Improving Spectral Efficiency by Improving BER using QAM Technique

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Abstract—Massive capacity, everywhere coverage and highest energy efficiency is requirement of next generation cellular networks. In order to meet these targets, device to device communication is being considered for future heterogeneous networks. In this paper we are going to improve spectral efficiency by improving bit error rate (BER) using qudrature amplitude modulation technique. We shall present BER for 16-QAM, 64-QAM, and 256-QAM in Gaussian noise channel and under flat Rayleigh fading conditions.

Keywords—BER;Spectral efficiency; Gaussion noise; flat Rayleigh fading conditions;M-arry QAM.

I. INTRODUCTION

The efficient use of the available radio frequency resources is an important design component of wireless communication systems. This is especially true in land mobile communications, where the cities and high volume communications area a large number of mobile terminals operating on frequency bands of limited width must be accommodated. To address these needs, in addition to improve the spectrum efficiency of each frequency band, schemes to effectively improve utilization of frequency resources include reusing the same frequencies in spatial domain, and time sharing with in the same channel.

In radio communications, spectrum efficiency is most often defined as the information transmission rate (bit-rate) for the given frequency of the band. Where this definition applies to digital systems, the spectrum efficiency unit is (bits/Hz). The above definition is modified for analog system to describe the number of channels accommodated by a given frequency band, and the applicable unit is (ch/Hz).

In mobile communication, the system subscriber capacity is most often determined by the number of mobiles that can occupy the same channel without an overlap in time regardless of the occupancy of specific channels by specific mobiles.

The expression for spectral efficiency in a mobile communication system must account for bandwidth and active traffic that a given area can accommodate. Over all spectral efficiency, η, for a mobile system is given by:

$$\eta_w = \frac{n_a a_c}{SW} \text{ [erl/Hz-m}^2\text{]}$$

Where W is bandwidth of assigned channel, S is area of zone cluster (or cell cluster) which determine frequency reuse unit, n_a is number of channels within a zone cluster and a_c is call traffic/channel. Overall spectrum efficiency is expressed using spatial efficiency, η_s, temporal efficiency, η_t and band efficiency η_b:

$$\eta_w = \eta_s * \eta_t * \eta_b$$

Spectral efficiency is indicated as spatial repeat pattern of the same channel frequency, Temporal efficiency is indicated by active time/channel ratio and Band efficiency defines the number of band/channel. Where $\eta_s = \frac{1}{s}$ [1/m^2], $\eta_t = a_c$ [erl/Channel] and $\eta_b = \frac{n_a}{W}$ [Channel/Hz].

Type of modulation	FSK	BPSK	ASK	GMSK	QPSK	8 PSK	16QAM	64 QAM	OFDM
Spectral efficiency(bit/Hz)	<1	1	1	1.35	2	3	4	6	>10

Table 1: spectral efficiency of different type of modulation

II. TECHNIQUE USED TO IMPROVE SPECTRAL EFFICIENCY

Spectrum efficiency reflects the number of channels per band, which is the inverse of the required bandwidth. Each channel is assigned certain frequencies. Channel bandwidths are the inverse values of the frequencies separating the channels (guard bands). Channel spacing depends on factors such as type of modulation scheme used and the modulation rate. It is also defined by how modulation shapes the spectrum and the amount of allowable adjacent channel interference. Spectrum efficiency can therefore be improved by compressing the modulation of modulating signal and by reducing adjacent channel interference.

By $\eta_s = \frac{1}{s}$ [1/m^2] improvement in spatial efficiency is related to the inverse value of the area occupied by zone cluster. Cell area S is multiplication of individual cell area (s_c) and Number of cells in repeating pattern (L). So spatial efficiency can be improved by reducing the area of the cells or increasing the cell reuse factor where Cell reuse factor is the inverse of the number of cells in repeating pattern.

Band utilization and spatial efficiency are also related to the number of channels that can be simultaneously used. Temporal efficiency is related to the rate of actual utilization of the available channels. Usage rate is a reflection of the average usage rate of each channel and eliminating the ‘non-uniformities’ of conditions which effect channel utilization that will improve time efficiency.

III. THE VARIOUS SPECTRUM EFFICIENCY TECHNIQUES

The factors that affect spectrum efficiency are including in the:

1. Frequency band
2. Spatial parameters
3. Temporal parameters

So basically there are three techniques, by using those, we can improve spectral efficiency

1. By reducing the required channel bandwidth
2. By improving frequency reuse distance
3. By improving channel usage rate

Reducing the required channel bandwidth:

There are two types of techniques for improving the efficiency by reducing the required channel bandwidth.

1. Narrow band by lowering the symbol rate
2. Reducing channel spacing by reducing adjacent channel interface

Low symbol rate can achieve with the help of reducing required bit rate and using M-array modulation. Bit rate can be performed by high efficiency voice coding and high efficiency video coding. QPSK and 16-QAM are the M-array modulation techniques which can be used for lowering symbol rate. High efficiency voice coding and video coding technique permit lower channel bit rate. Although this technique does not contribute to an increase in bit rate as a function of band efficiency, it does not allow an increased number of channels to be used, which is one of the way that spectrum efficiency can improve. However M-array modulation is generally susceptible to fading and countermeasures are required in this area.

Again reducing interchannel interference and improving interference counter measures can reduce adjacent channel interface. Filters, receiver power control and improved frequency stability can reduce interchannel interference and interference canceller and diversity error correction can improve interference countermeasures. Rejection of interference is also worse than other modulation systems. In this paper we will concentrate on high spectrum efficiency modulation system.

M-Array QAM:

In the fixed microwave communications and wired circuit modems we can use M-array qudrature amplitude modulation technique. If separation distance of the signal points in M-array QAM than the probability of noise induced error causing one signal point to be incorrectly recognized as another signal point. In phase modulation systems, the amplitude of signal points is a fixed level. So M-array phase system (M: multiple, in 4,8,16 phase) have been developed so as to transmit more information per symbol. As number of point's increases, the Euclidean distance is reduced and BER (bit error rate) performance degraded.

Error probability characteristics of M-array modulation systems:

We know

$$\gamma = \frac{E_b}{N_0}$$

For 16-QAM:

$$P_e(\gamma) = \frac{3}{8} erfc\left(\sqrt{\frac{2}{5}\gamma}\right) - \frac{9}{64} erfc^2\left(\sqrt{\frac{2}{5}\gamma}\right) \qquad (1)$$

For 64-QAM:

$$P_e(\gamma) = \frac{7}{24} erfc\left(\sqrt{\frac{1}{7}\gamma}\right) - \frac{49}{384} erfc^2\left(\sqrt{\frac{1}{7}\gamma}\right) \qquad - \qquad (2)$$

For 256- QAM:

$$P_e(\gamma) = \frac{15}{64} erfc\left(\sqrt{\frac{4}{85}\gamma}\right) - \frac{225}{2048} erfc^2\left(\sqrt{\frac{4}{85}\gamma}\right) \qquad - \qquad (3)$$

Rayleigh fading is the name given to form of fading that is often experienced in an environment where there is a large number of reflections present. Under flat Rayleigh fading conditions the BER for QAM is given by:

$$P(\gamma_0) = \int \frac{1}{\gamma_0} \exp(\frac{\gamma}{\gamma_0}) P_e(\gamma) d\gamma \qquad - \qquad (4)$$

Where γ_0 is average E_b/N_0 and erfc^2 term has such a small effect, it can be ignored. Consequently, using the integration of equation 4, the bit error probabilities of first three equations can be approximated as follows:

For 16-QAM:

$$P_{rav}(\gamma_0) = \frac{3}{8}\left[1 - \frac{1}{\sqrt{1 + \frac{5}{2\gamma_0}}}\right] \qquad - \qquad (5)$$

For 64-QAM:

$$P_{rav}(\gamma_0) = \frac{7}{24}\left[1 - \frac{1}{\sqrt{1 + \frac{7}{\gamma_0}}}\right] \qquad - \qquad (6)$$

For 256-QAM:

$$P_{rav}(\gamma_0) = \frac{15}{64}\left[1 - \frac{1}{\sqrt{1 + \frac{85}{4\gamma_0}}}\right] \qquad - \qquad (7)$$

Where E_b/N_0 is energy per bit to noise power spectral density ratio.

IV. NOISE CHANNELS

AWGN CHANNEL: Addition of white Gaussian noise to the signal that passes through the channel is AWGN channel. You can create an AWGN channel in a model using the communication AWGN Channel System object™, the AWGN Channel block, or the awgn function. Here some examples are given to use an AWGN Channel: QPSK Transmitter and Receiver and General QAM Modulation in an AWGN Channel. The relative power of noise in an AWGN channel is typically described by quantities such as

1. Per sample SNR (signal to noise ratio).
2. $\frac{E_b}{N_0}$ (Ratio of bit energy to noise power spectral density).
3. $\frac{E_s}{N_0}$ (Ratio of symbol energy to noise power spectral density)

Where:

$$\frac{E_s}{N_0}(dB) = \frac{E_b}{N_0}(dB) + 10\log_{10}(k)$$

k representing the number of information bits per symbol and vale of k can depend on size of modulation alphabet or code rate of an error control code. For example, if a system uses a rate-1/2 code and 8-PSK modulation, then

$k = (1/2)\log_2(8) = 3/2$.

Again

$$\frac{E_s}{N_0}(dB) = 10\log_{10}\left(\frac{T_{sym}}{T_{samp}}\right) + SNR(dB)$$

For complex input signals $\frac{E_s}{N_0}(dB) = 10\log_{10}\left(\frac{0.5T_{sym}}{T_{samp}}\right) + SNR(dB)$; where T_{sym} is the signal's symbol period and T_{samp} is the signal's sampling period. For example, if a complex baseband signal is oversampled by a factor of 4, then $\frac{E_s}{N_0}$ exceeds the corresponding SNR by $10\log_{10}(4)$.

RAYLEIGH FADING CHANNEL: The delays related with different signal paths can be changed in an unpredictable manner. Such kind of delay can only characterized statistically. The envelope of sum of two qudrature Gaussian noise signals fallow Rayleigh distribution. Probability density function of Rayleigh fading is:

$$P(r) = \begin{cases} \frac{r}{\sigma^2}\exp\left(\frac{-r^2}{2\sigma^2}\right); when(0 \le r \le \infty) \\ 0; when(r < 0) \end{cases}$$

Where σ is root mean square value of the received voltage signal and σ^2 is time average power of the received signal, before envelope detection. Probability of the received signal that does not exceed a specified value and it can be calculated with the help of CDF (cumulative distributive function).

So Rayleigh fading is statistical model and we can get result for propagation environment on radio signal. These models can be used by wireless devices. In Rayleigh fading model, the magnitude of a signal that pass through such a transmission medium will vary randomly and same will obey Rayleigh distribution. Rayleigh fading is viewed a reasonable model for signal propagation in troposphere and ionosphere. Rayleigh fading also effect of heavily built up urban environments on radio signal. The probability density $p(h) = \frac{h}{\sigma^2} e^{\frac{-h^2}{2\sigma^2}}$; with magnitude |h| is called a Rayleigh random variable and σ^2 is variance. This model is known as Rayleigh fading channel model and this model is reasonable for an environment where large number of reflectors presents.

V. RESULTS

E_b/N_0(dB)	BER		
	16 QAM	**64QAM**	**256QAM**
0	0.1409	0.1998	0.2546
5	0.0418	0.1007	0.1593
10	0.0017	0.0265	0.0785
15	1.84E-7	7.72-E	0.0198
20	1.40E-19	2.63E-8	5.05E-4
25	2.17E-57	5.81E-22	1.14E-8
30	2.02E-176	1.24E-64	6.96E-23

Table 2: BER for QAM in Gaussian noise channel

E_b/N_0(dB)	BER		
	16 QAM	**64QAM**	**256QAM**
0	0.9675	0.2470	0.2890
5	0.1031	0.1535	0.2047
10	0.0423	0.0766	0.1242
15	0.0148	0.0306	0.0609
20	0.0048	0.0106	0.0241
25	0.0015	0.0034	0.0083
30	4.96E-4	0.0011	0.0027

Table 3: Average BER for QAM system under flat Rayleigh fading conditions

For a video and data modulation, the use of 256-QAM has become more prevalent in cable systems. 256-QAM proposes the maximum bandwidth efficiency existing today among digital cable signals i.e. 8bits/symbol. 256-QAM will become a dominant modulation format of the digital multiplex. With the help of increasing fiber count, implementing equipment, adding wavelengths or improving compression techniques, segmentation in the plant in digital television signals we can create more bandwidth in HFC systems. 256-QAM and its 8 bits/symbol, provides 33% more efficient bandwidth usage in compare to 64-QAM, which represents 6 bits/symbol. Of course, this is at the expense of a higher SNR requirement. There will be also increased sensitivity to other impairments i.e. phase noise and interference. Cable channel required very high SNR and excellent linearity characteristics, because they need to support analog video also. Theoretical capacity of a 6 MHz channel with a 45 dB SNR is 90 Mbps. The transmission rate is 40 Mbps for 256-QAM. Fraction of this is consumed by error correction overhead.

As shown in figure and table in both AWGN and Rayleigh fading condition we can see that if we is going to increase the M-QAM BER is increasing.

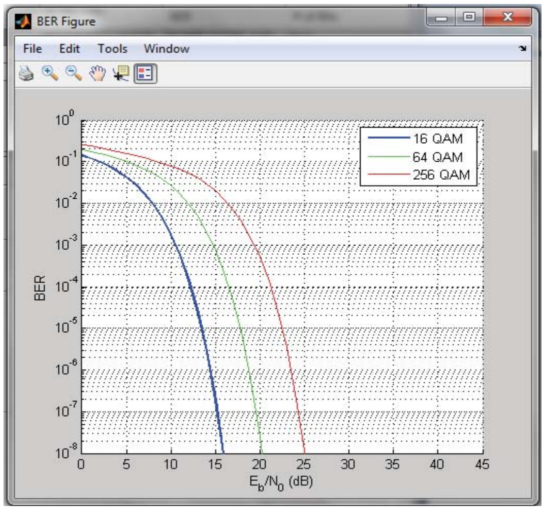

Figure 1: BER for QAM in Gaussian noise channel

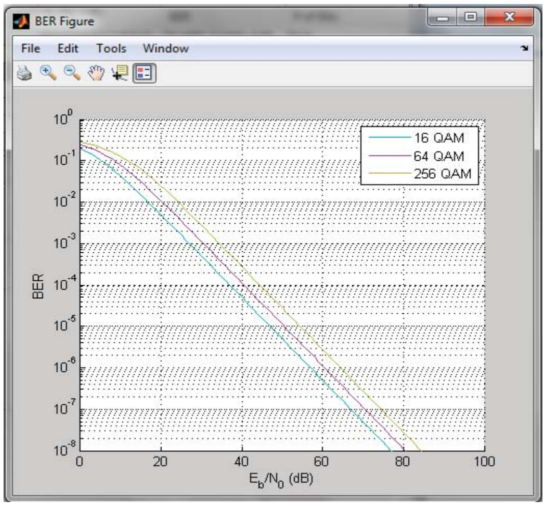

Figure 2: Average BER for QAM system under flat Rayleigh fading conditions

VI. CONCLUSIONS

Higher M-array schemes finally in an unacceptable BER and error correcting codes and waveform equalization circuits are required in these systems. The reduction in signal distance also makes high M-array systems susceptible to co-channel interference. So the use in cellular system must be considered judiciously.

Variations in amplitude and phase of the received signal cause the phenomenon referred to as fading in mobile communication. Since QAM system carry information in both amplitude and phase, so fading is major factor in performance degradation of these systems. In fixed microwave communication systems employing 16-QAM, automatic gain control (AGC) and utilization of a reference carrier regenerator has been successful in the control of amplitude and phase variations in the received signal. This problem is much more severe in 256-QAM system.

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