Trends in Adaptive Modulation and Coding

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***Abstract*—This paper presents a review of techniques proposed in the literature that target the best use of resources available in a wireless communication system. These are referred to as Adaptive Modulation and Coding (AMC) techniques. A brief overview of fundamental communication limits, in particular channel capacity, is also provided in order to establish the limits for any adaptation algorithm. Furthermore, an appropriately chosen example is presented in order to demonstrate the usefulness of accurate performance modeling in the AMC design. Finally, challenges and future problems are mentioned.**

***Index Terms*—Index TermsAdaptive, modulation, coding, capacity, OFDM**

I. Introduction

IN recent years there has been a significant increase in data-rate requirements described in the standards of new and upcoming wireless communication systems. In order to increase the data rates offered, a simple approach is to increase the allocated bandwidth. This approach is expensive, since the radio-frequency spectrum is nowadays fragmented and occupied by a plethora of systems. Therefore, research over the last years has been focused towards improving spectral efficiency, so that higher data rates can be achieved within a given bandwidth. Targeting to the inherent capacity of the underlying channel, techniques which adapt and adjust (in real-time) transmission parameters based on the link quality have been proposed. These are collectively referred to as "Adaptive Modulation and Coding" (AMC) and they provide as their output the values of transmission parameters to be employed in a following transmission period, based on feedback information and in accordance with particular cost functions related to the targeted Quality of Service (QoS).

In this paper, a review on the wireless-channel capacity definitions and related issues is first presented, with an emphasis on communication scenarios that involve the existence of Channel Side Information (CSI). This is of great importance for AMC since it provides the fundamental limits for its performance. In the subsequent section, the AMC framework is presented with an emphasis on practical considerations for algorithmic design in the context of multi-modal operation, along with a literature review of the proposed techniques. In Section IV, an example based on the discussed framework is presented which demonstrates the need for accurate compact link level modeling in AMC design for OFDMA systems. In Section V some challenges for future research conclude the paper.

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II. Fundamental Communication Limits

In this section a brief survey of schemes that model the existence of multiplicative noise (fading) in a wireless environment is provided, since such fading is the main source of channel variability that dictates the need for AMC methods and techniques. Furthermore, the fundamental information theoretic limits of such schemes are characterized. The main goal here is neither to provide an exhaustive analysis of the topic, nor to explain in depth the existing techniques. Instead, we aim to highlight the potential benefits of AMC.

A. Channel Capacity

The evaluation of capacity bounds for various channel models and system scenarios has been an interesting research topic since Shannon's pioneering work. The determination of such performance limits defines the framework for the design and development of optimal communication techniques. In many cases, the computation of the exact value of channel capacity is a difficult problem. In some cases, these bounds can lead to the exact determination of channel capacity. In all cases however, any available analytical characterization of a system's information capacity serves as a performance criterion and a tool for the system design.

B. Channel Capacity of Fading Channels with Channel Side Information

In wireless transmission, channel conditions may vary arbitrarily due to changes in the fading environment or due to the users' mobility. In most practical cases, and depending on the relative dynamics, the system is able to extract valuable information regarding the prevailing level (strength) of the channel-fading process. This type of information is usually referred to as CSI and can either be available at both ends (the transmitter as well as the receiver), or at the receiver (Rx) only but not at the transmitter (Tx). The degree of accuracy of this CSI is certainly a critical parameter for the performance of the system under consideration. The case in which the channel is assumed to be perfectly known at the receiver and/or the transmitter has been studied extensively in the literature. In a Rayleigh-fading Single-Input Single-Output (SISO) setting, it was addressed in an early work by Ericsson [1], where analytical expressions for the capacity of flat-fading channels with perfect receiver CSI have been derived. In a more recent work (Ozarow *et al.* [2]), results were derived for the *average* as well as the *outage* capacity in cellular mobile radio, assuming perfect CSI at the Rx.

In recent OFDM-type designs, a system implements a strategy whereby the estimated values of the CSI are relayed to the Tx with different levels of accuracy. It is therefore of particular interest to re-examine past results on the capacity of fading channels but now with Tx-side information available. Goldsmith and Varaiya [3] analyzed the capacity of flat fading channels with perfect CSI at the transmitter and/or the receiver. Borade and Zheng [4] investigated, among other scenarios, the channel capacity in the low signal-to-noise-ratio (SNR) regime when both sides have perfect CSI. They showed that, for very low values of the SNR the capacity is $\text{SNR}\log(1/\text{SNR})$ and this is achieved by on-off signalling with a fixed "on" level.

In practice, however, true access to perfect CSI cannot be guaranteed to either side, mainly due to the rapid changes in the fading environment and limited energy that can be allocated to non-data carrying symbols to assist the channel estimation. Thus, extensive research has addressed the case where CSI is either imperfect or, in the other extreme, completely unavailable to either side. Abou-Faycal *et al.* [5] have studied the capacity of the Rayleigh fading channel with purely unknown fading levels. They showed that the optimal input distribution is discrete. This is a somewhat surprising result, especially when compared with the optimality of the continuous Gaussian input distribution when CSI is available and perfect. Under a peak constraint on the input of a Rician fading channel, this discreteness property of the capacity-achieving input distribution has also been proven in [6]–[8] and, more generally, for a broad class of SISO channels in [9]. In a MIMO setting the capacity and optimal input distribution of a Rayleigh fading channel have been derived by Marzetta and Hochwald [10] where CSI is also unavailable to both sides. This work triggered further research on the discreteness of optimal input distributions on MIMO settings. Zheng and Tse [11] addressed the capacity of MIMO Rayleigh fading channels in high SNR.

In most cases of interest, however, these extremes, of having either perfect CSI or no CSI at all, are not valid. In particular, practical OFDM systems tend to be between those two extremes, except when there is very high mobility. The analysis of the capacity of fading channels with imperfect or "noisy" CSI is therefore of great practical interest. Médard [12] investigated the effect of imperfect channel knowledge on the channel capacity and obtained upper and lower bounds on the achievable mutual information rates. Lapidoth and Shamai [13] analyzed the effects of channel estimation errors on performance whenever Gaussian codebooks are employed along with nearest-neighbor decoding. The capacity of imperfectly known fading channels is addressed in [14] for the low-SNR regime and in [15] for the high-SNR regime. These results, however, have not considered explicit training and estimation techniques and the needed resources allocated to do so. An analysis of channel capacity in a training-based communication setting with Rayleigh block-fading can be found in [16]. Hassibi and Hochwald [17] looked into some training schemes for multiple-antenna channels recently.

We shall now focus further on fading channel capacity with CSI available at the Tx. When CSI concerns channel fading values, CSI is treated as causal side information at the Tx (as opposed to noncausal side information that is not treated in this survey). In this case, techniques such as adaptive rate/power control, MIMO beam-forming, water-filling etc. are all applicable. The causal case of Tx-CSI was first introduced by Shannon [18] wherein he showed that the CSI-endowed channel can be transformed into a no-CSI channel of an exponentially larger alphabet size.

Assuming causal Tx-CSI, we now describe briefly the results derived for typical fading models in the literature. Slow fading: When the Tx knows the CSI, one option is to control the transmit power such that the corresponding full information rate can be delivered regardless of the fading state. Regarding the power this effectively "channel inversion" strategy guarantees a constant receiver SNR, irrespective of the channel gain. Regarding the rate adaptation some pre-specified rates are chosen when such exact channel inversion is feasible. However, a very large amount of power must be spent in order to 'invert' a very bad channel, which encounters practical limitations of peak-power-constrained transmission.

Fast Fading: The goal now is to maximize the *average* information rate where the averaging occurs over many coherence-time periods. The optimal power and rate allocation in this case is based on the water-filling principle. In general, the Tx allocates more power when the channel is good, taking advantage of this improved channel condition, and less or even nothing when the channel is poor. This is conceptually the reverse of the channel-inversion strategy above. The natural implication of the water-filling capacity is a variable-rate coding scheme.

In the above setting, water-filling is done over time. A duality exists with a frequency-selective channel, where water-filling is done over the OFDM sub-carriers. In both cases, the problem can be viewed as that of a bit-power allocation over parallel channels.

Comparing the channel capacity in the case of full CSI at the Tx with the one in the Receiver-Only CSI (RxO-CSI) case, some conclusions can be drawn. In particular, at low SNR, the capacity with full CSI is significantly larger than the RxO-CSI capacity, whereas at high SNR the difference between the two tends to zero. Over a wide range of SNR, the gain of the water-filling procedure over the RxO-CSI capacity is very small. A comprehensive survey of information theoretic results on fading channels can be found in [19]. With imperfect channel knowledge at the transmitter, the capacity is $\beta\text{SNR}\log(1/\text{SNR})$, where β is a scalar parameter $(0 < \beta < 1)$, describing the fraction of channel energy in the part of the channel known to the transmitter. An analysis of partial transmitter knowledge over Rician channels can be found in [6], [7], too.

C. MIMO Capacity

In the above setting, the introduction of multiple antennas under suitable conditions provides an additional spatial dimension for communication and yields gains in degrees of freedom. This results to an increase in capacity: In fact, the capacity of such MIMO channels with N transmit and receive antennas is proportional to N. MIMO communication is a broad and interesting topic with many applications. In particular, in the high-SNR regime, MIMO techniques become the primary tools to increase capacity significantly through the degree-of-freedom gain previously mentioned, as well as the induced power gain.

The use of multiple transmit and receive antennas provides many benefits for both fast and slow fading channels. In fast fading, antenna diversity introduces a power gain as well as a degree-of-freedom gain. The analysis of fast-fading MIMO is simpler and addresses mainly channel capacity, whereas the analysis of slow fading is generally more complex. In this case, the outage probability is the goal as a function of the target rate. The outage probability reveals in principle the tradeoff that exists between the error probability and the data rate. In slow fading, there is a triple gain from the introduction of multiple antennas, namely in power, degrees of freedom and diversity. In the high-SNR regime, there is an approximation of the outage probability that captures the benefits of MIMO communication for slow fading channels. This is the fundamental tradeoff between the increased data rate (via an increase in the spatial degrees of freedom the multiplexing gain) and the increased reliability (via an increase in the diversity gain). The optimal diversity-multiplexing tradeoff is used as a benchmark in comparing the various space-time schemes and is helpful for the design of optimal space-time codes.

Considering the time invariant Gaussian MIMO channel, the spatial dimension plays the same role as the time and frequency dimensions in the time-varying fading channel with full CSI and the time-invariant frequency-selective channel. The capacity is therefore obtained by a water-filling power allocation scheme, albeit the water-filling takes place in the spatial domain. It depends highly on the singular values of the channel gain matrix, corresponding to the eigen-modes of the channel, or eigen-channels. For high SNR, where the level of "water" is low, it is asymptotically optimal to allocate equal amounts of power on the nonzero eigen-modes. The number of spatial degrees of freedom represents the dimension of the transmitted signal as modified by the MIMO channel. It provides a crude measure of the capacity of the channel. At a low SNR, the optimal policy is to allocate power only to the strongest eigen-mode. In this regime, the rank of the channel matrix is less relevant for the characterization of the channel capacity. Instead, the energy transmitted through the channel is a more critical parameter. For a detailed analysis of MIMO communication as well as the related concepts the reader is referred to [20].

III. Communication Techniques for Approaching the Limits

A. AMC Framework

As mentioned before, the objective of AMC is to optimize the use of available resources (system bandwidth, channelization, transmit power, time slots, computational power of executing platform) in order to achieve a specific Quality of Service (QoS). The AMC system is composed of: (a) an adaptation criterion or cost function, generally related to the QoS parameters; (b) the hypothesized nature of the CSI that the transmitter needs to know about the channel, which information is often imperfect, erroneous or obsolete; (c) the particular optimization algorithm chosen or developed for this problem; and (d) the resulting outputs of the AMC optimization algorithm (namely, a set of transmission parameters to be employed in the next transmission). As far as the adaptation criteria are concerned, there are multiple possibilities and combinations of AMC schemes in which some particular metrics and quantities may constitute the inputs (requirements and constraints) for one strategy or the criterion/output for the other. Some quantities (such as data throughput) may be introduced as the criterion (objective function), while others (like transmission power limit and delay) may be introduced as constraints. By varying these choices a large number of adaptation strategies are obtained. Accommodating that plethora of options is challenging and, in some cases, may result in very complex solutions that are hard to implement.

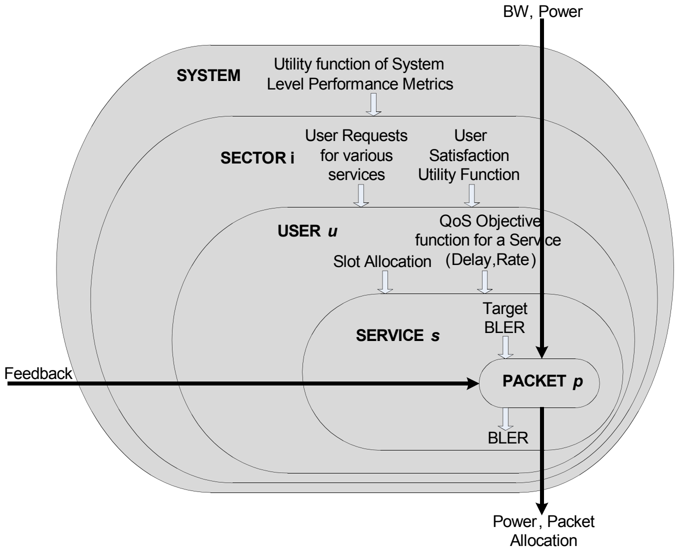

Fig. 1. AMC Framework.

An illustrative example of possible choices for cross-layer optimization in a cellular system is depicted in Fig. 1: Tx parameter optimization procedures at the system/sector level (higher layers) are usually called *RRM procedures*, while at the user/service layers *AMC algorithms*. All the optimization scenarios are intersected by the two basic common resources, bandwidth and power, and have as input the feedback information (feedback can contain various forms of information, CSI, error measurements, etc.). The objective function used for each layer is usually called the utility function. Utility functions are also used in cross-layer optimization. They are defined so as to balance efficiency and fairness when allocating resources in systems with heterogeneous services. Consequently, they can be used to optimize radio resource allocation for different applications and to build a bridge between the physical, MAC, and higher layers.

At the center lies the basic element of a packet-based communication system, namely the 'packet'. The interpretation of a packet herein is that of the smallest portion of a communication entity employed by a given system (containing unique information content). It can either be considered correctly received, or discarded at the end of the receiver's processing at the link level, thus determining the performance of the link. This approach is compatible with packet-based systems (like WiMax and LTE); where each packet is characterized by the code rate, block size and constellation used. It can also describe uncoded systems where a symbol can be considered as a packet.

When designing AMC algorithms, the packet Link-Level Performance (LLP) prediction under some CSI information is a fundamental requirement for all optimization problems. In some cases of interest (e.g. coded OFDM-based systems), the exact LLP function is difficult to be derived in an analytic form amenable to run-time optimization. This arise the need for a *Compact Link-Level Performance Estimation (CLLPE) model* that take into consideration the parameterization of the transmitted signal, given the channel and interference conditions. It should be detailed enough to include channel modeling issues such as: the effect of multiple antennas at the transmitter and/or the receiver, the MIMO technique applied (e.g., beam-forming or other spatial multiplexing scheme), and the receiver type. The accuracy of such models is more crucial in lower layers, while rougher approximations can be used at higher layers.

B. Review of AMC techniques

A review of possible adaptation strategies can be found in [21] with extensive bibliography on the subject, as well as a review on the link adaptation research history. A short summary of this review is presented herein. As mentioned before, there are multiple possible combinations of the adaptation criteria, requirements and constraints. For example, in the throughput-oriented strategy, the AMC algorithm aims in providing the highest bit rate (or spectral efficiency) for a required BER and fixed radiated power limit. This was one of the first adaptive transmission schemes proposed by Steele and Webb [22] for single-carrier QAM modulation and narrow-band fading channels. Exploiting the time-variant channel capacity, various concatenated coded schemes with an adaptive coding rate have been investigated in [23]; variable coding rate and power schemes in [24]–[28]; latency and interference aspects with turbo-coded adaptation in [29], [30]. The concepts elaborated for adaptive QAM modulation and coding have been invoked for OFDM QAM in [31], [32]. Adaptive subcarrier selection for OFDM TDMA dynamic links has been investigated in [33]–[35], space-time diversity in [36], [37], and multi-coded systems in [38], [39], as well as in the investigation of the key agents affecting AMC performance [40]–[43]. Interesting proposals for throughput-oriented AMC algorithms can also be found in [44]–[48].

The set of transmission parameters amenable to adaptation is in general large (i.e. constellation size, code rate, Tx power, symbol rate, number of subcarriers, the number of antennas, etc.). Targeting to reasonable complexity is also a decisive factor for the parameters selection. For example in [49] it was shown that by adjusting only the power or only the bit rate the resulting capacity is negligibly smaller than by adjusting both these parameters. In [50] a study on maximizing the spectral efficiency by optimally varying combinations of the transmission rate and radiated power with average power and instantaneous (or average) BER constraints has been presented. There, both continuous-rate adaptation and discrete-rate adaptation are considered. The conclusion has been that the use of only one or two degrees of freedom in adaptation yields spectral efficiency close to the maximum possible that would be obtained by utilizing all degrees of freedom.

In energy-constrained wireless networks a common adjustable parameter is the overall power consumption of a transceiver for a target QoS level. The motivations for this approach are usually: to extend the battery life, to minimize the electromagnetic radiation in populated areas, to reduce the cost in infrastructure-based networks, and to reduce the interference. In this case the transmission parameters should be adapted in order to minimize the power needed for the baseband signal processing and the power of the transmitting antenna. Thus, some trade-offs in choosing the optimization criteria are needed, such as the accuracy of the performance prediction (CLLPE model) within a given limit for the baseband processing. Interesting propositions for power-oriented AMC algorithms and strategies can be found in [24], [51]–[55].

There are interesting proposals in the literature concerning multi-user adaptive schemes. In multi-user systems (for instance, in adaptive FDMA) subcarriers may be adaptively allocated to users in an optimal manner, taking the quality of each user's channel into account. An example is the algorithm described in [56] which aims at minimizing the overall transmit power by adaptive multi-user subcarrier, bit, and power allocation. In [57] a general link and system performance analysis framework is developed that is used to compare the downlink performance of fully loaded cellular system with different types of link adaptation.

IV. AMC EXAMPLE USING CLLPE MODEL

In section III the notion of CLLPE was introduced, as a fundamental requirement for all optimization design strategies. In this section the usefulness of proper CLLPE modeling for AMC design in a coded OFDMA system in a frequency selective environment is demonstrated through an example. This example is chosen because it is compatible with emerging standards like LTE.ADV and WiMax, and the exact LLP function is very difficult to be derived in analytic form amenable to use in run-time optimization.

Finding CLLPE models for coded OFDM systems has been an active area of research and has received considerable attention in the literature [58]–[66]. The main motivation behind these efforts was to use the so-called *physical-layer abstraction* in order to determine the performance of a given link, and thus to avoid the need for extensive simulation for system level performance assessment. Various systems under development and the corresponding standardization bodies introduced EValuation Methodologies (EVM) documents which summarize these PHY abstraction methodologies for the respecting systems. For example the EVM Document of IEEE 802.16m [67] provides CLLPE models for coded OFDMA designs that can be used both for system level performance

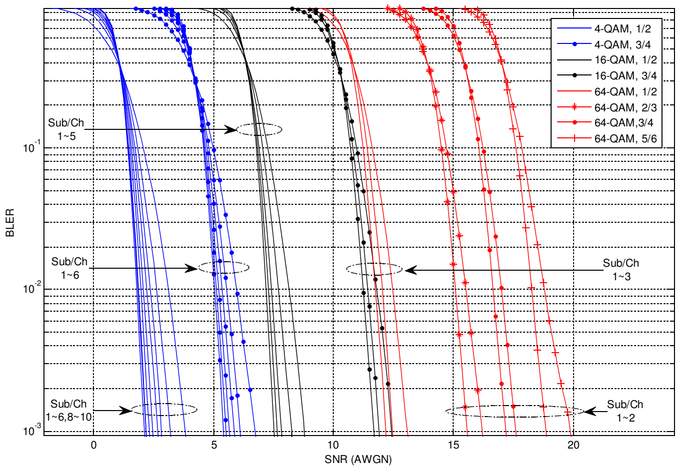

Fig. 2. Simulated performance on AWGN for the 32 WiMax compatible CTC Tx-modes.

assessment and AMC algorithmic design. In this case, the role of a CLLPE method is to predict the coded Block Error Rate (BLER) for a given received channel realization (frequency selective) across the OFDM sub-carriers used to transmit the encoded packet. The post-processing SNR values at the input to the FEC decoder are mapped to a single number, called *effective* SINR SNR_{eff}, which is then used to accurately relate the system-level SNR onto predefined AWGN link-level curves for determining the resulting BLER. This approach is referred as Effective SNR Mapping (ESM), and based on the adopted model can be categorized in: (a) Mutual Information ESM (MI-ESM) and (b) Exponential ESM (EESM) techniques. The most popular MI-ESM techniques are Received Bit Mutual Information Rate (RBIR) and Mean Mutual Information per Bit (MMIB). The expressions for calculating these methods for the WiMax OFDMA system can be found in [67].

Targeting in the AMC design for Bit-Interleaved Coded OFDM systems, a novel link performance prediction method tagged as "cumulant generating function based" ESM (ESM) is proposed in [66]. Differently from the conventional ESM methods, ESM relies on an accurate evaluation of the Pairwise Error Probability (PEP) figure through the statistical description of the BIC log-likelihood metrics.

In the example presented herein we use the MMIB method as a CLLPE model and the WiMAX-compatible basic parameterization. The channels used are the AWGN (frequency flat) and the frequency selective Pedestrian B Tap Delay Line (TDL) Scenario as described in [67]. Channel coding is based on the WiMax compatible Convolutional Turbo Codes (CTC) as described in [68]. The AWGN link-level BLER performance curves for the 32 CTC modes with varying block sizes (table 524 of [68]) are displayed in Fig. 2. This figure demonstrates the large variety of the available operation modes in the WiMax system and dictates the need for accurate performance prediction in order for a selection mechanism to make the best decision.

If we also take into consideration the various MIMO techniques available in the standard, then the number of possible modes is even higher. When using linear receivers, the overall MIMO channel translates to an equivalent SISO; thus, the problem of 'optimally' choosing the best mode is simplified, allowing the use of AMC techniques for an equivalent SISO channel. Thus, the incorporation of linear MIMO receivers does not lead to any fundamental change in the AMC design procedure, other than increasing the allowable Tx-modes. In the case of Maximum-Likelihood (ML) types of receivers the situation is more complicated. Theoretically, MI-based ESM techniques perform the abovementioned translation to equivalent SISO even for ML receivers, enabling the seamless incorporation of MI-based AMC techniques. In practice however, the model loses its "compactness" even in the case of a 2x2 system, making it useful only for performance prediction and not for real-time parameter adaptation.

In Fig. 3 we plot the actual (simulated) performance in the AWGN channel, and the actual and predicted (by using MMIB) performance in the frequency selective channel with and without Bit & Power Loading. The performance without using any bit-power allocation algorithm is depicted as C-BPL (Constant Bit & Power Loading). The MMIB-BPL is a scheme using bit-power loading based on the MMIB ESM technique. The mutual information (MI) of the coded bit depends on the actual constellation mapping of the symbol and the SNR. The MMIB per symbol is a function of the SNR, and is defined as the mean MI of all bits of a symbol; the exact expression can be found in [67]. In the algorithm presented in Fig. 3 an approximation of the MMIB is used via a parameterized sigmoid function [69]. The bit-power allocation is performed by using this approximation along with the iterative solution proposed in [70] for the power loading and Willink's solution for bit-loading [71], both with proper modifications. Details for the algorithm can be found in [69].

The results are displayed for two selected modes: 4-QAM with CTC rates of $1/2$ and $3/4$ and one sub-channel (48 sub-carriers) per codeword. In this simulation scenario the target is the performance assessment of a particular mode and the assessment of the mode selection procedure based on a chosen metric. Each SNR point represents the average SNR across each block (sub-channel) used and not the long-term average SNR of the system. The channelization is chosen to be the Partial Usage Sub-Channel allocation (PUSC) in order to address difficult scenarios with high SNR variations across the sub-carriers within a codeword. All channel realizations are normalized in power, thus the performance degradation of the frequency-selective scenario with respect to the AWGN case is only attributed to the SNR variations.

In Fig. 3 we can assess: (a) the degradation due to SNR variations by comparing the 'Simulation' curves with the 'Simulation AWGN' curves, and (b) the ESM prediction performance by comparing the 'prediction' curves with the real ones ('Simulation'). When the CLLPE model is used to choose the appropriate transmission packet, any deviation in the prediction is a measure for a needed power margin to compensate the modeling uncertainty. Thus, when optimizing the transmission parameters, gain in total power can be achieved not only with the classic 'shaping gain' by using BPL techniques, but also from the reduction of the prediction uncertainty.

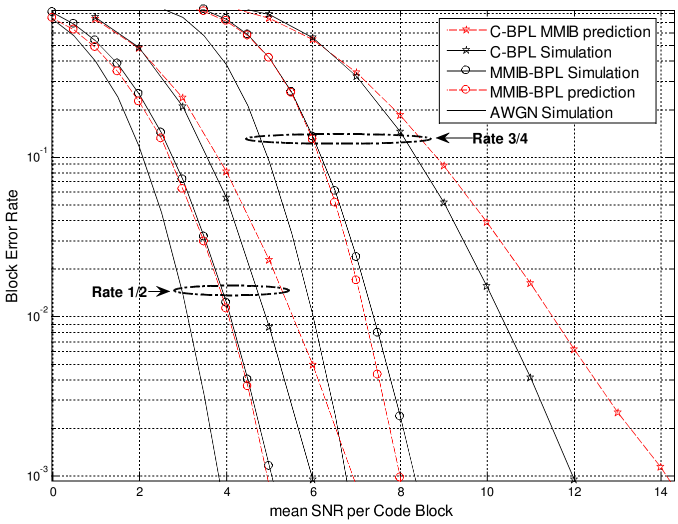

Fig. 3. Simulated BLER performance and prediction for two CTC modes with and without bit&power loading.

Classic SNR threshold-based methods lead to worst-case designs, where you always spend excessive power (high power margin) in order to guarantee the target BLER. In the example of Fig. 3 the average BLER prediction based on the MMIB is depicted. For a target BLER of 10^{-2}, for the case of $1/2$ code-rate, the prediction is only 0.7 dB far from the actual performance, while for the case of $3/4$ code-rate, the prediction deviation is 1.2 dB. It is important to emphasize that the depicted MMIB prediction is based on the instantaneous channel realization. For example, if the channel is flat, the performance prediction follows accurately the AWGN curve. The difference at the estimation of the mean can be interpreted as the average power loss for not having a perfect CLLPE model.

As expected by using MMIB-BPL, we have a performance gain compared with the C-BPL. An interesting outcome of this comparison is that the use of bit-power loading eventually leads to more accurate prediction compared with the C-BPL. In cases where the prediction under-estimates the BLER, we deliberately insert an SNR margin in order to guarantee the QoS. This is very small for the case of MMIB-BPL as depicted in Fig. 3 compared to the classic average SNR threshold approach. The later can be considered as a constant penalty from the flat (AWGN) curve due to channel selectivity.

V. Research Challenges

This section presents a small summary of open issues for AMC design in multi-modal, multi-parametric emerging standards. A first point of consideration is the selection of the available modes of operation to be used by the AMC algorithm. As the number of modes increase, the optimization algorithm itself can become very complex. An interesting research topic is to find a mechanism to limit the menu of available modes, i.e., to produce some general guidelines for mode selection (as a function of the scenario) without having to necessarily go through an exhaustive analysis.

Since optimization algorithms rely on information provided by measurements and estimated parameters, system robustness analysis is essential. In addition, any algorithmic design with practical interest must incorporate mechanisms that will take into account all possible errors (measurement, feedback, system imperfections, etc.) for the scenarios of interest.

Finally, for systems which involve high-order MIMO schemes using approximate Maximum Likelihood receivers (like WiMAX and LTE.ADV), it is very difficult to derive reduced-complexity link-performance models, even for the simpler case of uncoded performance [72]. Additionally, as per the previous paragraph, parameter estimation errors complicate the problem even more. Thus, developing proper analytic CLLPE models amenable for use in run-time optimization, along with an elaborate trade-off analysis between performance prediction accuracy and complexity is a very challenging part of the overall AMC design procedure.

VI. Conclusions

The paper presents a literature review on channel capacity and AMC techniques. The AMC framework is also presented, highlighting the need for compact link-level performance modeling in the AMC algorithmic design for multi-parametrical systems. As illustrated in the coded OFDMA example, accurate performance modeling can compensate the performance loss caused by limited parameterization, and for designs targeting guaranteed QoS can significantly reduce the power loss caused by the classic SNR worst-case threshold.

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