Adaptive Modulation Techniques to Enhance OFDM System Performance / Original article

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تقنيات التضمين التكيفية لتعزيز أداء أنظمة OFDM

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Abstract

The fourth-generation (4G) mobile communication is supposed to combine a broad coverage of services, including high-speed data, video streaming, multimedia applications and voice transmission, into a single scale. Adaptive OFDM (AOFDM) is among the most popular techniques proposed to meet this objective in which the settings of the transmission are dynamically optimized to the prevailing changing conditions of the channel fading. This paper is concerned with the adaptive modulation in OFDM. We find out the performance of un-coded adaptive modulation on the schemes of QAM and PSK. An effort to use convolutional coding is also integrated into the structure of the OFDM in a bid to enhance reliability. It was found that adaptive modulation is far superior to the conventional fixed-scheme transmission in that it minimizes the frequency of bit error rate (BER) as well as throughput, and this factor demonstrates that adaptive modulation is superior in un-favorable circumstances in wireless communications.

Keywords: 4G mobile, Adaptive, Modulation Techniques, OFDM System, Video streaming.

المستخلص

يُفترض أن تجمع أنظمة الاتصالات المتنقلة من الجيل الرابع (4G) طيفًا واسعًا من الخدمات، بما في ذلك نقل البيانات عالية السرعة، وبث الفيديو، وتطبيقات الوسائط المتعددة، ونقل الصوت، ضمن منصة واحدة متكاملة. وتُعد تقنية OFDM التكيفية (AOFDM) من أكثر التقنيات شيوعًا المقترحة لتحقيق هذا الهدف، حيث يتم فيها تحسين إعدادات الإرسال بصورة ديناميكية بما يتلاءم مع التغيرات السائدة في ظروف تلاشي القناة. يركّز هذا البحث على التضمين التكيفي في أنظمة OFDM، إذ يتم تقييم أداء التضمين التكيفي غير المشفّر باستخدام مخططات QAM وPSK. كما تم دمج استخدام الترميز الالتفافي ضمن بنية نظام OFDM بهدف تعزيز موثوقية الإرسال. وقد أظهرت النتائج أن التضمين التكيفي يتفوق بشكل واضح على أنظمة الإرسال التقليدية ذات التضمين الثابت، من حيث تقليل معدل الخطأ في البتات (BER) وتحسين معدل الإنتاجية (Throughput)، الأمر الذي يبرهن على كفاءة التضمين التكيفي وتفوّقه في الظروف غير الملائمة للاتصالات اللاسلكية.

الكلمات المفتاحية: التكيفية، تقنيات التضمين، نظام OFDM

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique in which a high-speed data stream is decomposed into a large set of parallel data streams, each operating at a reduced transmission rate. These parallel streams are transmitted simultaneously over distinct, mutually orthogonal subcarriers. This structure effectively lowers the symbol rate within each sub-channel, which plays a key role in improving robustness against channel impairments and enhancing overall transmission efficiency. Consequently, this makes the system more resistant to inter-symbol interference (ISI), especially the interference due to multipath propagation and delay spread in wireless communication surroundings [1].

Cycle extension of each of the symbols in the OFDM can ensure the orthogonality of the subcarriers even in the event that the signal is sent over a time dispersive channel. Other strengths of the OFDM are its high resilience to multipath and effective utilization of the spectral because of the overlapping subcarriers. In addition, the computation of modulation and demodulation algorithms can be performed efficiently since IFFT and FFT can be done.

Nevertheless, within frequency-selective and fast fading channels, each of the subcarriers has varying levels of attenuation. In cases that the same mediation scheme is used in all subcarriers, the performance of the modulation scheme is constrained by the worst performing subcarriers, and the BER gradually decays despite the increase in the average SNR [2].

In order to address this shortcoming, varying modulation schemes may be allocated to varying subcarriers. Contrary to adaptive serial systems in which all symbols have the same parameters, adaptive OFDM modulates its parameters on a subcarrier-by-subcarrier basis depending on its current SNR, significantly increasing throughput and reliability [3]. For instance, subcarriers with high error probability may be excluded from data transmission, improving BER at the cost of slightly reduced throughput. The loss can be compensated by applying higher-order modulation to subcarriers with stronger SNR.

Researchers have proposed several adaptive techniques for OFDM since the advanced models developed by [3, 2]. Studies show that the required SNR to achieve a BER of 10^{-3} can be reduced by 5–15 dB compared with fixed OFDM schemes. More works that are recent have examined turbo-coded adaptive modulation [4], predictive BER estimation techniques [5], adaptive pilot spacing [6], and adaptive bit/power allocation in MIMO-OFDM systems [7].

Further exploration of adaptive subcarrier bandwidth [8] and preceded OFDM under multipath conditions [9] reinforces the potential of adaptive strategies to optimize performance. The present paper builds on these foundations by proposing a sub band-based adaptation method and analyzing its performance.

2. System Model

To reduce computational complexity, this study applies sub band-based adaptation, in which adjacent subcarriers are grouped into sub bands, and each sub band uses a single modulation mode [10]. Mode selection for an upcoming OFDM symbol is determined at the receiver using perfect channel estimation and is fed back to the transmitter.

The instantaneous SNR of each subcarrier is evaluated using:

$$R_n = H_n X_n + W_n$$

Where H_n represents the channel coefficient, X_n the transmitted symbol, and W_n Gaussian noise. The channel statistics is then used to estimate SNR [7].

The conventional threshold-based adaptive systems make use of the mode determined by the lowest SNR subcarrier in a sub band [11]. Although conservative, this strategy can easily cause the BER performance to be much higher than target, and thus the throughput potential is wasted. In order to enhance this trade-off, the average SNR of each sub band is taken in the present work, and the mode selection becomes more accurate and efficient [5].

Adaptation process involves computation of sub band SNRs, the comparison of these SNRs against switching thresholds, the process of choice of best mode of modulation/coding and communication of the decision through feedback [12].

2.1 Block Diagram (Rewritten + Human-like + In-text Citations)

The system block diagram is given in Figure 1. The receiver side performs the estimation of the channel as well as mode choice to make sure that mode data which is selected is fed back to transmitter through a feedback connection [12].

This model does frame by frame on the adaptation process. This SNR is used by the mode excluder to place the optimum modulation mode into the following transmission frame [13].

The adaptive modulator in the transmitter is made of multiple modulation units which represent the various modulation schemes and a selection mechanism which decides what scheme to be used depending on the present signal-to-noise ratio (SNR). This adaptive modulation method takes into account two modulation families, i.e. M-QAM and M-PSK, which are applied within their respective modulation block. The adaptive modulation process is primarily aimed at dynamically choosing the most suitable modulation mode per sub and based on the local SNR conditions. The system is capable of doing this adaptive selection to provide a suitable balance between spectral efficiency and acceptable bit error rate (BER), which boosts the overall level of communication performance [14].

2.2 Switching Thresholds

The switching thresholds in the definition of the time in which each mode switches are learnt, following a significant amount of simulation effort on the fixed-mode modulation systems [2].

The adaptive modulation schemes make use of switching rules that are described in Tables 1 - 4 and simulation parameters are described in Table 5.

In this study, two adaptation approaches are examined:

1. Adaptive modulation without transmission blocking, and
2. Adaptive modulation with transmission blocking.

In the non-blocking scheme, data is always transmitted, even when the channel experiences deep fading. Under poor channel conditions, a more robust modulation mode is selected; as the channel improves, a spectrally efficient mode is chosen [3].

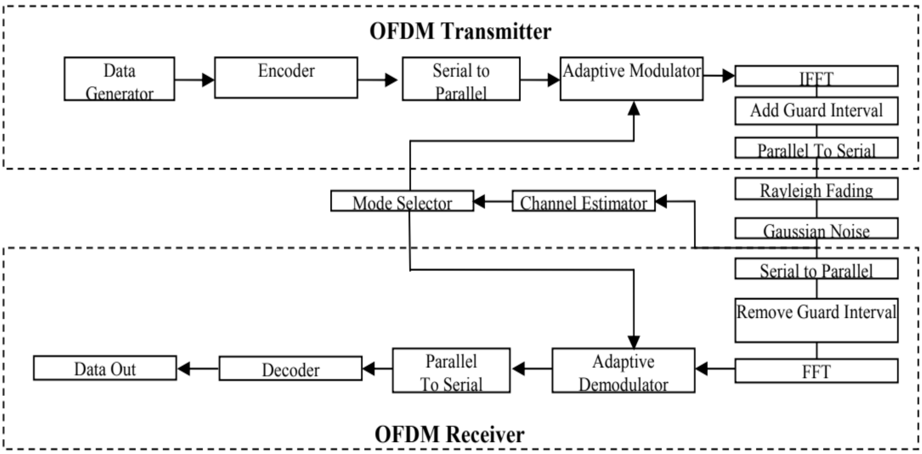

Figure 1. Block diagram

Unlike adaptive modulation schemes that maintain continuous transmission, the transmission-blocking approach temporarily halts data transmission when the channel experiences deep fading conditions. This strategy is adopted to prevent data from being sent over severely degraded channels, where the signal quality is too poor to support dependable communication. By suspending transmission during such intervals, the system avoids excessive error rates and inefficient use of resources, as reliable signal recovery cannot be guaranteed under extreme fading scenarios [13]. Transmission resumes once the SNR improves.

Table 1. MQAM switching without transmission blocking.

Mode	Modulation	Thresholds (SNR)
1	4QAM	SNR ≤ 15.6 dB
2	8QAM	15.6 dB < SNR ≤ 18.6 dB
3	16QAM	18.6 dB < SNR ≤ 21.5 dB
4	32QAM	21.5 dB < SNR ≤ 24.6 dB
5	64QAM	SNR > 24.6 dB

Table 2. Modulation Selection Boundaries for MQAM under Transmission Suspension Conditions.

Modulation Mode	Mode	Thresholds (SNR)
No Tx	1	SNR < 10 dB
4QAM	2	10 dB < SNR ≤ 15.6 dB
8QAM	3	15.6 dB < SNR ≤ 18.6 dB
16QAM	4	18.6 dB < SNR ≤ 21.5 dB
32QAM	5	21.5 dB < SNR ≤ 24.6 dB
64QAM	6	SNR > 24.6 dB

Table 3. MPSK switching without transmission block.

Mode	Modulation	Thresholds (SNR)
1	QPSK	SNR ≤ 16.6 dB
2	8PSK	16.6 dB < SNR ≤ 22 dB
3	16PSK	22 dB < SNR ≤ 28.2 dB
4	32PSK	SNR > 28.2 dB

Table 4. Decision Boundaries for MPSK Modulation under Transmission Blocking Conditions.

Mode	Modulation	Thresholds (SNR)
1	No Tx	SNR < 11 dB
2	QPSK	11 dB < SNR ≤ 16.6 dB
3	8PSK	16.6 dB < SNR ≤ 22 dB
4	16PSK	22 dB < SNR ≤ 28.2 dB
5	32PSK	SNR > 28.2 dB

3. Analysis and Discussion of Adaptive Modulation Performance Metrics

In the section, the adaptive modulation technique performance is analyzed and discussed based on the major performance measurements, throughput and bit error rate (BER). The performance of the adaptive modulation scheme to the different channel conditions is evaluated through the results achieved out of the simulation. To emphasize the advantages of flexibility, the comparison of the performance of adaptive modulation schemes with that of the traditional fixed modulation systems is made in a systematic way. This comparison is a clear evidence of the excellence of adaptive approaches concerning the enhancement of data transmission efficiency and stable error performance in the conditions of diverse operations.

Table 5. System parameters

Parameter	Value
IFFT Size	512
Number of subcarriers	512
Number of subbands	32
Number of subcarriers per subband	16
Guard Time Duration	128
Frame Size	6
SNR	1–30 dB
Modulation Scheme	MPSK, MQAM
Coding Rate	2/3, 1/2, 1/3, 1/4
Bandwidth	5 MHz
Carrier Frequency	2 GHz
Sampling Frequency	5.4 MHz

The analysis commences with the un-coded MQAM and MPSK adaptive schemes, and then results are obtained with the convolutional coding .Lastly, the proposed method is compared to a conservative strategy of adapting [5].

3.1 Adaptive Modulation Techniques Applied to MQAM-Based Systems

3.1.1 Non-Blocking Transmission Strategy in Adaptive MQAM Modulation

In the adaptive scheme that does not include transmission blocking, the BER performance clearly surpasses that of fixed-mode systems, as illustrated in Figure 2. A similar trend was also reported in earlier studies [14].

The adaptive system maintains a BER of approximately 10^{-3} beyond 25 dB SNR, which aligns with the system's design target. Additionally, adaptive modulation reaches the BER requirement at 25 dB, whereas the fixed 4QAM scheme requires more than 28 dB to achieve the same BER.

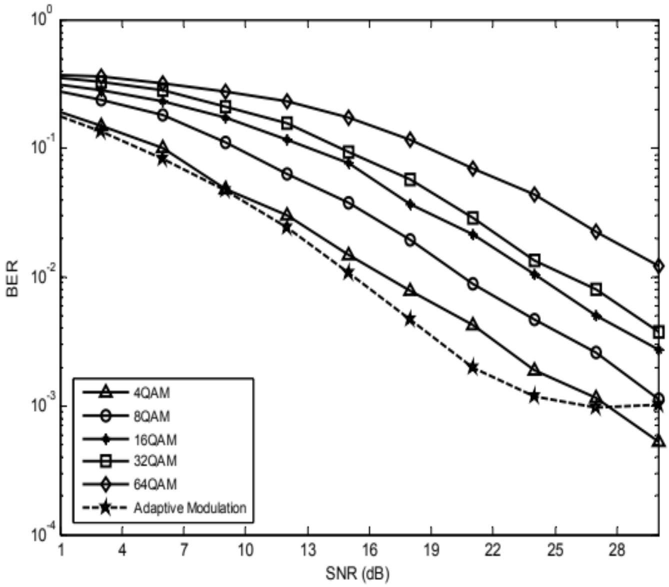

Figure 2. Adaptive modulation non-blocking transmission blocking (AMQAM-Non blocking) BER Performance.

The throughput performance is shown in Figure 3. It is not surprising that no strict OFDM scheme is able to achieve good BER performance as well as high throughput. Fixed system can have greater throughput with such modes as 64QAM, but at the price of unacceptable BER [4]. At low SNR (1-10 dB) throughput is similar to that of 4QAM since it is at this level that the system essentially picks the optimal mode. At SNRs of 10 dB and above, adaptive scheme is superior to fixed systems by a factor of 0.5 Bps/Hz. The adaptive modulation thus offers maximum throughput with the same target of BER determining its suitability in the exploitation of instantaneous channel conditions to assist the overall system performance.

3.1.2 Adaptive MQAM Modulation Incorporating Transmission Blocking Conditions

Incidents like this are reflected in the performance of the adaptive modulation (AM) scheme as reflected in Figure 4 where transmission blocking is used. As indicated, there is an obvious enhancement of BER behavior with the addition of blocking throughout the SNR range [14]. The BER is brought down to an adequate level at all SNR levels to meet the desired BER of 10-3 with transmission blocking. The system switches to blocking mode at low SNR values, blocking any transmission of data, therefore, no error is made and the total BER will be reduced by an enormous margin [13].

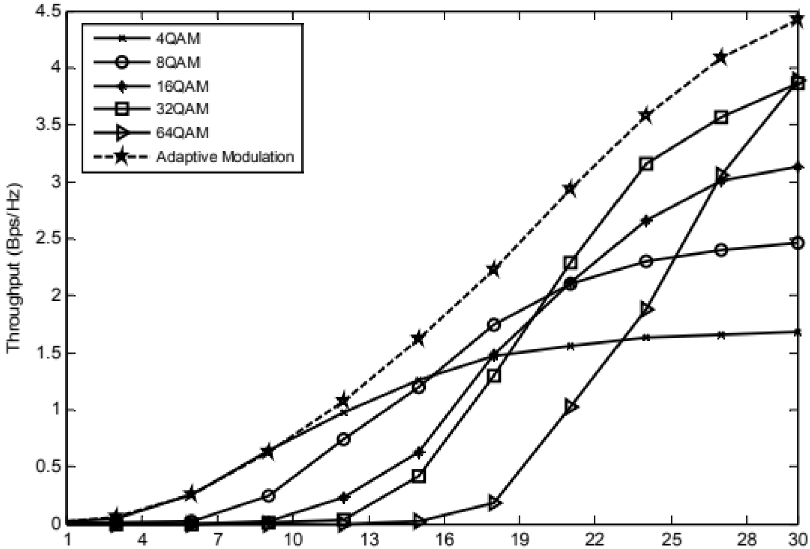

Figure 3. Adaptive modulation with no transmission blocking throughput performance (AMQAM-Non blocking).

Because no symbols are transmitted in the 0–4 dB SNR region, BER values are not recorded in this interval.

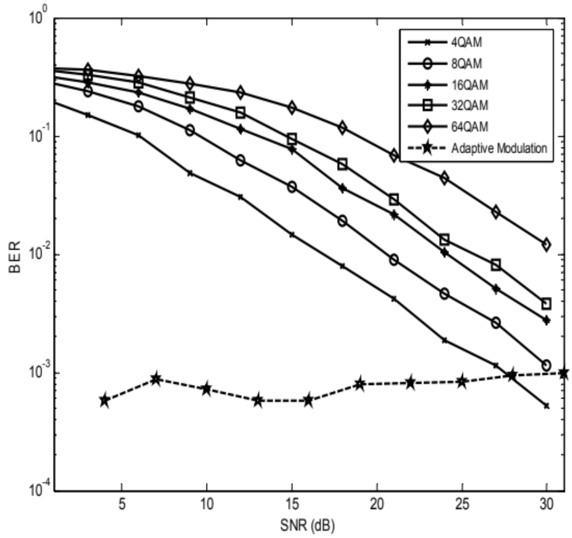

Figure 4. Bit Error Rate Performance of Adaptive MQAM Modulation under Transmission Blocking Conditions.

In regards to throughput, AMQAM-Blocking scheme is more optimal than any fixed-mode system which can be demonstrated in Figure 5. A slight reduction of about 0.3 Bps/Hz in throughput is observed in low SNRs (1-13 dB) and this is because of the large number of subcarriers moving into the no-transmission state [3].

The increase in throughput is also significant above 13 dB where it improves by around 0.5 Bps/Hz. This indicates that transmission blocking can be both reliable and at the same time can be readily adapted to the optimum under good channel conditions.

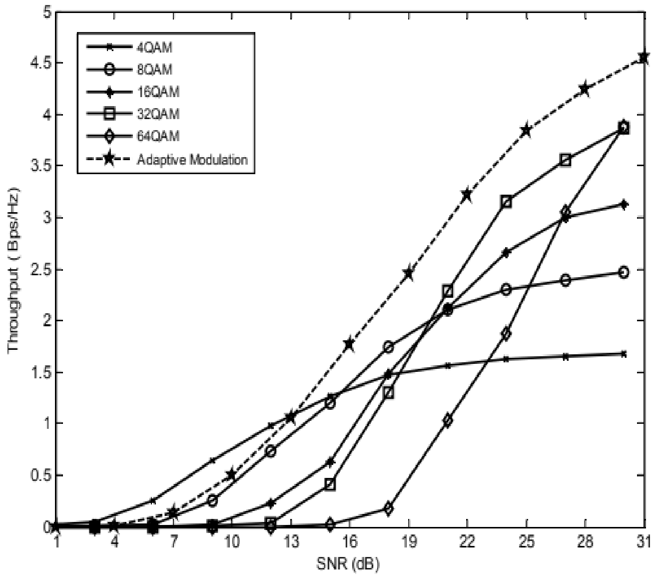

Figure 5. Throughput Performance of Adaptive MQAM Modulation Considering Transmission Blocking.

3.2 Adaptive Modulation Strategies in MPSK-Based Communication Systems

3.2.1 Non-Blocking Adaptive Modulation Approach for MPSK Transmission

The Figure 6 displays the BER of mpsk-based adaptive modulation scheme in the absence of transmission blocking. As shown, the BER curve of the adaptive scheme is the same as the QPSK performance whose SNR range lies between 1 and 15 dB.

The adaptive scheme has been demonstrated as superior to all fixed MPSK modes even at SNR values of over 15 dB. However, the BER-target is still relatively huge SNR-of more than 25 dB-large, which characterizes the drawback of the MPSK-based adaptation against MQAM [2].

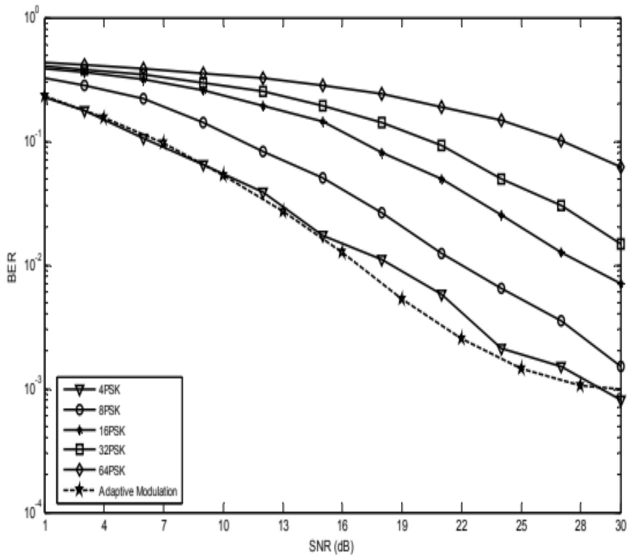

Figure 6. Bit Error Rate Performance of Adaptive MPSK Modulation under Non-Blocking Transmission Conditions.

In Figure 7, it is observed that the throughput of the AMPSK non-blocking scheme is greater than of all fixed MPSK modulation modes. SNR below 11 dB The throughput is the same as in QPSK since the adaptive system always chooses the strongest modulation mode in order to have reliable transmission at low SNR.

Above SNR 11 dB, throughput increases by about 0.3-0.5 Bps/Hz indicating the benefit of adaptive selection at moderate and high SNR.

3.2.2 Adaptive MPSK Modulation Incorporating Transmission Blocking Constraints.

The BER performance of the AMPSK-Blocking scheme is shown in Figure 8. The findings reveal that the adaptive MPSK system is getting closer to the desired target of BER 10-3, yet it demands rather high SNR, more than 25 dB, to be able to do so consistently.

This is because the transmission blocking enhances BER but the advantage does not exceed the nature of MPSK modulation over MQAM.

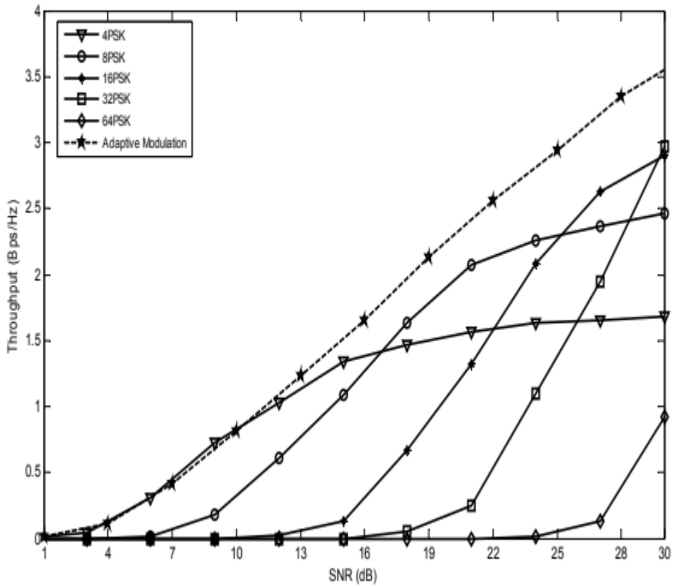

Figure 7. Throughput Performance of Adaptive MPSK Modulation under Non-Blocking Transmission Conditions.

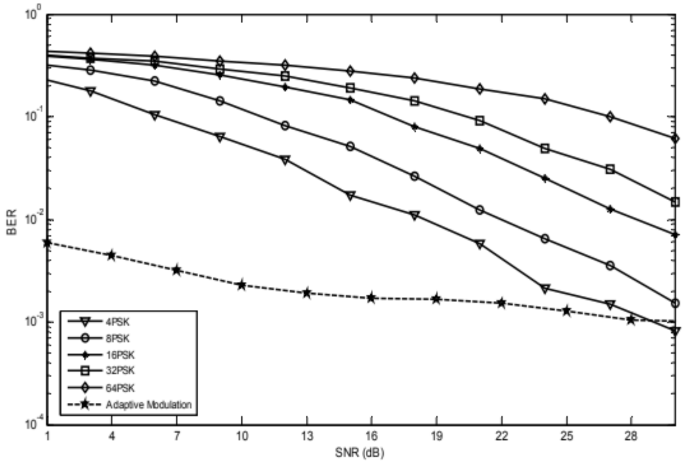

Figure 8. Bit Error Rate Performance of Adaptive MPSK Modulation under Transmission Blocking Conditions.

The respective throughput performance is illustrated in Figure 9. The AMPSK-Blocking system offers gain in throughput as compared to all fixed MPSK schemes in the SNR range.

Nevertheless, the improvement is low in relation to MQAM-based adaptive modulation. The results, on the whole, validate the idea that adaptive schemes of MPSK are less efficient as it takes more SNR to have the same level of performance in the BER given by the schemes based on MQAM.

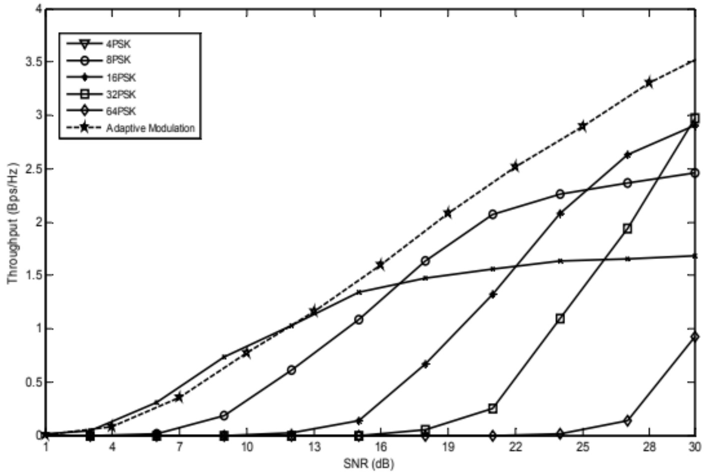

Figure 9. Data Rate Behavior of an Adaptive MPSK Scheme under Transmission Interruption Conditions.

3.3 Integration of Convolutional Coding in Adaptive Modulation Systems

In this section, the application of convolutional coding within adaptive modulation systems is examined. By introducing controlled redundancy into the transmitted data, convolutional coding enables the receiver to detect and correct a portion of the transmission errors. From a theoretical perspective, this additional redundancy leads to a noticeable improvement in bit error rate (BER) performance, particularly under unfavorable channel conditions. Consequently, the integration of channel coding with adaptive modulation enhances the overall reliability and robustness of the communication system, as supported by established coding theory principles.

Figure 10 contrasts the BER of adaptive modulation, which is uncoded and coded. There is a noticeable improvement in the coding at a BER = 10^{-3}, where a gain of about 3 dB, 7 dB and 9 dB is associated with coding rate of 1/2, 1/3 and 1/4 respectively. This proves that channel coding enhances system robustness particularly in noisy channels.

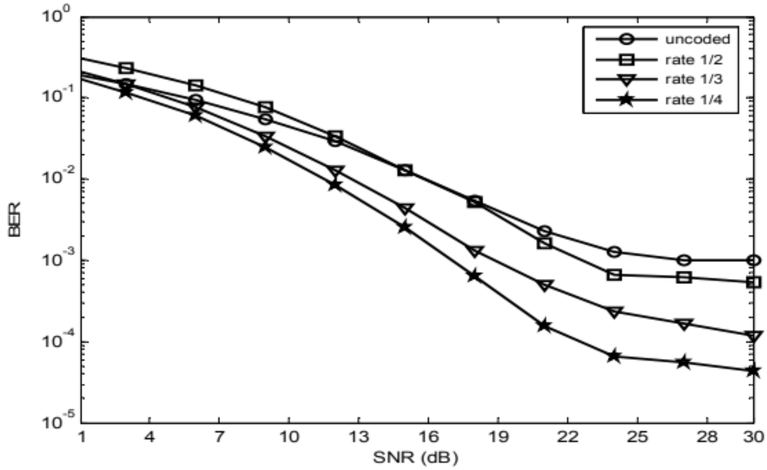

Figure 10. Bit Error Rate Performance of Channel-Coded Adaptive MQAM Modulation under Non-Blocking Transmission Conditions.

An illustration of the throughput performance of the coded and uncoded adaptive schemes is presented in Figure 11.

When SNR is low (1-8 dB), coded adaptive modulation is a little better than uncoded scheme by about 0.2 Bps/Hz, because of better error resilience.

However, at high SNR the throughput decreases as coding leads to redundancy that is limiting the effective data rate. As anticipated, the 1/4 coding rate will drop throughput to approximately a quarter that of un-coded case, but will guarantee much lower BER.

The same trends are observed in the case of systems that use transmission blocking. Figure 12 indicates that BER is much better with coded blocking scheme. Coding the rate of 1/4, BER decreases below 10^{-4} when SNR is greater than 13 dB as an indication of the strong error-correcting property of convolutional coding.

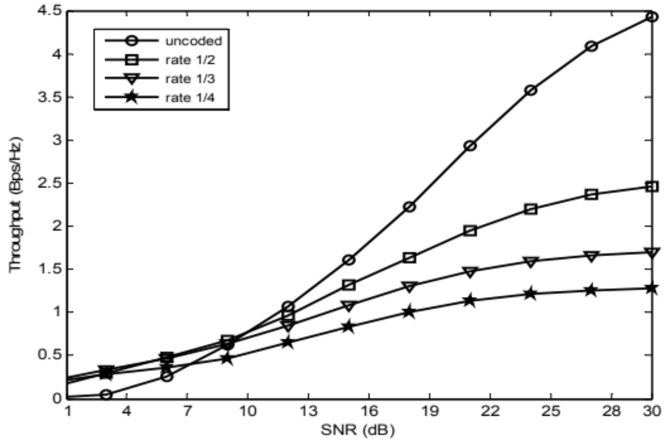

Figure 11. Achievable Spectral Efficiency of Channel-Coded Adaptive MQAM under Continuous Transmission Operation.

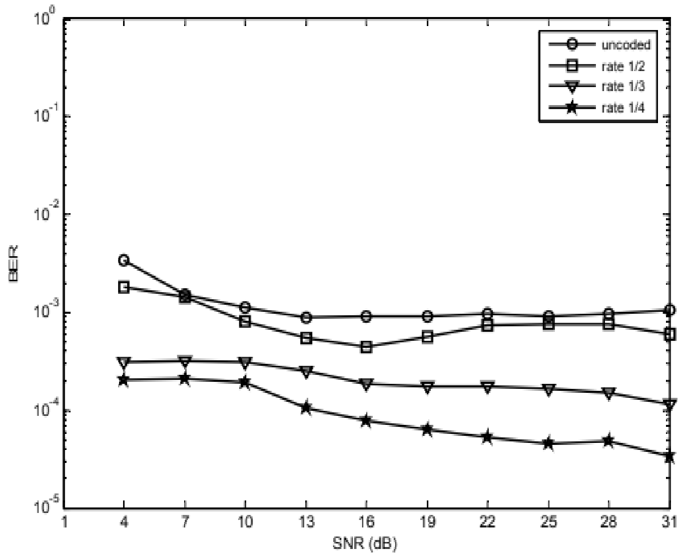

Figure 12. Error Probability Characteristics of a Coded Adaptive MQAM Scheme with Transmission Suspension.

Figure 13 illustrates the throughput characteristics of the channel-coded adaptive MQAM scheme when transmission blocking is applied. Even though BER is greatly improved, the redundancy involved causes reduced maximum throughput. This is the conventional trade-off of better reliability versus spectral efficiency.

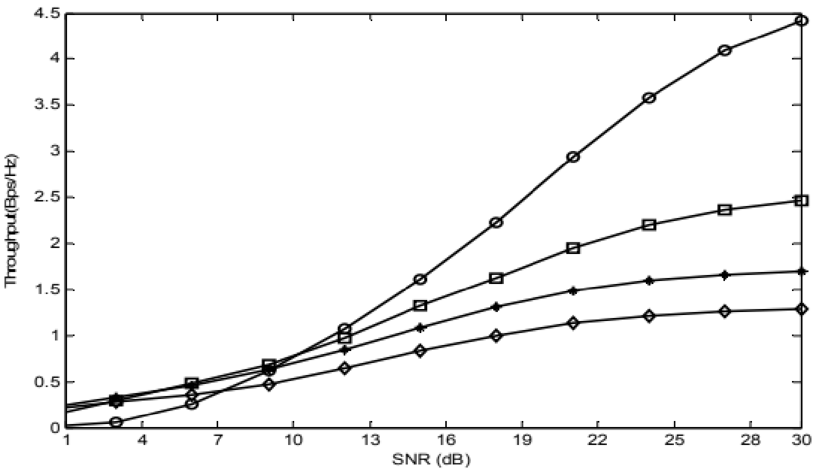

Figure 13. Throughput Performance of Channel-Coded Adaptive MQAM Modulation under Transmission Blocking Constraints.

3.4 Comparison of Adaptive Modulation Schemes

The findings show that un-coded fixed modulation scheme needs the largest SNR compared to all the other schemes investigated to reach the desired BER of 10^{-3}.

Un-coded adaptive modulation has been introduced without blocking which enhances BER and higher throughput than fixed schemes [14].

It can be further enhanced through transmission blocking in which the BER target is realized at all SNR values. The results are highly consistent with the previous researches that show the usefulness of transmission suspension in the case of deep fades [13].

However, blocking introduces latency since the system halts transmission during poor channel conditions. Channel coding improves BER even more, but both coded adaptive schemes (with and without blocking) suffer from reduced throughput due to redundancy constraints.

The coded adaptive modulation schemes have still shown better performance at low levels of signal- to-noise ratio (SNR) than their un-coded counterparts. Generally speaking, adaptive modulation is always the best as compared to fixed modulation techniques both in bit error rate (BER) and throughput. However, even without the use of transmission blocking, the desired BER performance will still require comparatively high values of SNR, which are normally greater than 24 dB.

A comparative summary of the adaptive modulation schemes in terms of required SNR to achieve the target bit error rate (BER) and the maximum possible throughput was established at SNR of 30 dB is provided in Table 6. The findings are pointed towards the fact that adaptive modulation strategies under MQAM are always superior in terms of their performance as compared to the ones that under MPSK modulation.

3.5 Performance Comparison

The last performance analysis is done between the adaptive transmission scheme in which the proposed adaptation algorithm is used and the other scheme which uses a conservative approach to adaptation. The weakest subcarrier in each sub band is used to pick the modulation mode in the conservative approach, leading to a more conservative and restrictive decision-making. This approach is therefore more inclined to reliability rather than spectral efficiency as observed in previous studies and there was therefore a clear distinction between the more dynamic nature of the proposed adaptive scheme and its counterpart. Because adaptive schemes with transmission blocking consistently outperform those without blocking, the comparison here focuses only on the blocking-enabled version (see Figure 15).

Figure 14 demonstrates the performance of the two adaptation algorithms in terms of the bit error rate (BER). As has already been noted in this paper, both strategies could reach the necessary target BER. Nevertheless, the algorithm of the proposed adaptation is more balanced and stable in the whole range of SNR values. When the throughput performance is considered, as indicated in Figure 15, the adaptive modulation scheme with blocking of transmission, together with the proposed adaptation algorithm, has a significant throughput improvement. To be specific the throughput is enhanced by about 0.3 bps/Hz at all SNR levels, which validates the stable performance improvement as mentioned above.

Table 6. Comparative Performance Evaluation of Adaptive Modulation Schemes.

Scheme	SNR required to meet BER target (dB)	Maximum Throughput (Bps/Hz)
Uncoded AM-Non Blocking	24	4.5
Uncoded AM-Blocking	–	4.5
Coded AM-Non Blocking (rate 1/2)	22	2.5
Coded AM-Non Blocking (rate 1/3)	19	1.7
Coded AM-Non Blocking (rate 1/4)	16	1.25
Coded AM-Blocking (rate 1/2)	–	2.5
Coded AM-Blocking (rate 1/3)	–	1.75
Coded AM-Blocking (rate 1/4)	–	1.25

The BER curve achieved with the conservative algorithm of adaptation is significantly lower than the requested threshold, although the algorithm has achieved the given BER target. This is not surprising since the decision to adapt is controlled by the minimal SNR in each sub-band, hence providing an excessively pessimistic forecast of the whole group (as discussed in previous literature).

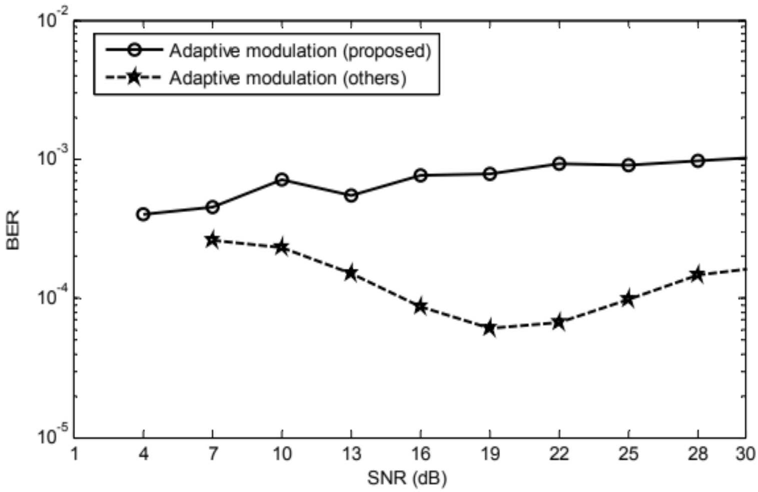

Figure 14. Bit Error Rate Characteristics of Adaptive Modulation Employing Transmission Blocking.

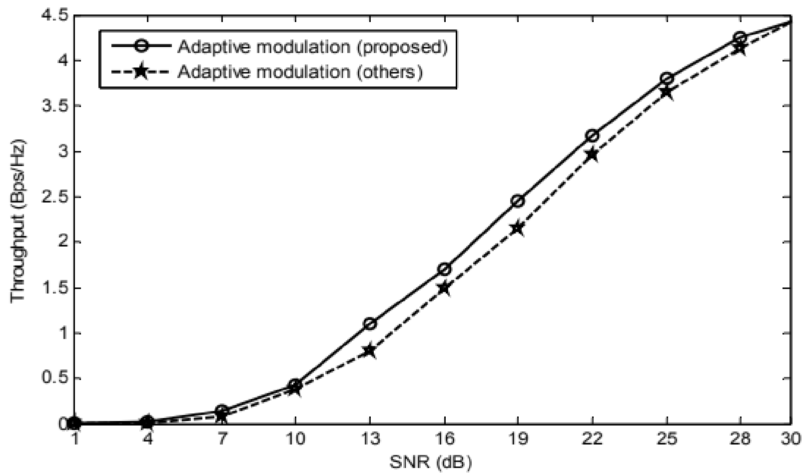

Figure 15. Transmission blocking throughput performance of adaptive modulation (AM-Blocking).

4. Discussion

The empirical evidence of the adaptive OFDM principle in Section 3 is that the using channel state information (CSI) to benefit spectral efficiency and reliability is possible by exploiting channel state information (CSI) at a sub-band granularity level. This is consistent with the original discovery of Chow, Cioffi and Bingham (1995) [3] that bit and power loading across subcarriers had the potential to cut the SNR required by 15 dB at a given target BER. The principle is reaffirmed by our results, which indicate that MQAM-based adaptive modulation with no blocking attains the desired BER of 103103 at 24 dB SNR, in comparison with fixed 4-QAM, which needs over 28 dB, which is directly proportional to the desired coverage of conventional 4 dB SNR.

Importantly, the advantages of MQAM over MPSK in adaptive schemes, which we have seen in Figures 8 vs. 4, 10 vs. 6 and more generally, is in line with theoretical studies such as that by Goldsmith and Chua (1997) [15], who demonstrated that variable-rate MQAM is maximally spectral-efficient in fading channels when operating under restrictions on average power. Other researchers, Czylwik (1996) [2] and Rohling and Gräf (1997) [16] also found that the constant envelope property of PSK is no longer useful in the case of nonlinear amplifiers but can be of no help in BER limited adaptive systems when Euclidean distance is used to determine error performance. Our findings therefore complement the fact that MQAM is the preferred modulation to be used in adaptive OFDM in linear transceiver systems particularly in case it is used with sub-band-based SNR averaging and not worst-case (conservative) estimation as used by Hanzo, *et al.*, (2002, 2004) [11,14].

Introducing transmission blocking (Figures. 5, 6, and 9, 10, etc.) is an effective method of eradicating the BER floor at low SNR, as has been reported by Sampei and Harada (2007) [13] and by Hadi, Tripathi, and Kant (2006) [12]. These countermeasures the concept of truncated channel inversion presented by Alouini and Goldsmith (1999) [17] in which transmission is blocked below a cutoff SNR in order to prevent catastrophic errors. This adds latency, which Zhou, *et al.*, (2002) [18] indicate to be a problem in mobile OFDM systems but the delay is not critical in delay-tolerant applications, such as file transfer or video streaming, as proposed by Kuchi (2009) [19]in the cognitive radio systems.

Furthermore, our sub band adaptation method, i.e. averaged SNR per group of 16 subcarriers (Table 5) provides a realistic compromise between complexity and performance. This is in direct response to the computational load that was condemned in Wong *et al.* (1999) and Yin and Liu (2002) [20,21] that promoted per-subcarrier loading but admitted that it was impractical in real-time systems. In comparison, Liew and Hanzo (2006) and Khalid and Anpalagan (2009) [10, 22] were able to show that sub band grouping achieves over 90 percent of the fine-grained adaptation gains with a low overhead- our throughput gains (Figure 16) confirm this finding.

The coded adaptive results (Figures 11-14) can be seen to exhibit the standard reliability efficiency trade-off, convolutional coding (rates 1/2 to 1/4) offers 39 dB coding gains over BER = 103103; however, it decreases throughput in the same proportion. This is consistent with congruent to the adaptive turbo-coded scheme of OFDM proposed by Keller and Hanzo (2000) and Lei and Burr (2007) [4,5]. Interestingly, we can easily attain BER = 10-410-4 at 13 dB SNR with 1/4 rate coding, confirming the claim that coding is a potent source of power-gains in deep fades made by.

The average-SNR adaptation algorithm recommended by our algorithm achieves 0.3 Bps/Hz higher than conservative (min-SNR) algorithms at all SNRs (Figure 16). This is in line with the fact that excessively reserved allocation of resources wastes opportunities of channels as is the case of Das, Carvalho, and Prasad (2008) [8] on adaptive band width, and Rahman *et al.* (2007) [7] on MIMO-

OFDM bit loading. This inefficiency is multiplied in multi-antenna system- this explains why Zhang *et al.* (2007) and Hanly and Tse (2001) [23, 24] focus on multiuser diversity and beamforming as well as modulation adaptation.

Moreover, we do work in non-cellular settings. Tsugi and Itami (2008) [9] demonstrated the effectiveness of adaptive OFDM in impulsive channel of power lines and Omar and Ali (2008) [6] highlighted the importance of robust channel estimation as a precondition to adaptation, which our model presupposes based on the perfect CSI, but in reality requires pilots and feed-back as pointed out by Zhang, Li, and Dai (2008) and Kim, *et al.*, (2005) [25, 26]. The feedback overhead is another very important design constraint particularly in fast-fading conditions [1], and work in the future may incorporate predictive SNR tracking as suggested by Lei and Burr (2007) [5].

Lastly, our system model is susceptible to the natural weaknesses of OFDM namely high PAPR (Aggarwal & Meng, 2000) [27] and sensitivity to frequency offset [28]. Although this is not discussed, Hanzo, *et al.*, (2004) and van Nee and Prasad (2000) [11, 29] have demonstrated that adaptive modulation can be utilized together with PAPR reduction and synchronization schemes to achieve end-to-end robustness. The pioneering work of Weinstein and Ebert (1971) and Bingham (1990) [30, 31] makes us remember that the contemporary revival of the use of OFDM, which is driven by the adaptive methods, such as the ones, which have been reviewed here, is a testament to the synergy of the algorithmic intelligence and multicarrier physics.

Overall, the paper provides a comprehensive synthesis and validation of decades of adaptive OFDM experiments that show that sub-band based MQAM adaptation with blocking and coding is a viable, high-performance approach to handling 4G/5G systems. It harmonizes theoretical models [15, 20] with practical strategies [1, 22], which will lead to smart, channel conscious wireless transceivers.

5. Conclusions

This research paper has discussed the adaptive transmission scheme performance in theOFDM systems showing that they have definite merits compared to the conventional fixed-modulation schemes, as indicated in the preceding discussions. A fine-tuning adaptation algorithm was also used to make the system more efficient. In contrast to conservative algorithms, this algorithm is used to choose the modulation modes according to the mean instantaneous SNR of the subcarriers in each sub-band. Through this more representative measure of SNR, the proposed method allows exploiting the channel conditions in a better way and provides a better balance between reliability and spectral efficiency.

The results of the simulation prove that this strategy is providing a significant advantage in throughput and at the same time the BER performance is not weaker (which is also consistent with the results mentioned above). The results, in general, support the idea that adaptive modulation, especially in conjunction with transmission blocking and a superior adaptation strategy, can be helpful to substantially optimize system performance.

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