u^2)}{1+10^{(zd-2\sigma u)/10}} du \qquad (5)$$

where $zd = m_{d1} - m_{d2} - R$. The fact that $P(s_1 \leq r.s_2)$ is a function of $m_{d1} - m_{d2} - R$ shows that co-channel interference is independent of absolute level and also that a reduction in the required protection ratio can permit an increase in the mean level of the unwanted signal [1]. So far we have assumed continuous interference, whereas in practice a base station will only carry a limited traffic of T Erlangs. In this case, the actual co-channel interference would be [1],

$$P_i = TP(s_1 \leq r \cdot s_2) \qquad (6)$$

Co-channel interference can be controlled by various radio resource management (RRM) schemes. RRM involves strategies and algorithms for controlling parameters such as transmit power, channel allocation, data rates, handover criteria, modulation scheme, error coding scheme, etc. The objective is to utilize the limited radio spectrum resources and radio network infrastructure as efficiently as possible.

III.COMMUNICATION CHANNELS

A. *Ideal channel - AWGN Channel*

In wireless communications, a practical communication channel is often modelled by a random attenuation of the transmitted signal, followed by additive noise. The attenuation captures the loss in signal power over the course of the transmission and the noise in the model captures external interference and/or electronic noise in the receiver. Hence, depending on the application, the mathematical model for the communication system includes a model for the distortion introduced by the transmission medium and termed the communication channel, or channel for short. In constructing a mathematical model for the signal at the input of the receiver, the channel is assumed to corrupt the signal by the addition of white Gaussian noise as shown in Fig. 2. below, therefore the transmitted signal, white Gaussian noise and received signal are expressed by the following equation with *s(t), n(t)* and *r(t)* representing those signals respectively:

$$r(t) = s(t) + n(t) \qquad (7)$$

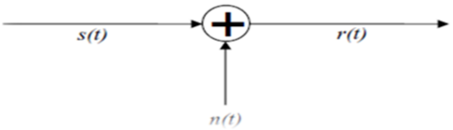

Fig.2. Received signal corrupted by AWGN

where *n(t)* is a sample function of the AWGN process with probability density function (pdf) and power spectral density as follows:

$$\emptyset_{nm}(f) = \frac{1}{2}N_o[W/Hz] \qquad (8)$$

where N_0 is a constant and called the noise power density.

B. *Worst case channel - Multipath Fading Channel*

When there is a dominant stationary (non-fading) signal component present, such as a line of sight propagation path, the small – scale fading envelope distribution is Rician.

In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. At the output of an envelope detector, this has the effect of adding a dc component to the random multipath. Just as for the case of detection of a sine wave in thermal noise, the effect of a dominant signal arriving with many weaker multipath signals gives rise to the Rician distribution [8].

As the dominant signal becomes weaker, the composite signal resembles a noise signal which has an envelope that is Rayleigh. Thus, the Rician distribution degenerates to a Rayleigh distribution when the dominant component fades away [8]. The Rician distribution is given by,

$$p(r) = \frac{r}{\sigma^2} exp\left(\frac{(r^2+A^2)}{2\sigma^2}\right) Io\left(\frac{Ar}{\sigma^2}\right) \; for\ (A \geq 0, r \geq 0)$$

$$= 0\ for\ (r < 0) \qquad (9)$$

The parameter A denotes the peak amplitude of the dominant signal and $I_O(.)$ is the modified Bessel function of the first kind and zero-order. The Rician distribution is often described in terms of a parameter K which is defined as the ratio between the deterministic signal power and the variance of the multipath. It is given by, $K = \frac{A^2}{2\sigma^2}$ or, in terms of dB

$$K(dB) = 10\ log\left(\frac{A^2}{2\sigma^2}\right)\ dB \qquad (10)$$

The parameter K is known as the Rician factor and completely specifies the Ricean distribution. As, $A \rightarrow 0, K \rightarrow -\infty$ dB, and as the dominant path decreases in amplitude, the Rician distribution degenerates to a Rayleigh distribution [8].

IV. SIGNIFICANCE OF MODULATION SCHEMES IN WIRELESS SYSTEMS

Digital modulation provides more information capacity, compatibility with digital data services, higher data security, better quality communications, and quicker system availability. The importance of modulation schemes in wireless systems has led to advancements in digital signal processors (DSPs), microprocessor design, and various cellular standards. Much of the success of wireless standards is due to the contribution of modulation schemes that allow power efficient mobiles that require minimal bandwidth and battery size and provide crisper voice technology.

From the viewpoint of mobile radio use, the out-of-band radiation power in the adjacent channel should be generally suppressed 60-80 dB below that in the desired channel [4]. So as to satisfy this severe requirement, it is necessary to ‘manipulate the RF output signal spectrum. Such a spectrum manipulation cannot usually be performed at the final RF stage in the transceivers because the transmitted RF frequency is variable. Therefore, intermediate-frequency (IF) or baseband filtering with frequency up conversion is mostly used [4]. However, when such a spectrum-manipulated signal is translated up and passed through a nonlinear class C power amplifier, the required spectrum manipulation should not be violated by the nonlinearities.

Specific requirements imposed on digital modulation for mobile radio use are: a compact output power spectrum, the applicability of class C power amplifiers, frequency variable local oscillators, high immunity to noise and interference and equipment simplicity [5].

In order to mitigate the impairments, some narrow-band digital modulation schemes with constant or less fluctuated envelope property has to be used. GMSK satisfies all the above mentioned criteria.

V. SPECTRUM MANIPULATION OF MSK

GMSK is from the Minimum Shift Keying (MSK) modulation family. GMSK differs from MSK in the aspect of filter used, hence the name Gaussian MSK. MSK is a binary digital FM with a modulation index of 0.5. It has the following important characteristics: constant envelope, relatively narrow bandwidth and coherent detection capability.

The most important characteristic of MSK is that it is a constant envelope variety of modulation. This makes the modulation scheme more immune to noise than ASK. Another advantage of MSK is that it does not produce Intersymbol Interference (ISI). However, MSK does not satisfy the requirements with respect to out of band radiation for single channel per carrier (SCPC) mobile radio.

GMSK uses a pre-modulation Gaussian filter which makes the output power spectrum more compact. The Gaussian filter must have narrow bandwidth and sharp cut-off in order to suppress the higher frequency components, lower overshoot impulse response to protect against excessive instantaneous frequency deviation and preserve filter output pulse area to assure the phase shift of π/2 in order to assure coherent detection capability [5]. The model of GMSK modulation is as shown in Fig. 3.

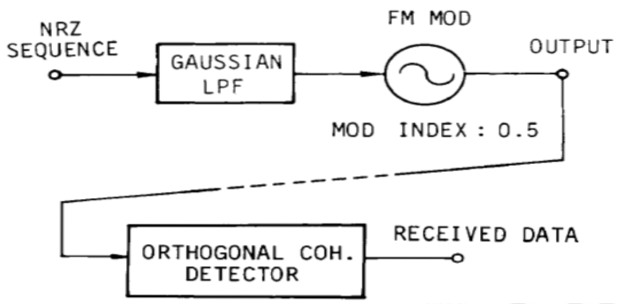

Fig.3. Simplified model of GMSK modulation.

Fig.4. shows the output power spectrum of the GMSK versus normalized frequency difference from the carrier centre frequency, where the B_bT is a parameter.

The Simple and easy method is to modulate the frequency of VCO directly by the use of baseband Gaussian pulse stream. However, this modulator has the weak point that it is difficult to keep the centre frequency within the allowable value under the restriction of maintaining the linearity and the sensitivity for the required FM modulation [4]. GMSK implemented in GSM uses the concept of differential encoding.

Differentially encoded data offers the advantage that information is carried in the phase changes, rather than in the phase itself. Under certain conditions, a phase ambiguity of ±180° can arise in the demodulation and detection process [6]. For example, certain synchronization and carrier recovery techniques result in a phase ambiguity. Differential encoding overcomes this ambiguity since the information is carried in the phase differences. Knowing the absolute phase becomes unnecessary. Differential encoding inserts memory into the signal, since each data bit sent is encoded with respect to the previous data bit.

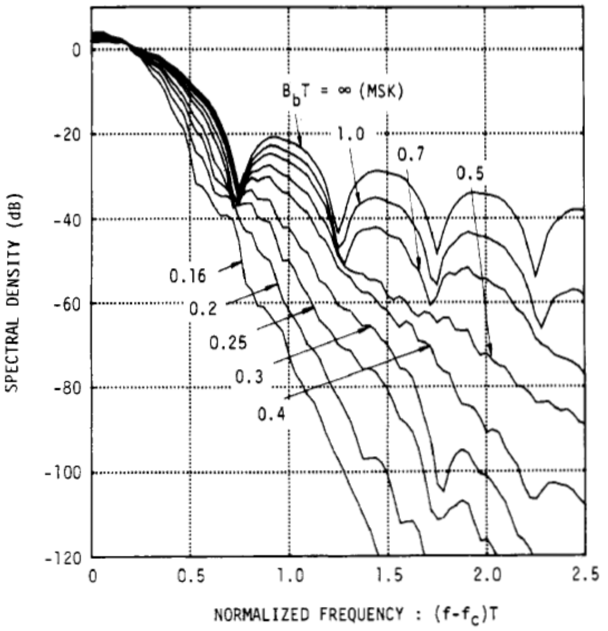

Fig.4. Power spectra for GMSK signal

A GMSK signal can easily be detected by an orthogonal coherent detector which is exactly same as for classical MSK. Coherent demodulation is required to facilitate linear equalization, which is necessary in GSM to compensate for ISI resulting from delay spreads due to multipath and from pre-modulation and pre-detection filtering [6].

With GMSK signalling, instantaneous frequency/ phase deviation is controlled and discrimination performance is affected depending on the introduction of pre-modulation LPF. Considering overall spectrum efficiency, system designer can select the effective variable parameter B_bT [5].

Narrow-band modulation is effective for the present purpose, even though it requires higher co-channel interference protection. As for GMSK modulation, an increase in *m* is obtained by reducing B_bT [5] where, m is the transmission efficiency of modulation.

VI. BER PERFORMANCE EVALUATION FOR DIFFERENT MODULATION FORMATS

A. *Bit Error Rate*

In telecommunication, an error ratio is the ratio of the number of bits, elements, characters or blocks incorrectly received to the total number of bits, elements, characters or blocks sent during a specified time interval. The most commonly encountered ratio is the bit error ratio (BER).

For a given communication system, the bit error ratio will be affected by both the data transmission rate and the signal power margin. Examples of bit error ratio are (a) transmission BER, *i.e.*, the number of erroneous bits received divided by the total number of bits transmitted; and (b) information BER, *i.e.*, the number of erroneous decoded (corrected) bits divided by the total number of decoded (corrected) bits. On good connections the BER should be below 10^{-9}.

BER for BPSK, QPSK and GMSK modulation schemes will be evaluated. The BER can be evaluated by changing the following parameters: receiver noise level, level of received signal, fading environment and level of interference signals.

B. *BER Performance*

BPSK is the simplest form of PSK. It uses two phases which are separated by 180° and so can also be termed 2-PSK. This modulation is the most robust of all the PSKs since it takes serious distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1bit/symbol and so is unsuitable for high data-rate applications.

The bit error rate (BER) of BPSK in AWGN can be calculated as [9]:

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{11}$$

Since there is only one bit per symbol, this is also the symbol error rate.

Theoretical BER in an AWGN and one-path Rayleigh fading channels have been reported [9]

$$BER_{BPSK-AWGN} = \frac{1}{2}\, erfc(\sqrt{E_b/N_o}) \tag{12}$$

$$BER_{BPSK-FADING} = \frac{1}{2}\left[1 - \frac{1}{\sqrt{1+\frac{1}{E_b/N_o}}}\right] \tag{13}$$

E_b/N_o is the ratio between energy per bit (E_b) and the noise power density (N_o).

QPSK uses four points on the constellation diagram, equi-spaced around a circle. With four phases, QPSK can encode two bits per symbol. Although QPSK can be viewed as a quaternary modulation, it is easier to see it as two independently modulated quadrature carriers. With this interpretation, the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. BPSK is used on both carriers and they can be independently demodulated.

As a result, the probability of bit-error for QPSK is the same as for BPSK [9]:

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{14}$$

The theoretical BER values with AWGN and one-path Rayleigh fading have been reported in [9] and shown below:

$$BER_{QPSK-AWGN} = \frac{1}{2}\, erfc(\sqrt{E_b/N_o}) \tag{15}$$

$$BER_{QPSK-FADING} = \frac{1}{2}\left[1 - \frac{1}{\sqrt{1+\frac{1}{E_b/N_o}}}\right] \tag{16}$$

This paper evaluates the BER performance of BPSK, QPSK and GMSK under different channel models using SIMULINK. The simulation yields BER of 0.000099, 0.0103 and 0.0102 under AWGN (Eb/No = 20dB), Rayleigh and Rician channels respectively for BPSK as well as QPSK. GMSK system implemented in SIMULINK gives BER of 0.009899 under AWGN (Eb/No = 20dB) channel for BT = 0.3 and 0.5. While, it gives BER of 0.1879 and 0.1232 for Rayleigh fading channel with BT = 0.3 and 0.5 respectively. GMSK under Rician fading channel gives BER of 0.3158 and 0.2351 corresponding to BT = 0.3 and 0.5 respectively.

VII. CONCLUSIONS

The cellular mobile system is a high capacity system. The different aspects of mobile radio propagation such as fading and shadowing are discussed here. Probability of co-channel interference with fading and shadowing is defined. Methods to control co-channel interference and the significance of GMSK as an effective digital modulation scheme for mobile radio are described in this paper. We have also made a comparative study on the BER performance evaluation of BPSK, QPSK and GMSK under different fading channels. BPSK and QPSK give slightly better BER performance than GMSK. However, the strong point of GMSK is its smooth phase transitions which make decoding easier and reduce complexity of amplifier design. In addition to this, GMSK's high spectral efficiency and hence power efficiency advantages make it the preferred choice of modulation in fading mobile channels.

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