Performance of multi-level QAM transceiver with adaptive power control in fixed wireless channel

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Abstract We consider the design of quadrature amplitude modulation (QAM) transceivers for fixed wireless communications. The use of adaptive power control in the transmitter (Tx) can provide BER performance robust to fading and improved BER performance. The BER performance is evaluated by analytical and simulation results when multi-level QAM transceiver employing power control in the Tx is applied to fixed wireless channel with flat fading and frequency selective fading. The effect of power control parameters such as power control range and power control step size is investigated.

1. Introduction

In recent, QAM has been applied to fixed wireless communications [1]. However, the application of QAM to wireless channel requires very accurate fading compensation. To reduce the fading effect, several fading compensation techniques have been studied. The pilot symbol assisted modulation (PSAM) which compensates fading in the receiver (Rx) cannot effectively reduce the effect of channel gain variation [2]. A simulation result was reported that 4-QAM with the use of power control could improve BER performance [4]. And the variable rate and variable power QAM scheme was proposed to increase the spectral efficiency [5].

Since the fading characteristics in fixed wireless channels are much milder than in mobile radio channel, it may be quite feasible to employ multi-level QAM schemes. For data transmission over a fixed wireless channel, we consider the design of multi-level QAM transceivers whose Tx power is adaptively controlled to compensate the fading effect. Compared to the conventional fading compensation technique in the Rx, the use of power control in the Tx can not only provide average BER performance improvement but also mitigate instantaneous BER fluctuation due to fading. The performance of the proposed QAM transceiver is analytically evaluated and verified by computer simulation under both flat fading and frequency selective fading environment.

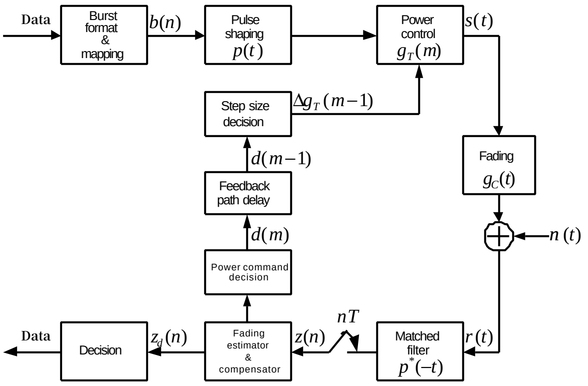


Fig. 1 Block diagram of muti level QAM transceivers employing adaptive power control

2. System model

2.1. QAM transceiver with Tx power control

Fig. 1 depicts the block diagram of a multi-level QAM transceiver using adaptive power control in the Tx. Assuming that the gain of the transmitter is controlled at a frame rate, a transmitted baseband signal $s(t)$ can be represented as

$$s(t)=\sum_{n=-\infty}^{\infty} b(n)\prod_{i=-\infty}^{m-1}\Delta g_T(i)\,p(t-nT_S) \qquad (1)$$

where T_S is the symbol duration, $b(n)$ denotes the n th symbol value, $\Delta g_T(m)$ is the incremental gain at frame time $t=mT_F$, $p(t)$ is the impulse response of the shaping filter,

Assuming that the propagation path is assumed to be a two-ray fixed wireless channel with its delay of lT_S, the received baseband signal can be represented by

$$r(t)=g_{C0}(t)s(t)+g_{Cl}(t)s(t-lT_S)+n(t) \qquad (2)$$

where $g_{C0}(t)$ is the channel gain of direct path, $g_{Cl}(t)$ is the channel gain of delayed path and $n(t)$ is additive white Gaussian noise (AWGN) term. The receiver can detect the pulses using a matched filter and the output $z(n)$ at time $t=nT_S$ can be represented by

$$z(n) = \prod_{i=-\infty}^{m-1} \Delta g_T(i)\big(b(n) g_{C0}(n) + b(n - lT_s) g_{Cl}(n)\big) + n(n). \quad (3)$$

When the received signal undergoes flat fading, i.e., $g_{Cl}(n) = 0$, the receiver determines whether the Tx power should be increased or decreased by comparing the power of the received pilot signal with that of the reference pilot signal at the fading estimation stage. And the residual gain variation due to the feedback path delay can be compensated in the Rx by using conventional fading compensation technique at the fading compensation stage [3]. However, in the case of frequency selective fading, i.e., $g_{Cl}(n) \neq 0$, the equalizer is used for combating inter-symbol interference (ISI) on time dispersive channels. The receiver determines whether the Tx power should be increased or decreased according to the magnitude of main tap coefficient of equalizer. The determined power command bit is delivered to the Tx via a feedback path. Then, the transmitter calculates the incremental gain $\Delta g_T(m)$ using this power command. Thus, the short term fading effect can be compensated, keeping the power of the received signal nearly constant.

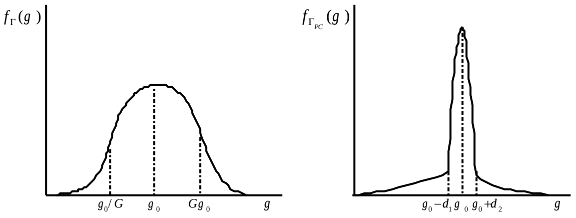
2.2. Fixed wireless channel

Recently, the gain of a fixed wireless channel was modeled as a product of two Rician random variables using experimental data measured in various channel environments [6]. The behavior of the channel gain was characterized by two gain terms; the fast gain term has a Rician factor K_f whose gain variance s_f is from 1.2 dB up to 15 dB with Doppler frequency f_d of 0.3~0.4 Hz, and the slow gain term has a Rician factor K_s whose gain variance s_s is from 1 dB up to 12 dB with f_d of 0.03~0.04 Hz. The probability density function (pdf) of the channel gain is jointly determined by the above two gain terms. The Rician factors of the two gain terms can be empirically determined by $K_f = 1343/s_f^2$ and $K_s = 860/s_s^2$. In a typical fixed wireless channel, which is prevalently appeared in experimental measurement data, the values of K_f and K_s are all set to 13.

By using the SNR pdf of Rician fading and the pdf of product random variable, the SNR pdf $f_\Gamma(g)$ of the received signal over a fixed wireless channel can be calculated by

$$f_\Gamma(g) = \int_0^\infty \frac{1+K_f}{g_0 x} \exp\big(-K_f - x(1+K_f)\big) I_0\left(2\sqrt{x(K_f^2 + K_f)}\right) \\ (1+K_s)\exp\left(-K_s - \frac{g}{g_0 x}(1+K_s)\right) I_0\left(2\sqrt{\frac{g}{g_0 x}(K_s^2 + K_s)}\right) dx, \quad (4)$$

where g_0 is the average E_b/N_0 (energy per bit to the noise spectral density ratio).



(i) Without Tx power control (ii) With Tx power control

Fig 2. SNR distribution of the received signal in fixed wireless channel

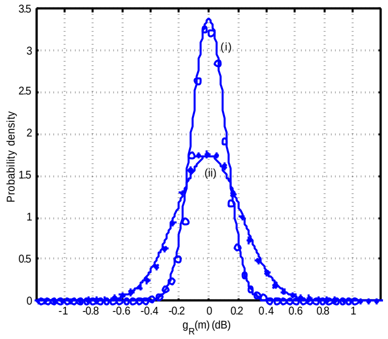


Fig.3 Distribution of $g_R(m)$ in typical fixed wireless channel: (i) $f_d T_F = 0.0108$, (ii) $f_d T_F = 0.0216$

3. Performance analysis

The BER of Gray-coded QAM signals with a lattice type signal constellation in an AWGN channel can be approximated by $P_G(g) = a\,\mathrm{erfc}(\sqrt{bg}) - c\,\mathrm{erfc}^2(\sqrt{bg}) \approx a\,\mathrm{erfc}(\sqrt{bg})$ where $\mathrm{erfc}(\cdot)$ denotes the complementary error function, $a = 3/8$, $b = 2/5$ for 16-QAM, $a = 7/24$, $b = 1/7$ for 64-QAM and $a = 15/64$, $b = 4/85$ for 256-QAM. When the gain variation is perfectly compensated only in the Rx, the BER of the QAM receiver in a fixed wireless channel is calculated by

$$P_F(g_0) = \int_0^\infty P_G(g) f_\Gamma(g)\, dg = \int_0^\infty a\,\mathrm{erfc}\big(\sqrt{bg}\big) f_\Gamma(g)\, dg. \quad (5)$$

The transmitter power is controlled according to channel gain variation so as to maintain a constant E_b/N_0 in the receiver. Assume that the maximum power control range is $\pm 10 \log G$ (dB) with respect to the reference power S_T. To analyze the BER performance of the proposed scheme, it is required to calculate the pdf of the SNR of the received signal after power control. Fig. 2 illustrates the SNR distribution of received signal in a fixed wireless channel.

When the variation of the channel gain is within the power control range, the gain distribution of the received signal can be approximated by a log-normal random variable since the transmitted power compensates the previous channel gain variation due to feedback path delay. Fig. 3 indicates the distribution of the received signal gain $g_R(m)$ in a fixed wireless channel when $f_d T_F = 0.0108$ and 0.0216. When the gain variation of the channel is larger than the maximum power control range, the gain of the received signal is only level-shifted by an amount of the maximum gain control.

Therefore, the BER of QAM signals with the use of Tx power control can be approximately calculated by

$$P(g_0) = \frac{a}{G}\int_0^{g_0-d_1} \mathrm{erfc}\left(\sqrt{bg}\right) f_\Gamma\left(\frac{g}{G}\right) dg + Ga\int_{g_0+d_2}^{\infty} \mathrm{erfc}\left(\sqrt{bg}\right) f_\Gamma(Gg)\, dg$$
$$+ a\frac{10}{\ln 10}\frac{C}{\sqrt{2p}\,s}\int_{g_0-d_1}^{g_0+d_2} \mathrm{erfc}\left(\sqrt{bg}\right)\frac{1}{g}\exp\left(-\frac{(10\log g - m_0)^2}{2s^2}\right) dg\,. \qquad (6)$$

where $m_0 = 10\log g_0$, s is empirically determined by a value equal to $s_f f_d T_F$, $C = \int_{g_0/G}^{Gg_0} f_\Gamma(g)dg$, and d_1 and d_2 are the variance of target SNR after power control.

4. Performance Evaluation

We assume that the proposed multi-level QAM scheme is operating in 2 GHz band with 200 kHz channel spacing and 160 kbaud symbol rate. The modulation scheme may be 16-QAM, 64-QAM and 256-QAM. The basic TDMA frame length is 36 ms. Each frame accommodates 16 time slots. In the case of frequency selective fading, we assume 2-ray fixed wireless channel that the ratio of the average power of delayed path and the average power of direct path is -15 dB and -20 dB, and the maximum delay time is $t_{\max} = 1\,T_S$

Since decision feedback equalizer (DFE) has excellent performance on frequency selective channel characteristics, we consider the DFE with $T_S/2$-spaced feed-forward filter (FFF) and T_S-spaced feedback filter (FBF). For the consideration of the maximum delay time, a DFE with 4-tap FFF and 1-tap FBF is sufficient to handle the channel dispersion. Since one time slot cannot allocate hundreds of equalizer training symbols, the recursive least squares (RLS) algorithm was used.

As the maximum power control range increases, the BER performance can be improved since the region beyond the power control range is decreased. Fig. 4 depicts the performance degradation of the proposed QAM transceivers in a typical fixed wireless channel compared to in AWGN channel in terms of the maximum power control range. It can be seen that the maximum power control range need to be determined depending upon the desired BER.

If the fixed step size is used for power control, the transmitter incrementally updates Tx power by pre-determined step $d(m) = d$ in dB according to the power command bit.

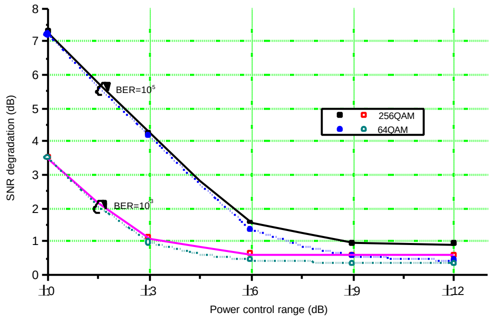


Fig. 4 Performance of the proposed QAM transceiever due to maximum power control range

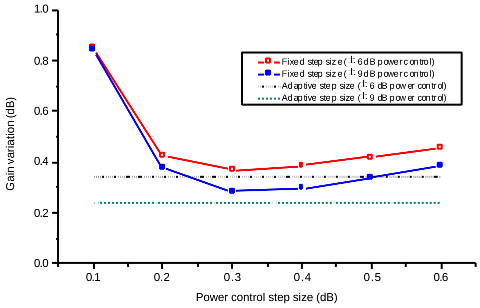


Fig. 5 Standard deviation of 256-QAM signal power after Tx power control

To adaptively control the incremental gain using a single bit, we consider the use of multiplicative adaptation as in constant factor delta modulation (CFDM) with a 2-bit memory. Given binary power command bit $d(m)$, the incremental updated power in dB is determined by $d(m) = Md(m-1)$ where M is determined from a set of four multipliers 0.9, 0.4, 1.5, 2.0 according to the value of $d(m), d(m-1)$ and $d(m-2)$. If the incremental updated power in dB scale is determined, the incremental gain in the Tx is calculated by $\Delta g_T(m) = 10^{d(m)/20}$. Fig. 5 depicts the gain fluctuation of the received signal when various power control step size are used for 256-QAM signal with $T_f = 36$ ms over a typical fixed wireless channel. It can be seen that the gain variation of received signal after power control is reduced as the maximum power control range increases. It is also seen that the performance is quite sensitive to the step size when the fixed step size is used. However, the use of adaptive step size shows the superior performance to any other fixed step size.

Fig. 6 depicts the BER performance of conventional QAM receiver without power control over a typical fixed wireless channel with $T_F = 36$ ms. It can be seen that BER performance is approximately 7 dB inferior to that in an AWGN channel at a BER of 10^{-5} in the case of flat fading. In the case of frequency selective fading, however, high level QAM is more sensitive to the power of delayed path.

Fig. 7 shows the BER performance of the proposed QAM transceiver over a typical fixed wireless channel with flat fading in terms of maximum power control range. In the case of ±6 dB power control, the performance is about 1.5 dB inferior to that in the AWGN channel. In the case of ±9 dB power control, it can be seen that the BER performance nearly aproaches that in the AWGN channel within only 1 dB loss.

Fig. 8 shows the BER performance of the proposed QAM transceiver over a typical fixed wireless channel with frequency selective fading. Simulation results show that the performance degradation of proposed QAM transceiver is more sensitive to maximum power control range. In the case of ISI with -15 dB, the use of ±6 dB power control provides the BER performance of the proposed QAM transceiver about 3~4 dB inferior to that in the AWGN channel at a BER of 10^{-5}. However, the use of ±9 dB power control shows the performance degradation of only within 1~1.5 dB.

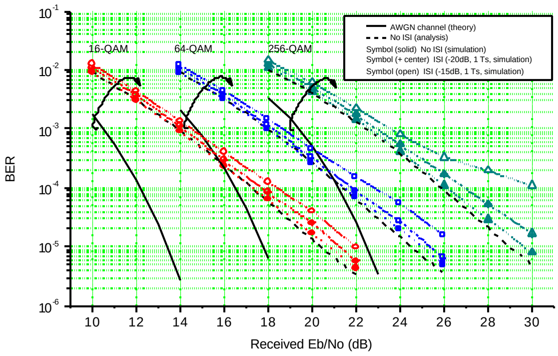


Fig. 6 BER performanc without power control in typical fixed wireless channel

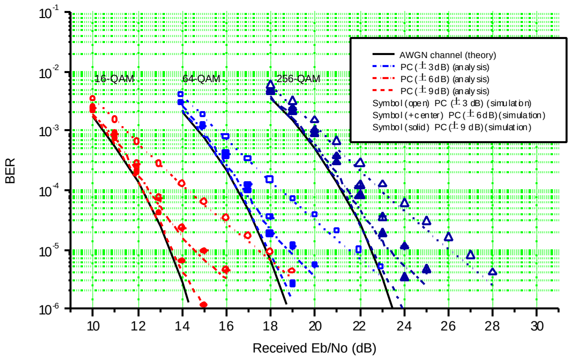


Fig. 7 BER performance of the proposed QAM transceiver in typical fixed wireless channel with flat fading

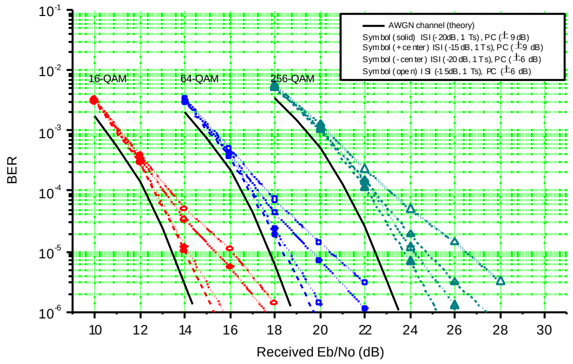


Fig. 8 BER performance of the proposed QAM transceiver in typical fixed wireless channel with frequency selective fading

5. Conclusion

We have proposed the use of power control in the Tx for employment of multi-level QAM schemes in fixed wireless channel with flat fading and frequency selective fading. The use of power control in the Tx, which adapts itself to the short-term fading, can provide improved BER performance. With the characterization of fixed wireless channel, the analytical BER expressions of the proposed multi-level QAM transceivers are derived. Anlaytical and simulation results show that the BER performance of proposed QAM transceiver in typical fixed wireless channel nearly approches that in AWGN channel if optimized power control parameter is used.

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