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EGC RECEIVER USING SINGLE RADIO FREQUENCY CHAIN AND SINGLE MATCHED FILTER OVER COMBINED RAYLEIGH AND RICIAN FADING CHANNELS

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ABSTRACT

Mobile satellite communication (MSC) system has become an essential part of the world telecommunication infrastructure. However, it is characterized by multipath fading effects. Equal Gain Combining (EGC) which was one of the techniques previously used to address this problem also suffers from hardware complexity. A modified EGC (mEGC) with single radio frequency chain and single matched filter was developed to mitigate the effects and reduce the hardware complexity. The performance of mEGC was evaluated using Bit Error Rate (BER) and the processing time. The results at mobile speed of 120 km/hr and signal-to-noise ratio (SNR) of 6 dB; BER of 0.0063, 0.0503, and 0.0693 were obtained as against 0.0114, 0.0504, and 0.0695, for the conventional EGC with 4QAM, 16QAM, and 64QAM, respectively, also, the processing time of 0.0313s, 0.0156s, and 0.0157s were obtained for mEGC as against 0.0469s, 0.0469s, 0.0417s, respectively for convectional. The modified EGC receiver gave approximately the same BER performance when compared with the conventional EGC receiver and thus reduced hardware complexity.

Keywords: equal gain combining, RF chain, matched filter, MQAM.

INTRODUCTION

Wireless communications through the satellite have become an essential part of world's telecommunication infrastructure. This is evidenced by the antennas that dot city and horizon, particularly in times of international crises and events. As a result of research and developments in the field of computer, telecommunication and internet application which lead to large transmission of data; satellites have become one of the best options for data communication because of the higher data transfer capability and higher performance to cost ratio [1]. Hence, satellite communication systems are now a major part of most telecommunication network, and have affected our everyday life through personal communication system and broadcast television [2].

Satellite communication systems are required to operate under increasingly hostile environment; this is because of the ever increasing demand and ubiquitous access of personal communication services [3, 4]. Communication via satellite and earth station and vice-versa are through space and being a wireless channel, is faced with different challenges in the troposphere and the ionosphere. When signals are transmitted through these physical channels, it degrades as a result of ionospheric scintillation and multipath fading.

Multipath propagation is a phenomenon that occurs when a transmitted signal propagates in multiples as a result of obstruction in terrestrial environment which result in fluctuation of the received signal [3, 5]. These fluctuations could be so severed as to produce a signal which is below the sensitivity of the receiver, thus causing poor reception of the signal [3]. Scintillation occurs in the ionosphere and defines as the variation in the amplitude level, phase, and angle of arrival of the received radio waves due to the total electron content (TEC) of the ionosphere.

The net effect of these two phenomena is signal fading at the receiver. The multipath fading is modelled as Rayleigh distribution because there is usually no line of sight at the lower part of the troposphere due to obstruction along the signal path while scintillation can be modelled as Rician distribution because of the possibilities of direct line of sight [4, 6-11].

Diversity combining is one of the combining techniques to enhance reliability of the transmission and consists of receiving redundantly the same information bearing signal over multiple replicas at the receiver to increase overall received signal-to-noise ratio (SNR). These received multiple replicas can be obtained in space (antenna), angle frequency, and time domains [11-13]. Different antenna receive different copies of the same signal, the chances that all these copies will be in deep fade are minimal. It offers a great potential for radio link performance improvement to many of the current and future wireless communication system. The system performance depends on how many copies of these multiple replicas are combined and which combination technique is used [14]. There are many combining techniques currently in used among which are Maximal Ratio Combiner (MRC), Equal Gain Combiner (EGC) and Selection Combiner (SC). MRC actually provides the maximum performance improvement relative to all other diversity combining techniques by maximizing the SNR at the combined output. However, MRC has the highest complexity and is expensive because it requires the knowledge of the fading amplitude in each signal branch and many components are involved. EGC is often used in practice since it equally weights each branch before combining and hence, does not require estimation of the channel fading amplitudes. EGC is similar to MRC except that the RF weighting factors were set to unity in EGC which implies that EGC does not require Radio frequency (RF) weighting. This means that EGC is less complex than MRC and presents significant practical interest because of its performance which is comparable to optional MRC technique [11, 15, 16].

For a diversity system with 'L' branches, the conventional EGC system consists of 'L' RF chains (low noise amplifier, frequency converter, and Analogue to Digital converter) to down convert to baseband, 'L' matched filter (MF) detectors. As a result of these multiple RFs and MFs detectors, hardware complexity and high cost are the challenges associated with the conventional EGC in the implementation.

In this paper, an EGC receiver using a single RF chain and single matched Filter is proposed over combined Rayleigh and Rician channel.

THE EGC RECEIVER

The conventional EGC receiver with multiple RF chains and multiple MFs

The conventional EGC system consist of 'L' radio frequency chains (low noise amplifier, frequency converter, and A/D converter) to down convert to baseband, and 'L' matched filter (MF) detectors, for a diversity system with 'L' diversity branches. This provides an intermediate solution as far as the performance and the implementation complexity are concerned compared to MRC. The model is shown in Figure-1.

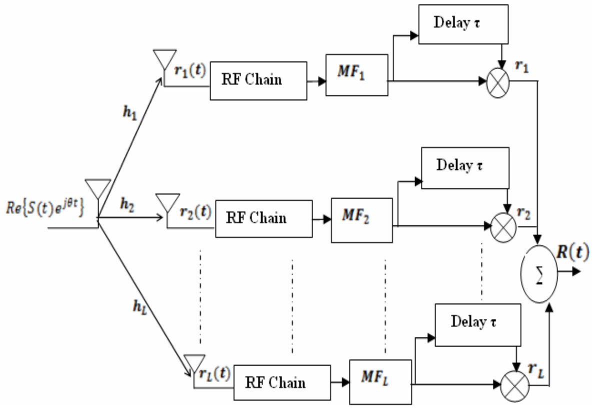

Figure-1. The conventional post detection EGC receiver with delay line.

The modified EGC receiver

In the proposed receiver, each signal branch is weighted with the same factor that is the branches are multiplied by one, irrespective of the signal amplitude. However, co-phasing of all signals is needed to avoid signal cancellation; this is because EGC does not require weighting at all. The received signals from 'L' independent and identically distributed (iid) paths are combined at the Radio Frequency (RF) stage. Figure-2 shows the combined signals, with delay line, being summed using single RF and MF in a post detection scenario.

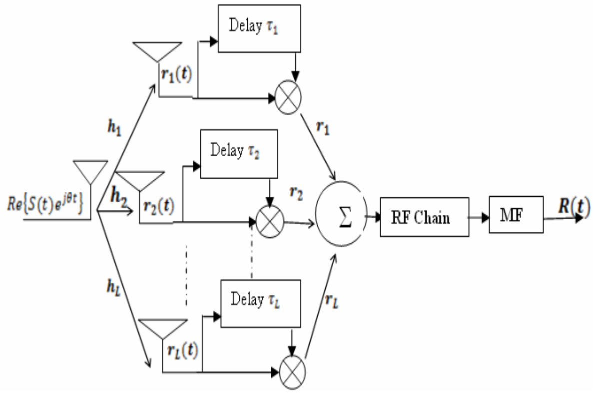

Figure-2. The modified EGC receiver with delay line using single RF and single MF.

MATERIALS AND METHODS

System model

The system model proposed for the combined Rayleigh and Rician fading channel consists of the transmitter, the frequency non-selective Rayleigh-Rician fading channel and the EGC receiver; as shown in Figure-3.

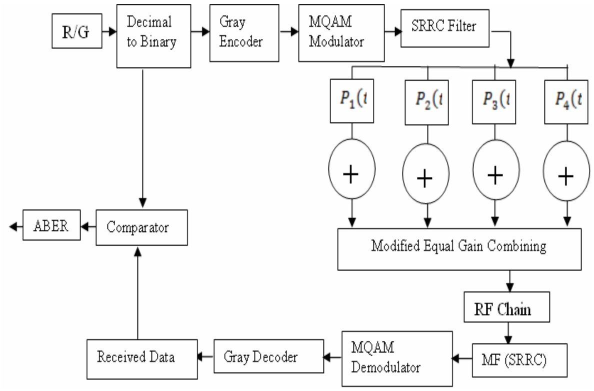

Figure-3. System simulation model.

where $P_l(t)$ is the transmitted signal after Rayleigh and Rician fading distortion symbol ⊕ is the additive white Gaussian noise (AWGN)

The source data, (the randomly generated binary data) is reshaped and modulated with M-ary Quadrature Amplitude Modulation (MQAM) scheme, square-root raised cosine (SRRC) filter is the MF used to reduce the spectral occupancy and convert it to the form suitable for transmission over the channel understudy in the MQAM. The received signals over the channels were combined at the RF stage using the EGC and then passed through the RF chain and matched filter (MF) for further processing and finally demodulated with MQAM demodulator after it has been gray decoded. The gray encoding is employed to reduce the average miscoded bits down to one per symbol. This helps to organise the signalling such that adjacent symbols are different by exactly one bit. 10000 samples are used for each SNR to generate the fading envelopes for the product fading channel. Each bunch of multipath components and the phases are random with similar delay times was considered. This is shown in Figure-3.

M-ary quadrature amplitude modulation

M-ary Quadrature Amplitude Modulation (MQAM) modifies the phase and amplitude of the signal simultaneously. It offers increased data throughput and spectral efficiency. It is accomplished by varying the amplitude of two sinusoidal waveforms that are in quadrature i.e. 90^0 phase shift to each other respectively and summing them together. This allows the effective transmission of two channels at the same frequency, thereby doubling the rate at which the data is transmitted. An M-QAM signal $S_i(t)$ set is represented by [5] as

$$S_i(t) = A_i Cos(2\pi f_c t + \theta) \quad i = 1,2......M \tag{1}$$

Where

$S_i(t)$ = transmitted signal

A_i = amplitude of the signal at i^{th},

θ_j = phase of the signal in M-ary signal set

f_c = carrier frequency and t is the period

By expansion

$$\begin{aligned} S_i(t) &= A_i\left(Cos 2\pi f_c t \cos\theta_i + \sin 2\pi f_c t \sin\theta_i\right) \\ &= A_i \cos 2\pi f_c t \cos\theta_i + A_i \sin 2\pi f_c t \sin\theta_i \end{aligned} \tag{2}$$

$$\begin{aligned} &if\ A_{I1} = A_i \cos\theta_i\ and\ A_{I2} = A_i \sin\theta_i \\ &S_i(t) = A_{I1} \cos 2\pi f_c t + A_{I2} \sin 2\pi f_c t \end{aligned} \tag{3}$$

$$Then, A_i = \sqrt{{A_{I1}}^2 + {A_{I2}}^2} \tag{4}$$

Combined Rayleigh and Racian channels model

Combined Rayleigh and Racian channels were used to model the satellite its expression is given by [5] as

$$\alpha(t,\tau) = \alpha(t)\exp\left(-j2\pi f_c \tau(t)\right)\delta\left(\tau_i(t)\right) \tag{5}$$

where

$\alpha(t)$ = attenuation factor which depends on the product of Rayleigh and Rician fading

$\tau(t)$ = propagation delay

f_c = carrier frequency

According to [13] flat fading channel models are appropriate for narrow band land mobile systems or mobile satellite systems. The received signal $r(t)$ through the atmosphere can be expressed as

$$r(t) = \alpha(t,l)\, s_l(t) + n_l(t) \tag{6}$$

Where

$s_l(t)$ = M-QAM transmitted signal

$a(t,l)$ = complex product fading distribution co-efficient

$n_l(t)$ = complex AWGN with zero mean and unit variance.

In [6] it was stated that the fading co-efficient a_l of the $l-th$ branch can be obtained as the product of the two fading coefficients

$$\begin{aligned} \alpha_l &= \alpha_{rician} . \alpha_{rayleigh} \\ \alpha_l &= \left[\alpha_{rician} \exp\left(-j\theta_{rician}\right) + n_{rician}(t)\right] \\ &\qquad \left[\alpha_{Ray} \exp\left(-j\theta_{Ray}\right) + n_{ray}(t)\right] \end{aligned} \tag{7}$$

where a_{rician} and a_{Ray} are the complex coefficients of the scintillation and terrestrial multip`ath fading, respectively. The phases θ_{rician} and θ_{Ray} are assumed to be uniformly distributed over (-π, π) and signal $n_{sc}(t)$ and $n_{ter}(t)$ are complex Gaussian random processes with power spectral density $2\sigma^2$and $2\sigma^2$, respectively. [17] described the envelope 'r' of the combined tropospheric fading and ionospheric scintillation as

$$\begin{aligned} r_{combd} &= r_{sc} . r_{fad} \\ r_{combd} &= r_{sc} . r_{fad} = \left|\alpha_{sc}\right| . \left|\alpha_{ter}\right| \end{aligned} \tag{8}$$

where $r_{ter} = \left|\alpha_{fad}\right|$ is the envelope of the Rayleigh fading in troposphere.

Rayleigh distribution

This is used to model terrestrial surface lower part of the atmosphere where there are multiple random reflective paths that are large in number to block line of sight components. The amplitude of the received signal is statistically described as Rayleigh probability density function (PDF). The received signal therefore comprises the summation of all the diffused components. The PDF of the Rayleigh distributions is given by [5] as

$$P_R(t) = \frac{r}{\sigma^2}\exp-\left(\frac{r^2}{2\sigma^2}\right) \quad 0 \le r \le \infty \qquad (9)$$

r = amplitude of the envelope of the received signal
σ = root mean square (rms) value of the received signal
σ^2 = time-averaged power of the received signal
$2\sigma^2$ = pre-detection mean power of the received signal

Rice distribution

If there is no obstruction to have a clear LOS between the transmission and receiver, Rice distribution is used for modelling the environment. In this case, signal arriving at the receiver is expressed as a sum of one dominant vector and several number of independently fading uncorrelated multipath components with amplitudes of the order of magnitude and phases uniformly distributed in the interval $(0, 2\pi)$.

The PDF of the envelope of the received signal is given by [5] as

$$P_{Rice}(r) = \frac{r}{\alpha^2}\exp-\left[\frac{r^2+\mathrm{A}^2}{2\sigma^2}\right] l_o\left[\frac{\mathrm{A}_r}{\sigma^2}\right] \quad r \ge 0 \ \mathrm{A} \ge 0 \qquad (10)$$

where 'A' is the peak amplitude of the LOS specular components

$I_o(.)$ is the modified $zero^{th}$ order Bessel function of the first kind.

There is a Rice factor $k = \frac{\mathrm{A}^2}{2\sigma^2}$ which is the ratio of power of specula component to the average power of the scattered component.

The Rice fading distributions span the range from Rayleigh $(k = 0)$, and Gaussian when $k \gg 1$ that is $k = \infty$ indicating constant amplitude (no fading). The Rice fading distribution is observed in the first resolvable LOS paths of suburban land-mobile [15] and applies also to the dominant LOS path of a satellite [18, 19].

Simulation model

The simulation of the system model under investigation was carried out using MATLAB application packages; because test and evaluations are less expensive and more reproducible than field trials at the speed considered. This process is carried out under the following assumptions; the noise is additive, white, and Gaussian. The pulse shaping matched filter considered here is the square-root raised cosine (SRRC) and the fading channel is a product of Rayleigh and Rician. The sampling interval, therefore, is equal to one symbol interval T. Table-1 contains the simulation parameters for the modified EGC.

Table-1. System simulation parameters for modified EGC.

Parameters	Specification
Modulation scheme	M-QAM
Fading	Rayleigh x Rician fading (LMSC)
Number of modified EGC paths	2, 3, 4
Carrier frequency	900MHz
Bandwidth of symbol	250kHz
Delay spread	250ns
Noise	AWGN
Velocity of mobile unit	120km/hr
Transmit filter	Square root raised cosine
Receiver matched filter	Square root raised cosine
Roll of factor	0.25
Number of samples/symbol	4
SNR	(0; 2; 4)
Rician factor (k)	(0, 10)
Number of symbol (data length)	10,000

RESULTS AND DISCUSSIONS

The results obtained from modified EGC with single RF and single MF using M-QAM over combined Rayleigh and Rician fading channel in an Independent Identically Distributed (iid) scenario at a mobile speed of 120km//h are presented in Figures 4 to 8. The Bit Error Rate (BER) in Figures 4 to 6 shows that the modified EGC and the conventional EGC were able to address the challenge of multipath fading and scintillation associated with Rayleigh and Rician fading in a mobile satellite channel as a result of lower BER obtained. Consequently the Figures 4 to 6 show that the performances of the modified EGC and conventional are almost the same, indicating the reduction in hardware complexity and cost due to the use of single RF chain and single MF. Figures 4, 5 and 6 showed the performances.

The results of the simulation showed that at a mobile speed of 120km/hr, and SNR of 6dB with 3 paths (L=3); BER of 0.0063, 0.0503 and 0.0693 were obtained as against 0.0114, 0.0504 and 0.0693 for conventional EGC with 4QAM, 16QAM, and 64QAM, respectively. With two paths, (L=2) the BER value obtained for the modified EGC at a mobile speed of 120km/h and SNR of 6dB; are 0.0171, 0.0776 and 0.1048, while 0.0252, 0.0774, and 0.1048 were BER values obtained for the conventional EGC with 4QAM, 16QAM, and 64QAM, respectively. Figures 7 and 8 depict the processing time against the number of paths for both EGC. The processing time for the modified EGC with 4QAM, 16QAM, and 64QAM signalling schemes were 0.0313s, 0.0156s, and 0.0157s, respectively for different paths for conventional EGC, 0.0469s, 0.0469s and 0.0471s, were obtained respectively.

The relatively lower processing time of the modified EGC is an indication of a reduction in the hardware complexity and consequently lower cost.

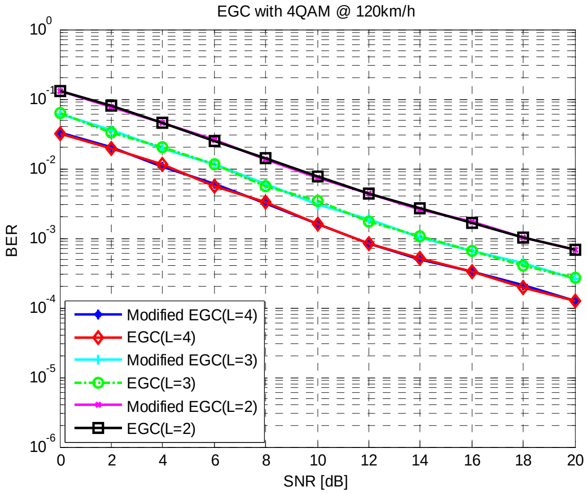

Figure-4. Simulation of BER for conventional and modified EGC with L = 2, 3, 4 using 4-QAM scheme, varying number of paths, L.

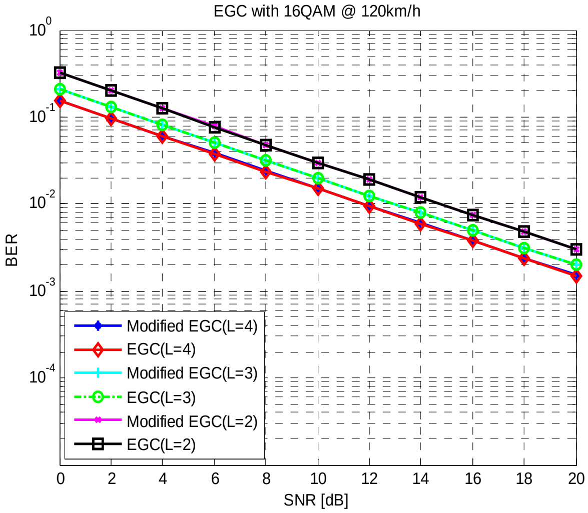

Figure-5. Simulation of conventional and modified EGC for L=2, 3, 4 with 16QAM.

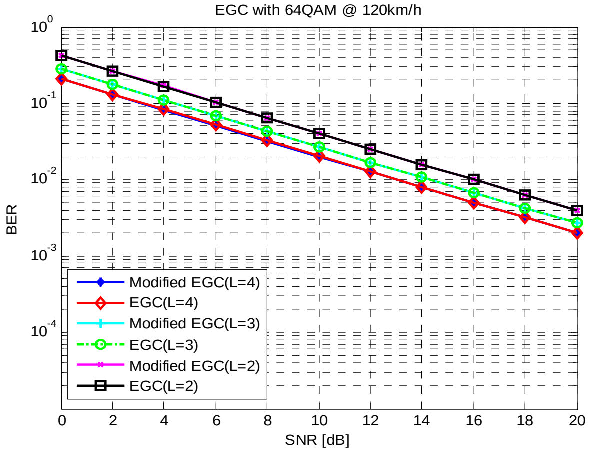

Figure-6. Simulation of BER for conventional and modified EGC for L = 2, 3, 4 with 64-QAM.

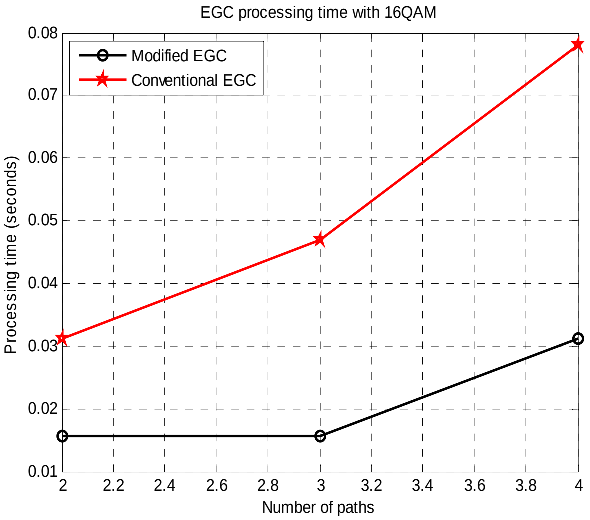

Figure-7. Processing time for conventional and modified EGC with varying number of paths for 16QAM.

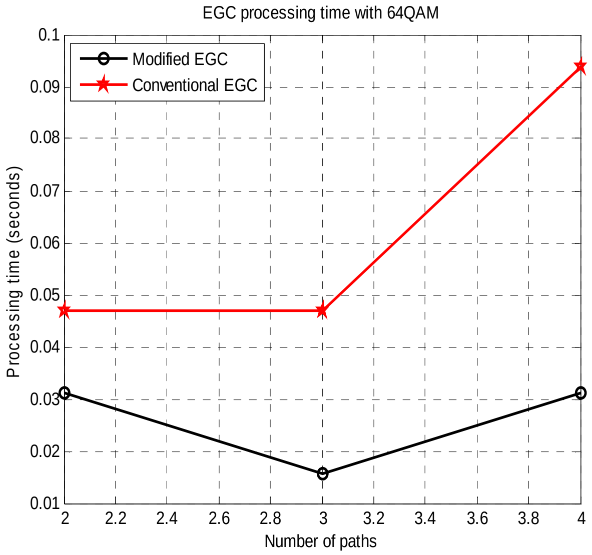

Figure-8. Processing time for conventional and modified EGC with the number of paths for 64QAM.

CONCLUSIONS

The modified EGC over the combined Rayleigh and Rician fading channels modelled as multipath fading and scintillation respectively using single RF chain and single MF with M-QAM has been investigated. This performance was evaluated using BER. Comparison was made with the conventional one. The results obtained have proved that the modified EGC is also effective as the conventional EGC in tropospheric and ionospheric environment. Consequently the effect of multipath propagation and scintillation due of Rayleigh and Rician fading was reduced to a minimal level by using modified EGC and MQAM. The results is in agreement with [20] where mathematical analysis was carried out to prove that a MRC with single RF chain and single MF have the same output as the conventional MRC with multiple RF chains and multiple MFs. Therefore, the modified EGC has significantly reduced the hardware complexity and gave a performance equivalent to the conventional EGC with reduction in processing time.

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