Adaptive Power Control with Selection Combiner over Nakagami-m Fading Channel

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Abstract- Acceptable Quality of Service (QoS) is of paramount importance in wireless communication system. However, QoS is affected by multipath propagation resulting in unreliable reception. Selection Combiner (SC) which is one of the techniques previously used to solve this problem is associated with poor performance due to fixed power level used in the technique. Hence, in this paper, an Adaptive Power Control (APC) technique using SC with a closed form expression over Nakagami-m Fading Channel is proposed. APC technique is developed using fixed power SC and Link Adaptation Algorithm (LAA). Ten thousand (10,000) bits are randomly generated and modulated using Quadrature Amplitude Modulation (QAM) scheme. The modulated signal is passed through the Square Root Raised Cosine (SRRC) filter for suitable transmission over the Nakagami-m fading channel. The faded signals at varying paths ‘L’ (2, 3, 4) are selected by Conventional Selection Combining (CSC) to instruct the transmitter for adjustment of power level based on the value of the received signal through LAA. Mathematical expression for the received signal using Probability Density Function (PDF) of Nakagami-m Fading Channel at varying paths is derived. The APC technique is simulated using MATLAB software and evaluated using Signal to Noise Ratio (SNR), Outage Probability (OP) and Bit Error Rate (BER) to determine the performance of the proposed technique. OP values of 0.0969 and 0.1063 are obtained for APC and CSC, respectively, at SNR of 6 dB with L of 4, while BER values of 0.0052 and 0.2599 are obtained for APC and CSC, respectively. The percentage reduction in OP and BER are 29.79% and 54.43%, respectively. The results obtained show that APC gives lower OP and BER values with increase in SNR when compared with fixed power SC due to self-adjustment of the allocated power. Therefore, the APC technique proposed can be used to enhance the performance of the wireless communication systems.

Keywords- Adaptive Power Control, Selection Combiner, Link Adaptation Algorithm, Bit Error Rate, Diversity Combiner

1 INTRODUCTION

Wireless communication which is a means of transmitting signals from one point to another has become an important tool for fast and efficient means of data transmission. The study of the characteristics of the transmission channel is required to maintain effective communication between users with high fidelity for transmission of vital information due to the hostile nature of the channel. The past 2G, 3G and 4G evolution technology era has seen a surge in research activities of radio channel due to a volatile increase in demand for proficient connectivity which was driven so far mainly by communication devices, soon projected to be concealed by 5G thus turning the world into a global village (David and Pmand, 2012). The increase in demand for communication has turned spectrum into a valuable resource leading to channel impairment that reduces the performance of the system (Abolade and Adeyemo, 2012).

The need to design a wireless communication system with effectual performance to meet-up with exponential increase in its services has steered the study of the characteristics of the radio channel. Propagation through the radio channel is often affected by three major propagation mechanisms such as reflection, diffraction and scattering which lead to multipath propagation in wireless communication. Multipath propagation is a phenomenon that occurs when signal propagates in multiple copies resulting in random fluctuation of the received power causing a severe degradation known as fading (Hafeth, 2005; Adeyemo et al., 2013). Therefore, the need to design a wireless communication system with efficient performance is of paramount importance in this periodical global covid-19 pandemic due to more demand for data for online meeting.

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To design an effective wireless communication system that has a good performance to meet-up with exponential increase in its services, the characteristics of the radio channel in which systems operate need to be considered. The performance of wireless communication system depends on some signal processing techniques at the transmitter and receiver such as amplification, coding, modulation, filtering as well as the nature of the channel at a particular time (Adeyemo et al., 2013; Rajkumar, 2016).

The measurement of wireless communication channel is required to know the channel status at a particular time. Therefore, wireless systems are equipped with channel measurement that allows the receiver to measure the fade depth of the received signal which may be controlled by adjusting transmitting power. Such a control is achieved in various ways such as adjusting the power level, symbol rate, coding scheme and any combination of these approaches. The receiver detects these changes directly from the received data without the need for an explicit rate change control information.

This paper focuses on adjusting the transmitting power which is referred to Adaptive Power Control (APC). APC is a technique that is used to achieve very high-power efficiency in signal transmission over fading channels by increasing the signal to noise ratio (SNR) of a signal to attain a given threshold level as well as maintaining the desired bit error rate (BER) which is a major parameter used in the assessments of systems used for data transmission from one location to another and outage probability (OP) of the signal which is the performance measure used to describe diversity systems that are operating in a fading environment. The goal of an APC technique is to adjust the transmit power such that the target Signal Interference Ratio (SIR) which is used for optimal allocation of radio resources to meet a given
Among the technique to mitigate effect of fading in wireless communication is Diversity Combining (DC). DC is a technique that combine the multiple copies of transmitted signal at the receiver to improve the signal strength of the received signal (Nirimal, 2005). DC technique consist of Maximal Ratio Combiner (MRC), Equal Gain Combiner (EGC) and Selection Combiner (SC). The upshot of past researchers on diversity combining technique reveals that SC technique is often used in practice due to its low complexity but suffers from poor performance when compared with MRC and EGC (Khoa, 2019). The combiner in SC evaluates the SNR of all diversity paths or branches that are available in the system and select the best one. The diversity output path from the combiner has a signal to noise ratio that is equal to the maximum SNR of all the diversity branches (Alekassandra et al., 2019; Niruddha et al., 2011; Shukla et al., 2011). The poor performance of SC is due to only one signal branch used out of the L available branches.

Therefore, this paper proposes an APC technique that adjusts the transmitting power based on the strength of the received signal. APC allows transmitter to adjust the signal power in compensating for channel condition. Multiple copies of transmitted signals follow different fading distributions such as Rayleigh, Rician and Nakagami-$m$ fading distributions. Nakagami-$m$ distribution is adopted in this paper due to its capability to model both indoor and outdoor mobile radio environment (Karagiannidis et al., 2005, Ray and Hu, 2001; Jayanthi, 2001). Signal processing in a mobile channel involves modulation of base band signal which is a process by which signal parameters are being modified into a form suitable for transmission over propagating medium (Shukla et al., 2011).

Some of the basic skills used in transmission of digital signal are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK). The evaluation of their performances at different environment has been carried out in the existing literatures. The hybrid version of the scheme is Quadrature Amplitude Modulation (QAM). Researchers are geared towards QAM due to its good performance in wireless environment.

Therefore, under this scheme are Binary Phase Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK). In this paper, QAM is a hybrid signaling scheme that is used to modulate the signal at the transmitter due to its ability to simultaneously vary the phase and amplitude of a signal in accordance with modulating signal (Rappaport, 2002; Adeyemo, 2013, Sushmaja et al., 2013). The contributions of this paper are: 1) to propose a technique that is self-adjusting with diversity combiner based on the Channel State Information (CSI) at a particular time thereby overcome the poor performance of existing SC with fixed power and 2) to derive a mathematical expression of OP and BER for the proposed technique over Nakagami-$m$ fading channel.

### 2 Related Work

In Hui et al. (2001), an improved switched diversity combining using fuzzy adaptive control was carried out to solve the problem of signal fluctuation in a mobile unit. The fuzzy adaptive control was used to adjust the threshold level at which switching was performed based on the present varying channel conditions. The result obtained revealed that the technique showed a significant improved performance in terms of diversity gain with reduction in BER when compared with non-DC technique. However, the technique suffers from poor performance when compared with other DC technique such as MRC and EGC.

Switched diversity approach for multi-receiving optical wireless systems was proposed in Hassan et al. (2011) to address the problem of signal variability at the receiver. Combination of switch combiner and selection combiner called Switch-to-Dominant Combiner (SDC) was used to combine the available signal branches. The signal with the highest SNR was processed and BER was used to analyze the load processing performance of SDC scheme. The results obtained revealed that SDC improved the quality of service with reduction in BER when compared with selection combiner and switch combiner. However, SDC has a poor performance when compared with other DC technique. Also, in Jaherul (2012), performance analysis of threshold combining diversity techniques in wireless communication system was proposed to solve the problem of signal fluctuation at the receiver due to multipath fading.

In this work, the signal branch with SNR greater that the set threshold was selected and used until the signal falls below the set threshold of 2 dB. When the branch fell below the set threshold, other branch that was greater than the set threshold was selected and used as output signal until the branch fell below the set threshold. The result obtained showed a better performance with reduced Outage Probability (OP) when compared with non-DC but has a poor performance when compared with MRC and EGC due to only one branch used.

Furthermore, performance analysis of hybrid MRC/EGC diversity combining techniques is presented in Hima and Seema (2016) to solve the problem of variability of signal at the receiver using hybrid MRC/EGC. In this work, the multiple copies of the received signal were combined using three Maximal Ratio Combining. The signal output of MRC was then compared using EGC. The results obtained revealed that, the hybrid combiner gives better performance with drastically reduction in BER when compared with other DC such as MRC, EGC and SC. However, the technique has highest hardware complexity when compared to other DC techniques. In Yunjing et al. (2003), timing sensitivity Errors with EGC, MRC techniques were carried out and the effect of imperfect timing was analyzed in EGC and MRC techniques over Rayleigh and Nakagami-$m$ fading channels using Binary Phase-Shift Keying modulation. The bit-error probability was derived in the case of EGC, while error rate bounds are presented in the case of MRC. The Theoretical results were justified by computer simulation. Results showed that both EGC and MRC are fairly sensitive to timing.
errors and comparatively, MRC is said to be more sensitive but the system suffers hardware complexity. Previous works on DC show that MRC, EGC and hybrid MRC/EGC have better performance compared to SC, but at the expense of high hardware complexity resulting in high power consumption and implementation cost. However, SC technique with low hardware complexity has poor performance in time varying channel due to fixed transmitting power used in the system. Therefore, in this paper adaptive power allocation based on the received signal is proposed to improve the performance of the fixed power SC.

2.1 CONVENTIONAL SELECTION COMBINER
Conventional Selection Combiner (CSC) scans through multiple copies of received signal and selects branch with highest SNR. Fig. 1 depicts the block diagram of CSC in which the branch with highest signal strength is selected at a particular time. The signal output of CSC is equal to the signal on only one branch among the received multiple copies. Therefore, coherent sum of all received branches is not required (Abolade and Adeyemo, 2012; Hafeth, 2005). Also, in CSC, signal co-phasing is not required since only one branch is output at a time unlike MRC and EGC that require co-phasing of the received signal to avoid signal cancellation (Adeyemo et al., 2013). However, the technique suffers from poor performance due to only one branch and fixed power used.

\[ f_{SC}(r) = \frac{2}{\Gamma(m)} \left( \frac{m}{2\sigma^2} \right)^m r^{m-1} \exp \left( -\frac{mr^2}{2\sigma^2} \right) \]  

(1)

where: \( m \) is the Nakagami-m fading parameter 
\( \Gamma(.) \) is the gamma function
2\( \sigma^2 \) is the pre-detection mean power of the received signal
\( r \) is the SNR of the received signal

Therefore, since Selection Combiner (SC) selects the signal with highest SNR among the multiple branches, the received signal at the output of SC ‘\( r \)’ is given as 
\[ r = \max r(t) \]  

(2)

where: \( \max r(t) \) is the received signal with highest SNR at a particular time

Substituting Equation (2) into (1) gives
\[ f_{SC}(r) = \frac{2}{\Gamma(m)} \left( \frac{m}{2\sigma^2} \right)^m (\max r(t))^{m-1} \exp \left( -\frac{m(\max r(t))^2}{2\sigma^2} \right) \]  

(3)

Equation (3) is the PDF of the received signal for the proposed technique over Nakagami-m fading channel and max \( r(t) \) in Equation (3) is adjusted based on the channel’s response.

![Block Diagram of an Adaptive Power Control Technique](image)

3.1 DERIVATION OF OUTAGE PROBABILITY FOR THE PROPOSED TECHNIQUE
Outage Probability (OP) is also one of the metrics used to measure the performance of the proposed APC technique. Higher OP indicates poor performance while lower OP value indicates better performance. According to (Narayan, 2005), outage probability ‘OP’ is given as
\[ OP = P(r < \gamma_0) = \int_0^{\gamma_0} P_r(r)dr \]  

(4)

where: \( r \) is the SNR of the received signal
\( \gamma_0 \) is the set threshold
\( P_r(r) \) is the PDF of the received signal

The PDF of the received signal over Nakagami-m fading channel is given in Equation (3). Therefore, substituting Equation (3) into Equation (4) gives
\[ OP = \int_0^{\gamma_0} \frac{2}{\Gamma(m)} \left( \frac{m}{2\sigma^2} \right)^m (\max r(t))^{2m-1} \exp \left( -\frac{m(\max r(t))^2}{2\sigma^2} \right)dr \]  

(5)

\[ OP = 2 \frac{1}{\Gamma(m)} \left( \frac{m}{2\sigma^2} \right)^m \int_0^{\gamma_0} (\max r(t))^{2m-1} \exp \left( -\frac{m(\max r(t))^2}{2\sigma^2} \right)dr \]  

(6)
For \( m = 1 \), equation (6) becomes

\[
OP = \frac{2}{\pi} \Gamma(m) \max r(t) \exp \left(-\max r(t) \frac{t^2}{2\sigma^2}\right) dr
\]  

(7)

Integrating equation (7) with respect to \( r \) gives

\[
OP = \frac{2}{\pi} \max \gamma_0(t) \exp \left(-\max \gamma_0(t) \frac{t^2}{2\sigma^2}\right)
\]  

(8)

Equation (8) is the outage probability for the proposed APC technique over Nakagami-m fading channel.

### 3.2 Derivation of Bit Error Rate for the Proposed Technique

Bit Error Rate (BER) is one of the metrics used to measure the performance of wireless communication systems. The higher value of BER depicts the poor performance of the system while, lower value depicts better performance of the system. The expression for BER (\( P_b(E) \)) is given by [24] as

\[
P_b(E) = \int_0^\infty P_b(E/r) f_{SC}(r)dr
\]  

(9)

where: \( P_b(E/r) \) is the conditional error probability

\( E \) is Signal Energy per symbol

\( r \) is the received SNR

\( f_{SC}(r) \) is the PDF of the output SNR which is obtained in Equation (3). Therefore, substituting Equation (3) into Equation (9) gives

\[
P_b(E) = \int_0^\infty P_b(E/r) \frac{1}{\Gamma(m) \left(\frac{2\sigma^2}{r}\right)^m} (\max r(t))^{2m-1} \times \exp \left(-\frac{(\max r(t))^2}{2\sigma^2}\right) dr
\]  

(10)

But conditional error probability \( P_b(E/r) \) in an uncorrelated channel is given by

\[
P_b(E/r) = \frac{1}{2} \exp \left(ar\right)
\]  

(11)

where: \( a = 0.5 \) for modulation that does not require synchronization (Adeyemo et al., 2020). For such type of modulation, Equation (11) becomes

\[
P_b(E/r) = \frac{1}{2} \exp \left(0.5r\right)
\]  

(12)

Substituting Equation (11) into (10) gives

\[
P_b(E) = \int_0^\infty \frac{1}{2} \exp(0.5r) \frac{1}{\Gamma(m) \left(\frac{2\sigma^2}{r}\right)^m} (\max r(t))^{2m-1} \times \exp \left(-\frac{(\max r(t))^2}{2\sigma^2}\right) dr
\]  

(13)

Equation (13) is the Bit Error Rate (BER) for the proposed technique. The proposed technique is simulated using MATLAB software and the link adaptation algorithm for the proposed APC technique is given in algorithm 1. The signal strength ‘\( Q \)’ in algorithm 1 is obtained using

\[
Q_i = \frac{G_i P_i}{\sum_{j \neq i} G_j P_j + N}
\]  

(14)

where \( P_i \) is the transmitter power,

\( N \) is the receiver noise power,

\( \gamma_0 \) is the threshold SIR,

\[ \sum_{i \neq j} G_i P_j \] is the co-channel interference.

\( G_{ii} \) is the antenna gain.

### Algorithm 1: Link (Power) Adaptation Algorithm

1. Begin
2. \( P = 30 \) W
3. Initialize \( P, N, \gamma_0, \sum_{i \neq j} G_i P_j, G_{ii} \)
4. compute SNR of the received signals
5. select max SNR
6. compute signal strength ‘\( Q \)’ for the selected branch using Equation (14)
7. if \( (Q > 0.1) dB \) or \( (Q < 0.59 dB) \) then
8. new transmitting power \( (P_1) = 25 \) W
9. else if \( (Q > 0.6) dB \) or \( (Q < 1.59 dB) \) then
10. new transmitting power \( (P_2) = 20 \) W
11. else if \( (Q > 1.6 dB) \) or \( (Q < 2.59 dB) \) then
12. new transmitting power \( (P_3) = 15 \) W
13. else \( (Q > 2.59) \) then
14. new transmitting power \( (P_4) = 10 \) W
15. else
16. new transmitting power \( = P_i \)

### 4 Simulation Results and Discussion

Figs. 3, 4 and 5 present the Outage Probability (OP) against SNR for Adaptive Power Control (APC) and Fixed power Selection Combiner (CSC) at different paths (\( L = 2, 3, 4 \)) using QAM signaling schemes over Nakagami fading channel. Fig. 3 depicts OP against SNR for APC and CSC at L of 2 with QAM scheme. At SNR of 6 dB, the OP values of 0.3254 and 0.4223 are obtained for APC and CSC, respectively, while the corresponding OP values of 0.1624 and 0.2307 are obtained for APC and CSC, respectively with L of 3 as depicted in Fig. 4.

Fig. 5 depicts the OP values of 0.0969 and 0.1069 obtained at SNR of 6 dB with L of 4 for APC and CSC, respectively. The results obtained revealed that, the proposed APC technique showed better performance with lower OP than CSC due to self - adjustment of the proposed technique that adjust transmitting power based on channel condition. The results obtained also revealed that, OP values decrease with increased in the number of path due to increase in the strength of the received signal as the power of transmitting signal increases.

Figs. 6, 7 and 8 show the BER values obtained using QAM modulation schemes at \( L = 2, 3 \) and 4, respectively. Fig. 6 presents the BER results with L of 2 over Nakagami fading channel for APC and CSC. At SNR of 6 dB, the BER values obtained are 0.2890 and 0.4463 for ASC and CSC, respectively. Results obtained show that, APC gives lower BER values than CSC and this is due to self – adjustment of the proposed technique. Also, BER value decreases with increased in the number of path and...
reduction in error rate as signal strength increases. The results obtained also reveal that BER values reduces as SNR increases due to increase in signal strength.
Rate (BER). The proposed APC technique has been evaluated using OP and BER as performance metrics by comparing with fixed power SC technique. OP and BER values for adaptive power control and fixed power SC are obtained at different SNRs using different paths with QAM modulation scheme. The results obtained reveal that the proposed APC technique performs better than fixed power SC due to reduction in OP and BER values obtained. The percentage reduction in OP and BER are 29.79% and 54.43%, respectively. The better performance of APC is as a result of increasing signal power based on the strength of the received signal which makes the technique to be self-adjusted. Therefore, APC has been shown to have a better performance over fixed power SC.

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