On Enhancing Hierarchical Modulation

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***Abstract*—Hierarchical modulation offers an important coverage/throughput tradeoff for wireless communication, however it has received relatively little attention to date. Traditional hierarchical modulation suffers from the interference between layers. It results in both low achievable capacity and high bit-error rate. In this paper, an enhanced hierarchical modulation technique along with three optimization schemes are presented and discussed. The proposed enhanced hierarchical modulation, in which the enhancement-layer signal constellation is rotated, can help achieve high performance with minimizing inter-layer interference. For achieving the goals, three schemes are proposed from different perspectives of hierarchical modulation and demodulation. The first scheme is straightforward. It is proposed for maximize the achievable spectral efficiency with rotating the enhancement-layer signal constellation. The second one is proposed for lowering the demodulation symbol-error rate with maximizing the modulation efficiency and asymptotic modulation efficiency, which are suggested by us for quantizing the effect of inter-layer interference. The last approach is suggested for maximizing RF power amplifier efficiency with reducing the peak-to-average-power ratio of modulated symbols. This approach is especially critical for multi-carrier communications. All proposed schemes are simple and efficient. They can help recover the performance loss of regular hierarchical modulation with little complexity increase. Computer simulations are provided to support our conclusions.**

I. INTRODUCTION

Broadcast multicast service (BCMCS) has increasingly been popular for delivering multimedia content to mobile users. BCMCS can be implemented through either a dedicated digital broadcast infrastructure like DVB-T/H/S2, MediaFLO and DMB or a 3rd generation and beyond radio access network like UMTS or cdma2000 network. Traditional digital broadcast air interface and network are designed with the tradeoff between maximum achievable capacity and intended coverage in mind. Their throughput is limited by the maximum transmit power and the worst channel condition so that each user in the coverage area can reliably receive services. This means that all covered users share services with same quality. The users under good reception condition may not have many advantages, even though their achievable throughput can be much higher or they can afford more advanced signal processing capability. Furthermore, it is known that the reception condition of mobile users usually changes all the time. Therefore, it is interesting to provide users with differentiated quality of services (QoS's) based on not only the content they requested but also the receiver capability as well as their reception conditions. On the other hand, there are also rising interests in upgrading existing digital broadcast systems with more services for new users while be able to keep existing users unchanged, delivering additional or better QoS's to users with advanced receivers while still be able to guarantee other users' services, and providing unequal protection on digital contents with high spectral efficiency [1], [2], [3], [4]. Many technologies are under investigation for these goals, e.g., rateless coding, hierarchical modulation, multiple-input multiple-output (MIMO) and selective retransmission. Backward compatibility and implementation complexity are among the major concerns in upgrading existing systems. Since there are a large number of users already served by existing systems, it is prohibitively expensive to simply replace existing user equipments by next-generation ones. It is expected that existing receivers are able to continue to operate in upgraded systems, even though they are not able to receive supplemental services provided by upgraded networks. On the other hand, there always are power consumption and computation complexity concerns in receiver design. And this is especially important for mobile terminal design. Hierarchical modulation is one of the promising technologies for upgrading existing systems while maintaining strictly backward compatibility. One of the key advantages of hierarchical modulation is the added complexity and cost is low. It has been proven and included in various standards, such as DVB-T [1], MediaFLO [2], UMB (Ultra Mobile Broadband, a new 3.5th generation mobile network standard developed by 3GPP2) [4], etc, and is under study for DVB-H.

Hierarchical modulation, also called layered modulation, is one of the techniques for multiplexing and modulating multiple data streams into one single symbol stream, where the base-layer symbols and enhancement-layer symbols are synchronously overlapped together before being transmitted. When hierarchical modulation is employed, users with good reception and advanced receiver can demodulate more than one layer of data streams. For a user with conventional receiver or poor reception, it may be able to demodulate the data streams embedded in low layer(s), e.g, the base layer only. From an information-theoretical perspective, hierarchical modulation is taken as one of the practical implementations of superposition precoding, which can help achieve the maximum sum rate of Gaussian broadcast channel with employing interference cancellation by receivers. From a network operation perspective, a network operator can seamlessly target users with different services or QoS's with this technique. However, traditional hierarchical modulation suffers from inter-layer interference (ILI) so that the achievable rates by low-layer data streams, e.g. the base-layer data stream, can be dented by the interference from high-layer signal(s). For example, for the hierarchically modulated two-layer symbols with a 16QAM base layer and a QPSK enhancement layer, the base-layer throughput loss can be up to about 1.5bits/symbol with the total receive signal-to-noise ratio (SNR) of about 23 dB. This means, due to ILI, there is about 1.5/4 = 37.5% loss of the base-layer achievable throughput with 23dB SNR. Furthermore, the demodulation error rate of either the base-layer and enhancement-layer symbols increases too. Therefore it is interesting to study the approaches for recovering the performance loss of regular hierarchical modulations. Furthermore, multicarrier transmission, e.g. orthogonal frequency-division multiplexing (OFDM), is widely used for BCMCS as well as next generation wireless systems, due to its high diversity gain and high spectral efficiency with simple receiver design. However, the advantages of OFDM, specially when it is modulated by high-order signal constellations, are counter-balanced by the high peak-to-average-power ratio (PAPR) issue. High PAPR of modulated signals can significantly reduce the average output power of the high-power amplifier (HPA) at the transmitter due to more back-offs. It also increases the receiver demodulation and decoding errors and therefore limits the throughput of whole transceiver chain. Therefore, it is important to understand how hierarchical modulation affects the PAPR of multicarrier modulations.

In order to recover the capacity loss due to ILI as well as possible high PAPR, an enhanced hierarchical modulation and three associated optimization schemes are presented and analyzed in this paper. With the proposed hierarchical modulation, the signal constellation of enhancement layer is rotated so that better performance, such as high throughput, low error rate and high power efficiency, is achievable. For achieving these, three approaches are presented and discussed. The first approach is proposed from an information-theoretical perspective for restoring the capacity loss with maximizing the achievable spectral efficiency. It is pretty straightforward. However, from a signal-processing perspective it is known that the performance loss of hierarchical modulation is also related to the resulted Euclidean distance profile of signal constellation. For tracking the Euclidean distance profile change, several parameters like effective signal power, effective SNR and modulation efficiency are proposed. And the second approach is to minimize demodulation errors with maximizing the modulation efficiency of hierarchical modulations. The last approach is more from an implementation perspective with considering the transmit power efficiency for multicarrier communication. With avoiding high back-offs and maximizing average output power, it shows that high transmit power efficiency is achievable by optimizing hierarchical modulation. Above all, one of the most important advantages of the proposed enhanced hierarchical modulation is the incurred implementation complexity is low. This makes it attractive and easy to be employed in actual system implementations. The proposed enhancement was adopted in UMB by 3GPP2 [4]. Though the schemes proposed here can straightforwardly be generalized for most hierarchical modulations and multicarrier transmission schemes, the following discussion will be limited to two-layer signal constellations over OFDM with QPSK-modulated enhancement layer and QPSK- or 16QAM-modulated base layer. The reason for this is not only because of the simplicity of QPSK and 16QAM modulations over OFDM but also because QPSK and 16QAM as well as OFDM are among the most popular signal constellations and transmission schemes adopted in various digital communication systems and standards. It is shown that the use of QPSK as enhancement layer can yield significant performance gain with our approaches. On the other hand, many high-order regular or hierarchical signal constellations may be decomposed into multiple QPSK signals adding together and most results for OFDM can be applied to other multicarrier transmission too.

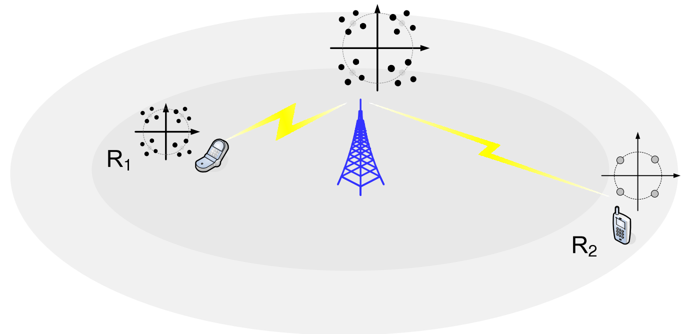


Fig. 1. A broadcast channel model with two coverages and the enhanced QPSK/QPSK hierarchical modulation.

II. System Model And Problem Description

Instead of the traditional single-coverage broadcast model, a broadcast channel model with two coverages is considered here, which is illustrated in Fig. 1. In this model, the broadcast station (BS) transmits signals to all mobile stations (MS) in the covered area. The MS's located near to the coverage edge may only be able to reliably decode the data stream of a low rate R_1 while the MS's close to the BS can possibly decode multiple data streams with a high sum rate R_2. For achieving this, hierarchical modulation is employed by BS so that the modulated symbol stream comprises two synchronously superposed subsymbol streams. The rationale behind it is the finding from the study of broadcast channel capacity, which states that with superposition precoding (SPC) a little throughput sacrifice on the users near to the coverage edge may lead to a big increase for the users with good reception [6]. This concept is illustrated in Fig. 2, where the achievable rates of two multiplexing schemes, time-division multiplexing (TDM) and SPC, are plotted and compared. It shows that SPC can outperform TDM most of the time and with moving up the network operation point $(R_1,\ R_2 - R_1)$ a little bit along the SPC curve a much higher sum throughput R_2 is achievable. And hierarchical modulation can be taken as a practical implementation of SPC.

The signal constellations of regular square-shaped QPSK/QPSK and 16QAM/QPSK hierarchical modulation are

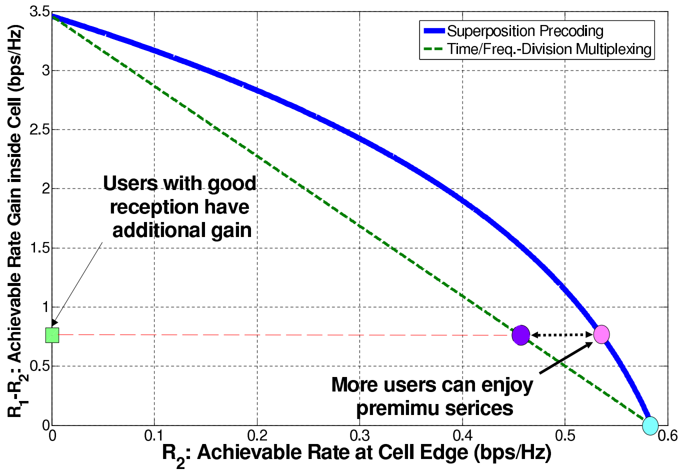
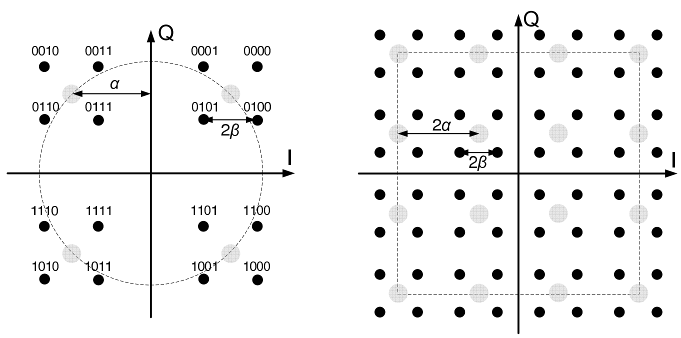


Fig. 2. Achievable capacity region of broadcast channel.



(a) Regular QPSK/QPSK Hierarchical Modulation

(b) Regular 16QAM/QPSK Hierarchical Modulation

Fig. 3. Regular hierarchical modulation examples: the base layer is QPSK/16QAM and the enhancement layer is QPSK.

shown in Fig. 3 [1]. The minimum Euclidean distance (MED) of base layer and enhancement layer are denoted by 2α and 2β, respectively [2]. With superimposing base-layer signal and enhancement layer signal together, the MED of resulted two-layer hierarchical modulation becomes

$$d_{\min} \;=\; \min\left\{2\left(\alpha-\beta\right),\;2\alpha,\;2\beta\right\} \;<\; 2\alpha\;. \qquad (1)$$

When the MEDs of the base-layer and enhancement-layer signal constellations satisfying $\alpha = 2\beta$ the regular QPSK/QPSK hierarchical modulation becomes the regular 16QAM. And smaller MED usually results in more ambiguity and more demodulation errors especially when ζ is large. The power-splitting ratio ζ between the enhancement layer and the base layer is defined by

$$\zeta \;=\; \frac{P_{\rm E}}{P_{\rm B}} \qquad (2)$$

with $\zeta < 1$ in most cases. For QPSK/QPSK hierarchical modulation, the power-splitting ratio is $\zeta_{\text{QPSK/QPSK}} = \frac{\beta^2}{\alpha^2}$. For 16QAM/QPSK modulation, $\zeta_{\text{16QAM/QPSK}} = \frac{\beta^2}{4\alpha^2}$. When $\zeta_{\text{QPSK/QPSK}} = \frac{1}{4}$, the QPSK/QPSK modulation in Fig. 3(a) becomes regular square-shaped 16QAM. In general, the enhancement-layer signal can be taken as additional noise by base layer. This means most existing conventional receivers can continue to demodulate base-layer signals with no additional change but at a lower signal-to-noise-and-interference ratio (SINR) $\hat{\gamma}$ defined by

$$\hat{\gamma} \;=\; \frac{P_{\rm B}}{P_{\rm E}+\sigma^2} \;<\; \gamma \;=\; \frac{P_{\rm B}}{\sigma^2} \qquad (3)$$

with the background additive Gaussian white noise (AWGN) power σ^2.

III. The Enhanced Hierarchical Modulation

Regular hierarchical modulation may seriously suffer from ILI, which not only decreases the base-layer SINR from γ to $\hat{\gamma}$ but also lowers the achievable spectral efficiency. It is well-known that the achievable throughput of a hierarchical modulated signal essentially depends on the power distribution profile of the signal [5] in signal space. This somehow is similar to channel coding. From a channel coding point of view, higher throughput is achievable by the *i.i.d. Gaussian code* defined in coding space, even though it may not be implementable from an engineering standpoint. How to transmit a signal close to Shannon channel capacity and implementable in a relatively easy way is not only critical for the signal constellation design but also every other component in a communication system, including modulating signals.

In order to increase channel capacity with minimum complexity increase, we proposed to optimize the signal constellation of hierarchical modulation with optimally rotating the enhancement-layer signal constellation for improving the spectral efficiency, decreasing demodulation errors and increasing transmit power efficiency. For the QPSK/QPSK hierarchical modulation shown in Fig. 3(a), the QPSK signal constellation of the enhancement layer is rotated in counter-clockwise by θ, $0 \le \theta \le \frac{1}{4}\pi$, and resulted signal constellation is shown in Fig. 4(a). For 16QAM/QPSK signal constellation, the regular and enhanced hierarchical modulations are shown in Fig. 3(b) and Fig. 4(b), respectively. Now the question becomes how to choose the parameter θ for each modulation. In the following, three schemes are proposed from different perspectives of signal modulation and demodulation.

IV. Optimizing Hierarchical Modulation

A. Maximizing Achievable Rates

In general, the achievable rate of a N-ary modulated signal, of either regular or hierarchical signal constellation, through AWGN channel is given by [5]

$$\begin{aligned} R \;=\;& \log_2\left(N\right) - \\ & \frac{1}{N}\sum_{i=0}^{N-1} \mathrm{E}\left\{\log_2\left[\sum_{j=0}^{N-1} e^{-\frac{|s_j+n-s_i|^2-|n|^2}{2\sigma^2}}\right]\right\}\;. \end{aligned} \qquad (4)$$

This is the achievable rate when a receiver tries to decode the whole hierarchically modulated symbol. With (4), the AWGN

[1]In this paper, a hierarchical modulation is denoted by *layer 0 (or base layer) constellation / layer 1 constellation / . . .* , where the signal constellation of different layers are separated by backslash from the lowest layer (also called base layer) to the highest layer.

[2]Without loss of generality, it is assumed that $\alpha \ge \beta$ in most cases.

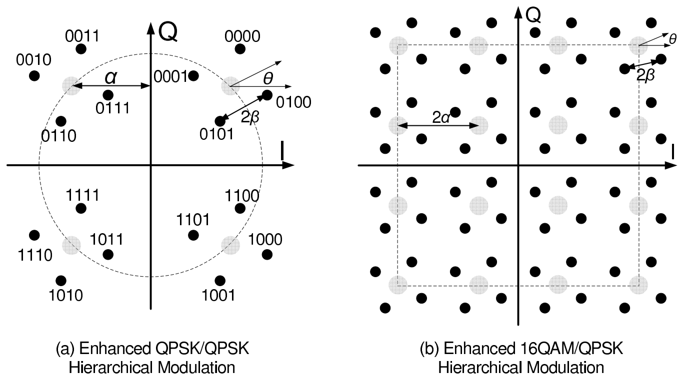


Fig. 4. Enhancing hierarchical modulation by rotation.

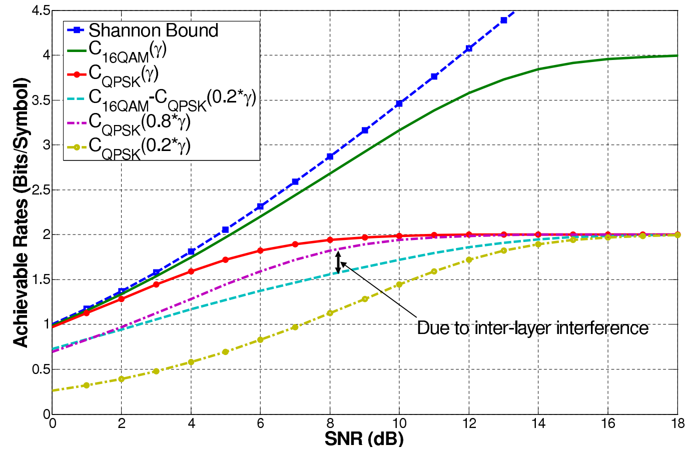


Fig. 5. Achievable rates of regular 16QAM modulation: a hierarchical modulation perspective.

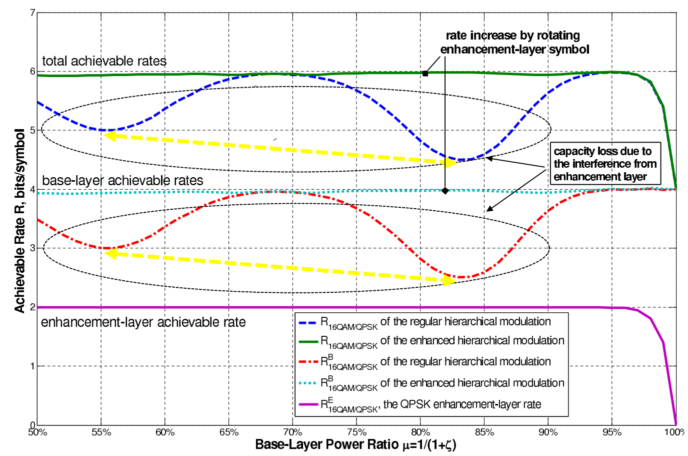


Fig. 6. Achievable rates of 16QAM/QPSK hierarchical modulation with different power splitting and $\frac{P}{\sigma^2} = 20$dB.

capacity of regular QPSK and 16QAM can be plotted in Fig 5. Though the rate in (4) is achievable for a user capable to decode the whole constellation, it is more than achievable for a user with a conventional receiver and detecting the base-layer signals only. The achievable rate of either base layer or enhancement layer along is lower than the total rate in (4). Following the concept of the successive interference cancellation, the achievable rate, also termed *equivalent capacity*, for a receiver decoding up to l layers of a hierarchical modulated symbol is [7]

$$\tilde{R}_l \;=\; \sum_{i=0}^{l-1} R_i \;=\; R - \sum_{j=l}^{L} R_j \;. \tag{5}$$

To illustrate this, let's take the regular 16QAM as an example since a regular 16QAM can be take as a special case of QPSK/QPSK hierarchical modulation with $\zeta_{\text{QPSK/QPSK}} = \frac{1}{4}$. This means the achievable rate of the enhancement layer is the same as the regular QPSK capacity but the achievable rate of the QPSK base layer becomes

$$\begin{aligned} \mathrm{R}^{\mathrm{B}}_{\text{QPSK/QPSK}}\left(\gamma,\ \tfrac{4}{5}\right) &= \mathrm{R}_{\text{QPSK/QPSK}}\left(\gamma,\ \tfrac{1}{4}\right) - \mathrm{R}_{\text{QPSK}}\left(\tfrac{1}{5}\gamma\right) \\ &= \mathrm{R}_{\text{16QAM}}\left(\gamma\right) - \mathrm{R}_{\text{QPSK}}\left(\tfrac{1}{5}\gamma\right) \;, \end{aligned} \tag{6}$$

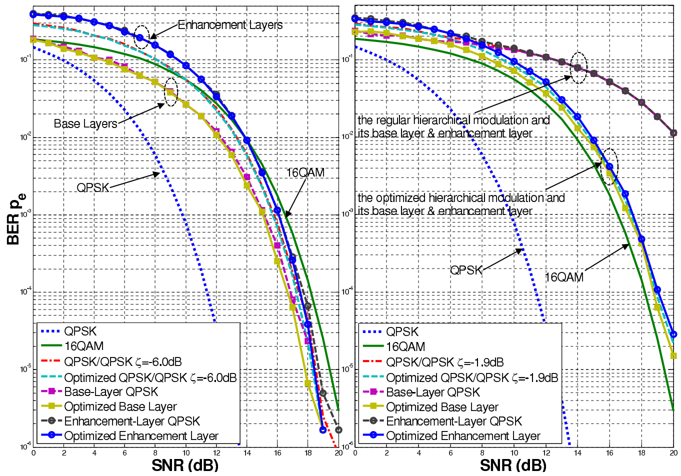
where $\mathrm{R}^{\mathrm{B}}_{\text{QPSK/QPSK}}\left(\gamma,\ \frac{4}{5}\right)$ denotes the achievable rate of the base-layer of a QPSK/QPSK hierarchical modulation with total SNR γ and the power fraction $\frac{4}{5}$. It is plotted in Fig 5 too. Due to the ILI from the QPSK-modulated enhancement layer, it shows that the actual throughput of the QPSK base layer $\mathrm{R}^{\mathrm{B}}_{\text{QPSK/QPSK}}\left(\gamma,\ \frac{4}{5}\right)$ is lower than the corresponding QPSK rate $\mathrm{R}_{\text{QPSK}}\left(\frac{4}{5}\gamma\right)$, i.e.,

$$\mathrm{R}^{\mathrm{B}}_{\text{QPSK/QPSK}}\left(\gamma,\ \tfrac{4}{5}\right) \;\leq\; \mathrm{R}_{\text{QPSK}}\left(\tfrac{4}{5}\gamma\right) \;. \tag{7}$$

This kind of degradation can be further illustrated in Fig. 6, where the hierarchical modulation is 16QAM/QPSK-modulated with the 16QAM-modulated base layer. In Fig. 6, the achievable rates of each layer and the whole signal constellation are plotted with the total SNR fixed at $\frac{P}{\sigma^2} = 20$dB and the power of the 16QAM sublayer changing from 50% to 100% of the total power P. One of the interesting things shown in Fig. 6 is the equivalent capacity of the 16QAM base layer changes periodically instead of monotonically with increase the power ratio of the base layer. One of the good things in Fig. 6 is this kind of capacity loss can be recovered by optimally rotating the enhancement layer. This is one of the advantages of the proposed enhanced hierarchical modulations.

B. Maximizing Modulation Efficiency

Besides the above information-theoretical point of view on hierarchical modulation, it is also interesting to understand hierarchical modulation from a practical signal-processing perspective. At this time, the performance of hierarchical modulation will be evaluated through an actual implementation, where demodulation error is one of the major concerns. In general, it is difficult to give a simple closed-form BER or symbol-error rate (SER) expression for hierarchical signal constellation, which also depends on receiver design and bits-to-symbol mapping. The BER of square-shaped M-QAM constellation and a hierarchical QAM constellation for maximum likelihood (ML) demodulator can be computed by using recursive algorithms [8]. For a simple QPSK modulation,



a) ζ=0.25 b) ζ=0.65

Fig. 7. Bit-error rate of uncoded QPSK/QPSK hierarchical modulations using maximum likelihood demodulation .

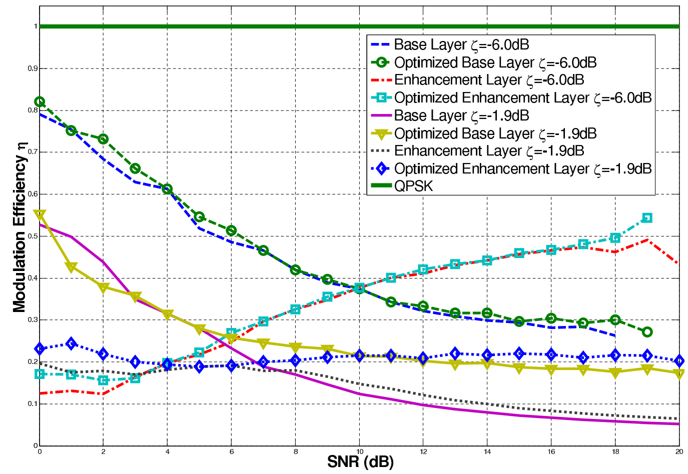


Fig. 8. Hierarchical modulation efficiency of QPSK/QPSK hierarchical modulation using maximum likelihood demodulation.

tt is known that the BER is

$$\mathrm{P}_{e,\text{QPSK}}\left(\gamma\right) \quad = \quad \mathrm{Q}\left(\sqrt{\tfrac{\gamma}{2}}\right) \ , \tag{8}$$

where $\mathrm{Q}\left(x\right) = \frac{1}{2}\mathrm{erfc}\left(\frac{x}{\sqrt{2}}\right)$ denotes the Q-function.

From a signal processing standpoint, demodulation error and capacity degradation may happen when there is a change of interference distribution, even though the received SNR γ is the same. The BER performance of regular QPSK/QPSK becomes deteriorated in Fig. 7 when $\zeta_{\text{QPSK/QPSK}}$ increases. However, with optimally rotating the enhancement-layer signal constellation, the performance loss can be recovered. This kind of recovery is more significant with large ζ. In order to quantify and understand this kind of BER performance loss due to interference and receiver design, one approach we propose for capturing this kind of degradation is to calculate the effective signal-to-noise ratio (ESNR) of the whole transceiver chain, which is defined by

$$\tilde{\gamma}\left(\gamma\right) \quad \equiv \quad \Psi^{-1}\left(p_e(\gamma)\right) \ , \tag{9}$$

where $p_e(\gamma)$ is the demodulation BER of the signal with SNR γ, and $\Psi^{-1}\left(*\right)$ denotes the inverse function of $\Psi\left(\cdot\right)$, the demodulation error probability function with no ILI. The ESNR for the QPSK-modulated base layer or enhancement layer of any hierarchical modulation can be calculated by

$$\tilde{\gamma}_{\text{QPSK/QPSK}} \quad = \quad 2\left[\mathrm{Q}^{-1}\left(p_e(\gamma)\right)\right]^2 \ . \tag{10}$$

More specifically, the ESNR for the base layer of regular QPSK/QPSK hierarchical modulation with ML demodulator is given by

$$\tilde{\gamma}^{\mathrm{B}}_{\text{QPSK/QPSK}}(\gamma) = 2\left[\mathrm{Q}^{-1}\left(\frac{\mathrm{Q}((1-\sqrt{\zeta})\gamma)+\mathrm{Q}((1+\sqrt{\zeta})\gamma)}{2}\right)\right]^2 . \tag{11}$$

By normalizing ESNR with γ, we can obtain hierarchical modulation efficiency (ME) η by

$$\eta\left(\gamma\right) \quad = \quad \frac{\tilde{\gamma}}{\gamma} \quad = \quad \frac{1}{\gamma}\Psi^{-1}\left(p_e(\gamma)\right) \ . \tag{12}$$

With no interference, $\eta\left(\gamma\right) = 1$; otherwise, $\eta\left(\gamma\right) < 1$. η is also the measure of inter-layer resistance for hierarchical modulation. The high ME value means stronger interference-resistance the modulated signal has. The ME of QPSK/QPSK hierarchical modulation are plotted in Fig. 8. We can see the enhanced hierarchical modulation has higher ME than the regular modulation. The difference is more obvious when ζ becomes large. This means the enhanced hierarchical modulation has the stronger inter-layer interference resistance than that of regular hierarchical modulation.

Furthermore, in order to isolate the noise effect from demodulation/decoding, the asymptotic modulation efficiency (AME) η_∞ is given by

$$\eta_\infty \quad = \quad \lim_{\gamma\to\infty}\eta\left(\gamma\right) \quad = \quad \lim_{\sigma\to 0}\frac{\sigma^2}{P}\Psi^{-1}\left(p_e\right) \ , \tag{13}$$

which is the ME in high SNR region. For the ME in (11), the AME can be calculated by

$$\eta_\infty \quad = \quad \lim_{\gamma\to\infty}\frac{2\left[\mathrm{Q}^{-1}\left(\frac{\mathrm{Q}((1-\sqrt{\zeta})\gamma)+\mathrm{Q}((1+\sqrt{\zeta})\gamma)}{2}\right)\right]^2}{\gamma} . \tag{14}$$

With (13) and (14), it shows that AME indicates how fast ESNR is approaching SNR when $\gamma \to \infty$. This can be expressed by

$$\eta_\infty \quad = \quad \frac{\partial\eta(\gamma)}{\partial\gamma}|_{\gamma=\infty} \ . \tag{15}$$

The AME for QPSK/QPSK hierarchical modulation can also be found in Fig. 8, where they are the points when SNR becomes larger and larger. The AME of a hierarchical modulation only depends on its signal constellation design and is independent to the background noise.

C. Minimizing Peak-to-Average-Power Ratio

Since OFDM has been widely adopted and intensively studied for next-generation wireless systems, it is important to understand how the enhanced hierarchical modulation works with OFDM. Here we investigated the PAPR reduction performance when it is transmitted over OFDM. An OFDM

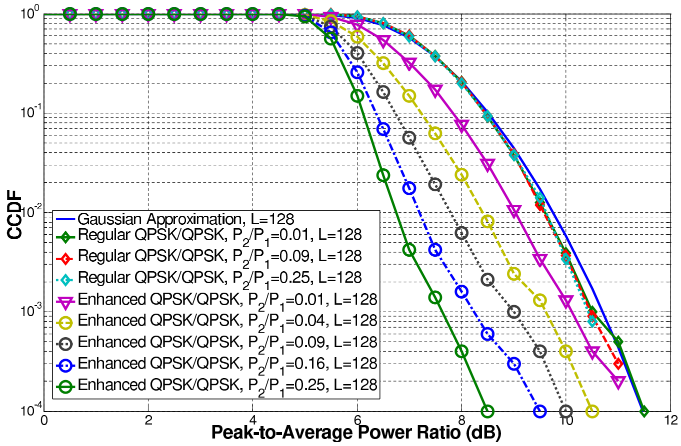


Fig. 9. PAPRs of hierarchical modulations over OFDM with $L = 128$.

signal is the sum of L independent modulated symbols $\{s_l:\ 1 \le l \le L\}$ mapped onto L different subcarriers with the frequency separation $\frac{1}{T}$, where T is the symbol period with no additional overhead such as cyclic prefix (CP) and zero prefix (ZP). At the transmitter side, the discrete time-domain samples $\{x_m:\ 1 \le m \le L\}$ are the inverse fast Fourier transform (IFFT) of the complex symbols $\{s_l:\ 1 \le l \le L\}$:

$$x_m = \frac{1}{\sqrt{L}} \sum_{l=0}^{L-1} s_l e^{j2\pi \frac{ml}{L}} . \tag{16}$$

Before transmission, x_m is usually extended by attaching a CP or ZP. When CP is applied, the extended OFDM symbol

$$\tilde{x}_n = \begin{cases} x_n & 1 \le n \le L \\ x_{n+L} & -L_{cp}+1 \le n \le 0 \end{cases} . \tag{17}$$

The extended OFDM symbol then passes through digital-to-analog converter and pulse-shaping filter before up-converted to the carrier frequency. The PAPR of OFDM signal is usually defined by

$$\xi = \frac{1}{\mathrm{E}\{|x_m|^2\}} \max_m |x_m|^2 , \tag{18}$$

though in practice the PAPR of the analog signal equivalent of $\{\tilde{x}_n:\ -L_{cp}+1 \le n \le L\}$ is more of interest.

The PAPR values of the regular QPSK/QPSK hierarchical modulation and its enhancement are plotted in Fig. 9. It shows that the PAPR of regular hierarchical modulation can be reduced with optimally rotating enhancement-layer symbols. And when the power splitting ratio η becomes larger and larger, the PAPR reduction performance will be more significant.

V. Conclusions

In this paper, one enhanced hierarchical modulation scheme and three optimization approaches are proposed for higher throughput, less error rate and higher power efficiency. One approach is to maximize the spectral efficiency, one approach is to maximize modulation efficiency and the last one is to minimize the PAPR when it is used with OFDM. The rationales as well as the performance of the proposed approaches are analyzed. They can be used for helping upgrade and design BCMCS systems with minimum complexity increase. It is adopted in the 3.5G standard UMB by 3GPP2.

References

[1] DVB Project. Dvb terrestrial (dvb-t): Hierarchical modulation. *http://www.dvb.org/*, March 2000.

[2] FLO Forum and Qualcomm. Flo technology overview: Revolutionizing multimedia. *http://www.floforum.org/*, 2007.

[3] H. Jiang and P. A. Wilford. A hierarchical modulation for upgrading digital broadcast systems. *IEEE Transaction On Broadcasting*, 51(2):223–229, June 2005.

[4] 3GPP2. Ultra mobile broad physical layer. *C.P0084-001*, February 2007.

[5] G. Ungerboeck. Channel coding with multilevel/phase signals. *IEEE Trans. Information Theory*, 28:55–67, January 1982.

[6] T. Cover. Broadcast channels. *IEEE Trans. Information Theory*, 18:2–14, January 1972.

[7] J. Huber and U. Wachsmann. Capacities of equivalent channels in multilevel coding schemes. *Electronics Letters*, 30(7):557–558, March 1994.

[8] P. K. Vitthaladevuni and M.-S. Alouini. A recursive algorithm for the exact ber computation of generalized hierarchical qam constellations. *IEEE Trans. Information Theory*, 49(1):297–307, January 2003.