Adaptive/Configurable Channel Coding & Modulation for TDMA-Based Wireless Broadband Fixed Cellular Systems

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Abstract:

Use of efficient channel coding and modulation scheme is crucial for the design of a high spectral efficiency fixed cellular system. In this paper different strategies on adaptive/configurable concatenated channel coding & modulation in a broadband dense wireless fixed access system, based on TDM/TDMA multiple access scheme have been analyzed. The first strategy, being the most simple one is to configure the modulation & coding according to the channel conditions on a *sector by sector* basis. In other words, for sectors where only some terminals are suffering from high interference/noise, coding and modulation should be configured to the worst case scenario. The second strategy is based on the adaptation following *group of terminal (GOT)* basis. According to a carrier to noise and interference power ratio C/(N+I) analysis, the terminal stations within a sector could be grouped according to their reception conditions. For each set of GOT different coding & modulation can be used. The last strategy is based on the adaptation according to terminal stations, i.e. *slot by slot* basis. At the cost of higher complexity, the results showed that the spectral efficiency can be enlarged by using adaptive channel coding and modulation (Strategy II). However, the configurable scheme (Strategy I) can be also seen as an alternative candidate that provides much lower complexity with significant gain. Indeed, in a real deployment scenario, the third system (Strategy III) is much flexible to be adapted to different network conditions, e.g. overlapped cell configuration. But this scheme, due to *slot by slot* based transmission can not exploit the interleaving gain and suffers from high amount of extra synchronization overhead.

1 Introduction

Fixed microwave Point-to-Multi-Point (PMP) digital transmission systems will become an important part of the local distribution and feeder networks. The currently allocated microwave frequency ranges for PMP applications are from 3.5- up to 28 GHz. Other alternative frequencies are the 32 and 42-GHz which provide large bandwidth of about 2 GHz. In the *Channel-allocations* of the CEPT, the available spectrum is split into smaller channels, e.g. 14-28 MHz channels using Frequency Division Duplex (FDD) [1], where several service providers with a moderate number of channels are licensed to serve the same area. Channel-allocations form the basic criteria for the design of a suitable cellular system to achieve i) high data rates, ii) full coverage and iii) high inter-cell interference immunity.

For microwave PMP systems usually the presence of a line of sight (LOS) between the base station (BS) and the terminal station (TS) is guaranteed. However, the microwave radio link is mainly subjected to high rain-attenuation and high amount of other cell interference.

Indeed, data services (e.g. IP, ATM) are characterised by spontaneous traffic with high burstiness and capacity-on-demand requirements. By realising asynchronous time division multiplexing of data packets at the air interface, a high multiplexing gain can be gathered. Therefore, here we assume a Time Division Multiple Access (TDMA) approach, that shares one broadband physical channel by all wireless terminal stations of the same radio sector. The access to the shared physical channel is controlled by a Medium Access Control (MAC) protocol that performs an intelligent capacity-sharing algorithm offering immediate on-demand access to the available channel resources.

Adaptive channel coding & modulation has been proposed and used in many applications and standards [2-3]. It has been shown that the system capacity can be increased by adapting the coding redundancy to the actual channel conditions.

In this article we examine different strategies on adaptive channel coding and modulation for packet-data transmission of multimedia services in a broadband wireless access (BWA) system.

The article is organised as follows. In section 2 an overview on the digital Point-to-Multipoint (PMP) system has been given. Cellular issues and microwave channel characteristics are briefly described in section 3. Section 4 will be mainly devoted to different channel coding and modulation strategies. Performance analysis is done in section 5. Finally in section 6 the main conclusions are derived.

2. Radio Transmission Scheme

A digital *point-to-multi-point* cellular access network is made out of a Base-Station (BS) and several fixed Terminal Stations (TS). Each cell is divided into different sectors (e.g. 15-90 degree sector angle), where for each sector appropriate antennae with Frequency Division Duplex (FDD) are used. The BS will be connected through the Service Node Interface (SNI) to different core networks (e.g., IP, ATM, PSTN); where the TS will be connected for instance to a PABX or to different local networks by the User Network Interface (UNI). Figure 1 illustrates the system under study which is based on a TDM/TDMA multiple access scheme, where a Medium Access Controller (MAC), installed in the BS supervises the traffic and the bandwidth assignments within a cell/sector. The transmitter (BS or TS) comprises RF-, IF-Unit and a digital modem (modulation/demodulation, channel coding/decoding and synchronization).

Furthermore, we suppose an asymmetrical data rate for IP/ATM applications; where different ATM service classes (CBR, VBR, UBR, ..) should be supported by assigning the highest priority to real time services.

The channel coding and modulation can be adapted/configured to the TS/Sector reception conditions. It is based on a combination of concatenated channel coding (inner convolutional and outer Reed Solomon code) and MPSK modulation (M=4, 8, 16). Different strategies for the adaptation of channel coding and modulation can be considered. The criterion for the adaptation will be based on the analysis of the C(N+I) in a cellular environment.

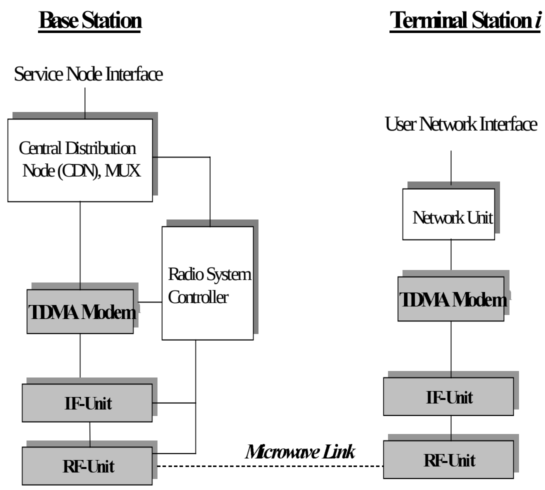

Figure 1. Digital microwave PMP-transmission system based on TDM/TDMA

3. Cellular Aspects & Channel Conditions

In cellular environments cell sectorization together with frequency de-coupling could be deployed for increasing the system capacity. However, in a dense cellular system only cell sectorization with frequency de-coupling will not be sufficient to de-couple sufficiently the inter-cell (or inter-sector) interference [4]. The following methods could be used additionally to achieve the highest capacity:

- antennae polarisation,
- employing highly directive TS antennae,
- and individual link/sector based optimisation.

Different cell-sectorization is possible: from four (90° BS-Antenna) up to 24 (15° BS-Antennae) sectors could be envisaged. Vertical or horizontal polarisation could be used. The TS could employ high gain directive antenna (e.g. 5-7° planar or parabolic antenna). Finally, if the cell sectorization and polarisation is not sufficient to combat the interference, the frequency division could be used to de-couple the remaining other-cell interference.

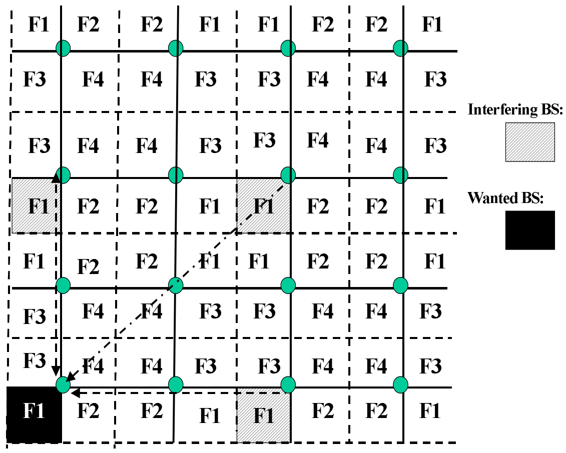

Figure 2. A Rectangular 4x4 Multi-cell Configuration with 4 Frequencies

The carrier to interference power ratio C/I is given by the ratio of distances between the TS to the wanted BS, and the TS to the interfered BS. The C/I becomes worse with larger distance and increasing cell overlap. Indeed, the amount of interference depends strongly on the sector and the position of the TS within a sector. Areas close to the regular grid formed by the base stations (see Figure 2) suffer from higher interference, since the directional antenna of a TS at this location shows both to the wanted and to interfering base stations. Therefore, the size of areas sensitive to high interference depends strongly on the beamwidth of the TS antenna.

As it is shown in Figure 3-4 the C/I-values for some critical areas could be lower than 15dB, where only for links in this area robust modulation schemes has to be used.

Furthermore, it should be emphasised that in a cellular environment with high sectorization using cross-polarisation (vertical and horizontal), the use of high order modulation (e.g. M= 64) would be quite difficult due to the presence of high amount of inter-sector interference.

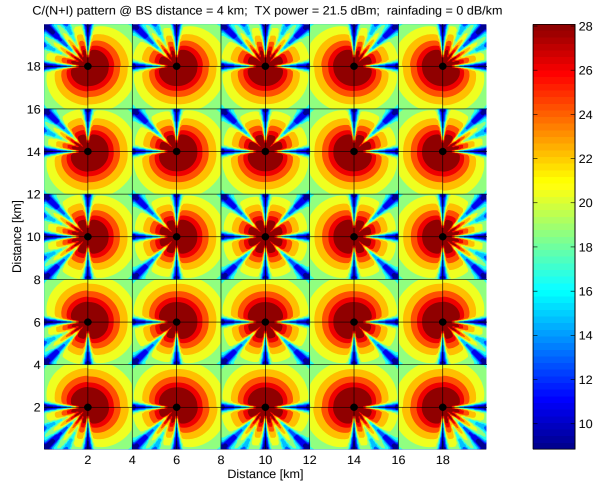

Figure 3. C/(N+I) Distribution in a Rectangular 5x5 Multi-cell Configuration

Indeed, in addition to high amount of interference the BWA microwave radio link is disturbed by high rain-attenuation. The rain attenuation increases as the carrier frequencies become higher. The amount of rain attenuation given in Figure-5 for different frequencies have been derived from the model given in [5-6]. For instance, for 26 GHz carrier frequency and 99.99% link availability the rain attenuation for a 3 km coverage can be greater than 15 dB!

Therefore, by exploiting these facts different kind of modulation constellations and code rates could be used for different links in different regions of a sector. This allows to individually optimize each link and hence to increase the total spectral efficiency.

4. Channel Coding and Modulation Strategies

As channel coding and modulation we will consider a concatenated coding scheme with an optional symbol interleaving between the inner and outer codes. This choice is based mainly on the achievable coverage due to its high coding gain at low bit error rate (BER=10E-11). As inner coding a convolutional coding (mother code rate ½) with memory 6 will be used. As outer coding a shortened

Reed Solomon code based on the mother code RS (255, 239, 8) will be employed.

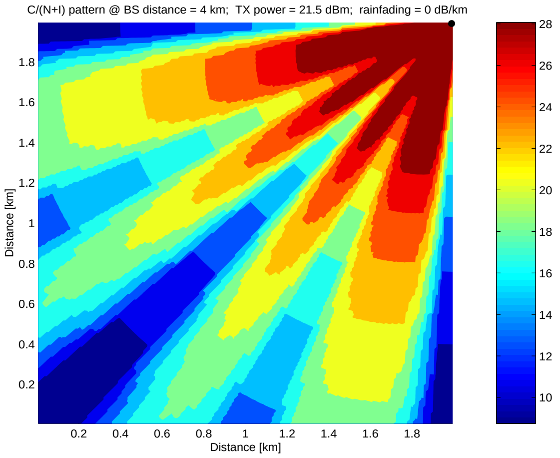

Figure 4. C/(N+I) Distribution in a worst sector of a Rectangular 5x5 Multi-cell Configuration

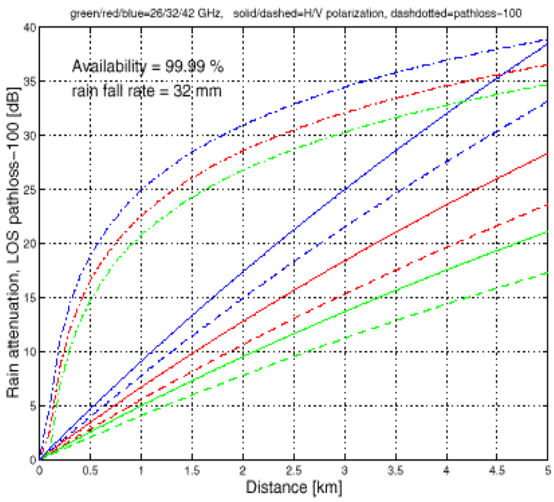

Figure 5. Rain and Path loss for different micro-wave frequencies

Exploiting these facts, different strategies on the application of adaptive/configurable channel coding and modulation for the downlink can be analyzed (see Table-1), where for the uplink we consider a single robust coding and modulation (e.g. QPSK, r=1/2). In all these strategies, we will consider the fact that the data rate in clear sky conditions can be larger than in the presence of rain. In other words, in heavy rain situation, mainly high priority services, for instance real time CBR can be guaranteed, while in clear sky all services (CBR, VBR, UBR, etc.) should be offered.

The first strategy, being the most simple one is similar to a broadcast situation, where the modulation & coding can be configured according to the weather conditions *sector by sector* basis. In other words, for sectors, where only some terminals are suffering from high interference and noise, the choice of coding and modulation should be based on the worst case scenario. However, for sectors having a better interference budget, high level modulation in clear sky condition (guaranteeing all services) and low order modulation in rain conditions (guaranteeing only some services, i.e. CBR) can be employed.

The second strategy is based on the adaptation following group of terminal (GOT) basis. Following a C/(N+I) analysis, the terminal stations within a sector could be grouped according to their reception conditions into different groups. For each set of GOT different coding and modulation can be used. Here, a frame structure is needed to synchronize all TS.

Trans. Schemes	**Strategy I**	**Strategy II**	**Strat. III**
Adaptation	*sector by sector* basis	*Group of TS* (GOT) basis	*slot by slot* (variable)
Synch. Overhead	Non	~ 5 %	32 symbols per slot
Robustness	High	High	Low
Complexity	Low	Moderate	High
Flexibility	Moderate	Moderate	High
Additional-Features	TDM receiver	TDM receiver	TDMA receiver

Table-1: Basic Characteristics of Different Adaptive Coding & Modulation Schemes for the Downlink

The last strategy is based on the adaptation per terminal station basis, i.e. *slot by slot* basis. This strategy requires a TDMA demodulator in the TS. Regarding synchronization overhead, this strategy requires much higher overhead (e.g. 32 synchronization-symbols per slot). In addition, due to slot by slot transmission (e.g. each slot convoys one ATM-packet of 53 bytes), it would be difficult to apply interleaving between inner and outer codes

5. Performance Analysis

In case of concatenated coding, the statistic of errors before Reed Solomon decoding (after Viterbi decoding) depend strongly on the interleaving depth and the channel characteristics. For high degree of symbol interleaving, errors can be considered independently. However in case of low degree of interleaving (i.e. correlated errors) a Markov model has to be considered [7-8]. Following the analysis given in [7, 8], the requited C/(N+I) values (see Table-2) to achieve a BER of 10E-11 for different coding and modulation schemes with and without interleaving has been semi-analytically estimated.

Mod.	Inner Code rate	C/(N+I) in dB with outer RS (228, 216, 8) & interleaving	C/(N+I) in dB with outer RS (69, 53, 8) & without interleaving
QPSK	1/2	3.2	4.5
QPSK	2/3	4.8	6.2
8-PSK	2/3	8.5	9.8
16-PSK	¾	14.5	16.2

Table-2: Estimated C/(N+I) for different coding and modulation schemes, BER = 10E-11

Indeed, for the estimation of the average spectral efficiency of the system a link budget evaluation is needed in order to select the optimal coding and modulation parameters, individually for each TS. It can be evaluated by:

$$P_{TX} = a_{pathloss} + P_{noise} - G_{TX\_antenna} - G_{RX\_antenna} + a_{rain} + offset + C/(N+I),$$

where

- P_{TX} (= 23 dBm) is the transmit power,
- $a_{pathloss} = 10 \cdot \log_{10}\left(\frac{4\pi f_c}{c} \cdot d\right)^2$ is the line-of-sight path loss, where f_c (= 26 GHz) is the carrier frequency, c is the velocity of light, d is the distance.
- $P_{noise} = F \cdot N_{thermal} = F \cdot KT \cdot B$ is the noise power at receiver input, where F (F= 8 dB) is the receiver noise figure, K is the Boltzman constant, T (=23°) is the temperature, B (=28 MHz) is the bandwidth.
- G_{BS} (=14 dB) and G_{TS} (=28 dB) are the antenna gains for transmitter and receiver, respectively
- *offset* (=3.5 dB) is an extra implementation margin.

The C(N+I) distribution in the presence of Rain (zone H with 99.99 % link availability) for the worst sector has been calculated, which is given in Figure 6.

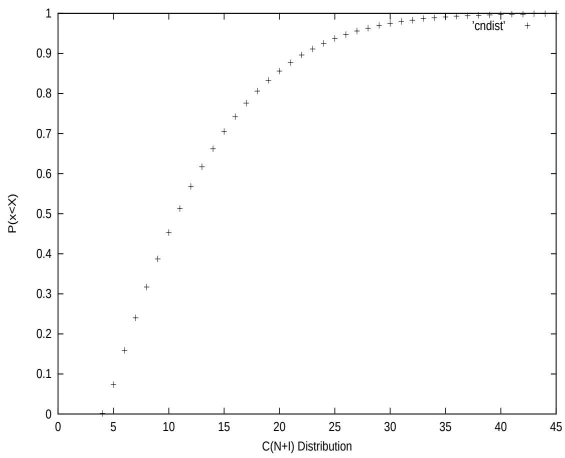

Figure 6. C(N+I) CDF in Clear Sky a 5x5 Rect. Cell Configuration

The average spectral efficiency of the system is estimated for a 4 x 4 rectangular cell configuration with four frequencies with maximum coverage of up to 3.2 km. The results are presented in Table 3 for a filter roll-off factor of α = 0.25 for MPSK modulation. At the cost of higher complexity, the results show that the spectral efficiency can be enlarged by using adaptive channel coding and modulation (Strategy II). However, the configurable scheme (Strategy I) can be also seen as an alternative candidate, which provide much lower complexity. It should be noticed that in a real deployment case, the third system (Strategy III) is much easier to adapt to different networks conditions, e.g. overlapped cell configuration. But this scheme, due to slot by slot based transmission can not exploit the interleaving gain and suffers from high amount of extra synchronization overhead.

Trans. Schemes	Strategy I	Strategy II	Strategy III
Coding schemes	4, 8, 16PSK With interl.	4, 8, 16PSK With interl.	4, 8, 16PSK Without interl.
Clear Sky			
Av. Spectral Efficiency	**1.67 bit/s/Hz**	**2.03 bit/s/Hz**	**1.57 bit/s/Hz**
Modulation	8& 16 PSK	8 & 16PSK	8 & 16PSK
Av.Data rate	**46 Mbps**	**57 Mbps**	**44 Mbps**
Rain Cond.			
Av. Spectral Efficiency	**1 bit/s/Hz**	**1.51 bit/s/Hz**	**0.92 bit/s/Hz**
Modulation	QPSK2/3	QPSK2/3, 8 & 16PSK	QPSK1/2, 8 & 16PSK
Av.Data rate	**28 Mbps**	**42 Mbps**	**26 Mbps**

Table-3: Average Spectral Efficiency in Cellular Environment with 4 Freq. for MPSK, $\alpha = 0.25$

6. Conclusions

In this paper different strategies on adaptive/configurable channel coding & modulation for a TDMA-based multiple access scheme have been analyzed. At the cost of higher complexity, the results showed that the spectral efficiency can be significantly enlarged by using adaptive channel coding and modulation (Strategy II). However, the configurable scheme (Strategy I) can be also seen as an alternative candidate, which provide much lower complexity. Indeed, in a real deployment scenario, the third strategy (Strategy III) is much flexible to be adopted to different network conditions, e.g. overlapped cell configuration. But this scheme, due to slot by slot based transmission can not exploit the interleaving gain and suffers from high amount of extra synchronization overhead.

7. References

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