CHAPTER PREDICTIONS AND ADAPTIVE CODE - MODULATION IN DIGITAL BROADBAND COMMUNICATION BASED ON HIGH ALTITUDE AERONAUTICAL PLATFORM, HAAP.

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Abstract
In this paper, the predictions and adaptation of faded aeronautical channels induced by impaired weather will be presented. The signal variations due to rain fading are generally much slower than variations due to multipath and shadowing. This is a principal problem in means of propagation for stratospheric platforms at High Altitude Aeronautical Platform (HAAP), destined to digital communication in broadband. The emphasis of this paper is given by practical adaptive modulation-coding methods. Specifically, we considered a variable-rate, variable-power modulations and variable code rate.

Keyword
HAAP, aeronautical channels, impaired weather, channel fading prediction, adaptive code - modulation.

1. Introduction
The increase of mobile personal communications, high speed data transmission, video conference and access to Internet, may look for new technological alternatives in the wireless systems. The High Altitude Aeronautical Platform (HAAP) [1] may be a good solution to resolve the problem of the increasing needs in Telecommunications by new infrastructures in the sky. The aim of this study is to examine the feasibility of an airborne platform to support broadband telecommunication services. The stratospheric platforms are stations of radiocommunication of the point-multipoint type. We can anticipate that they will be usefull for broadband and also they will have frequencies in the band millimetre Ka band. Planning services that will use Ka-band (28.48) GHz in southern areas of the planet, there is a high percentage of time in the presence of hydrometeors such as rain, snow, etc. The communication link will suffer deep fades and signal fading for a long period of time the order of seconds. To maintain the integrity of the link is important for an estimate and forecast the behavior of the radio channel. [2]-[5] Considering rain attenuations, which is a dominant factor of signal fading over airborne-earth path over Ka-band we developed simple linear estimators for receiving signal attenuations using autoregressive models [6 - 9]. These estimators present a result where with we can predict the receiving signal attenuations within a margin error of ± 0.5 dB. When we can estimate the channel and this estimate is sent back to the transmitter, the transmission scheme can be relatively adapted to the channel characteristics.[10 - 11] The adaptive transmission, which requires an accurate channel prediction or estimates at the receiver, and a reliable feedback path between the receiver and the transmitter was proposed by J.Cavers. The basic idea behind the adaptive transmission is to maintain a constant Eb/N0 by varying the transmitted power level and symbol transmission rate. [12] If we add an adaptation scheme changes in the levels of M-QAM modulation and besides this we add changes in the channel encoding rates, get a better response when the channel downlink duration worse long periods or time intervals.[13-15] Gathering the above, you can get more capacity in the services Terrestrial CDMA integrated high altitude platforms thus obtaining a flexible broadband wireless communication through the HAAP.[16-19] The paper is organized as follows: in Chapter 2, presents the scenario defined by the ITU-R for the case of HAAP, followed by the climatic situation is describe of rain clouds, in Chapters 3 and 4 the channel models and prediction, respectively. In chapter 5 and 6 describe solution with adaptive techniques in transmission of different levels of modulation. In Chapter 7, presents the proceedings of the different FEC coding rates that will be used. Finally in Chapter 8 shows the graphs obtained in Matlab simulations highlighting the results of applying this technique for prediction and adaptation HAAP channel.

2. Main Scenario
The ITU-R (International Telecommunications Union-Radio) has assigned frequencies (centre of the frequency band assigned to a station) of 28-48 Ghz for the provision of broadband services from HAAP. The study is based on Southern Chile services, many of whose population centres, such as, Santiago are located in ITU rain region K. The aeronautical channels over high frequencies such as Ka-band exhibit a high signal attenuation due to rain, which can be as high as 20-30 dB. This causes HAAP links to be designed with at least a 10 dB power margin over the requirement when the weather conditions are good so that this margin can prevent data loss due to bad weather conditions. HAAP total coverage area is divided into three zones.[2-3] These zones are necessary to ensure users to have a consistent broadband service across the HAAP wide footprint (about a 1000 km diameter) [2]-[3]. These zones are:
SAC (Sub-Urban Area Comm): the SAC extends from the UAC in about 76.5-90.5 km, depending on the operating altitude. Angles of elevation range from 30º to 15º.

RAC (Rural Area Comm): the angles of elevation are from 15º to 5º. This is reserved for dedicated high point to the access point and wide-area coverage at lower frequency bands, such as 800 Mhz to 5 Ghz bands. There is too much atmospheric and rain attenuation at 28-48 Ghz [4-5]. In this paper, the main scenario is the weather impairment between the main platform and the earth-receiver. Then, due to this reason, adjustments of the energy levels transmitted from the platform are needed to maintain the quality service in the user.

**Figure N°2.** Air terminal platform with weather impairment effect. \( r = \) horizontal distance receiver; \( \Delta r = \) horizontal distance with high signal attenuations ; \( \beta = \) the angle of elevation of the receiver.

**3. System Model**

Consider a discrete-time channel with stationary and ergodic time-varying gain \( \gamma[i] \) and additive Gaussian noise (AWGN) \( n[i] \).

Let \( \bar{S} \) to denote the transmit signal power average, \( N_0/2 \) to denote the noise density of \( n[i] \), \( B \) to denote the received signal bandwidth, and \( g \) to denote the average channel gain. With an appropriate scaling of \( \bar{S} \), we can assume that \( \bar{g} = 1 \). For a constant transmit power \( \bar{S} \), the instantaneous SNR received is \( \gamma[i] = \bar{g}[i](N_0B) \) and the average SNR received is \( \bar{\gamma} = \bar{S}/(N_0B) \).

Suppose, however, that based on the channel estimated \( \hat{g}[i] \) we adapt the transmit power at time “i” or equivalently, on \( \hat{\gamma} = \bar{g}[i]/(N_0B) \). Then, we denote the transmit power at time “i” with this adaptive scheme by \( S(\bar{\gamma}[i]) \), the received power at time “i”, then it will result in \( \bar{\gamma}[i]S(\bar{\gamma}[i])/\bar{S} \).

Since \( g[i] \) is stationary, the distribution of \( \bar{\gamma}[i] \) is independent of “i”, and we denote this distribution by \( p(\gamma) \). When the context be clear, we will omit the time reference “i”, related to \( \gamma \) and \( S(\gamma) \).

Figure N°3. Adaptive system model modulation-coding in the presence of multiplicative noise.[13]

The system model is illustrated in Fig. N°3. We assume that an estimate \( \hat{g}[i] \) of the channel power gain \( g[i] \) at time “i” is available for the receiver after the estimated time delay of \( \tau_e \) and the same estimate is available for the transmitter after a combined estimation and feedback path delay of \( \tau_0 + \tau_0 \). The channel gain estimation error \( \varepsilon[i] \) is defined as \( \hat{g}[i]/g[i] = \varepsilon[i]/\gamma[i] \). We assume that the feedback path does not introduce any errors, which can be assured by increasing its delay time using a transmission protocol. The availability of the channel information at the transmitter allows it to adapt its transmission scheme relative to the channel variation.

In the numerical calculations (see illustration), we will assume \( p(\gamma) \) to be either log-normal or exponential (Rayleigh fading), although our formulas can be applied to any distribution of \( \gamma \). The log-normal distribution arises from the attenuation of the transmitted signal by surrounding buildings, weather impairment raindrops or rain fall, and the exponential distribution arises from multipath. We will consider the two distributions separately due to the following reasons: The Rayleigh fading can be removed with a sufficient number of diversity branches in the transmitter or receiver, in which case the adaptive modulation will need only to respond to the log-normal channel variations. [Goldsmith]. The long term statistics of rain attenuation can be modeled by a log-normal process [Vilar-Burgeño]

\[
P_L(L) = \frac{1}{\sqrt{2\pi \sigma_d L}} \exp \left( -\frac{(L-m_d)^2}{2\sigma_d^2} \right), \quad L \geq 0;
\]

Where \( L \) is attenuation in decibels; \( m_d \) and \( \sigma_d \) are also presented in decibels. The study of Matriciani [9] regarding the relation of rain attenuation between a fixed system and a mobile system shows that the probability distribution of the envelope of a mobile receiver can be obtained from the fixed system by multiplying a factor which varies between 0.5 and 2.0 and that it is independent from rain attenuation. When rain attenuation is considered only in a mobile channel, the receiver signal can be represented as:

\[
r = R \cdot \exp \left( -h(L+c) \right);
\]

Where \( R \) is Rician fading due to multipath; \( h=\ln(10/20) \) and \( L \) (in dB) is the rain attenuation; \( c \) is constant scaling factor of rain attenuation from the fixed system to the mobile system.
4. Channel Prediction

The airborne-to-earth channels in order to high frequencies of 28-48 Ghz are characterized by time-varying fading of the signals. Random attenuations due to rain are the predominant impairable signal factor. However, scintillation effects cannot be ignored even if we have good weather conditions when there are not rain attenuations. The amplitude of scintillation processes has been modelled by Vilar [5]. The log amplitude of scintillations has a zero-mean conditionally normal distributions (i.e. the amplitude is log-normal in a linear scale) with a variance of scintillation log-normally distributed by itself. In a short-duration time (up to 1 minute), the variance can be considered as a constant. Therefore, we denoted the amplitude of scintillations as a random process $x(t)$ and we defined $z(t) = \ln x(t)$, the short-term distribution of the log amplitude $z(t)$ of scintillation may be considered as normal with a constant variance $\sigma_z^2$ with the following pdf:

$$p_z(z) = \frac{1}{\sigma_z \sqrt{2\pi}} \exp\left(-\frac{z^2}{2\sigma_z^2}\right); \quad (3)$$

Where $-\infty < z(0) < \infty$.

The rain attenuation of the signal can be modelled as a random process $x(t)$, which log amplitude $y(t) = \ln x(t)$ is shown as normally distributed with the following pdf:

$$p_y(y) = \frac{1}{\sigma_y \sqrt{2\pi}} \exp\left(-\frac{(y-m_y)^2}{2\sigma_y^2}\right); \quad (4)$$

Where $-\infty < y(t) < \infty$.

The auto regressive (AR) models have been derived from standard techniques [6] and also in literature [5]. Rain attenuations have PSD with a slope of $f^{-2}$ and the corner frequency of $10^3 - 10^4$ Hz and receiver signal scintillations have PSD with a slope range of $f^{-2.4} - f^{-3.4}$.

The AR models have been described in [7] [8] and these are applied to modelling rain attenuation process, one-pole AR describes rain attenuations, and two-pole AR describes the scintillations. The signal attenuation $y[n]$ is modelled as the out of all-pole filter driven by a zero-mean white noise process $w[n]$ so that we can get the expression:

$$y[n] = \sum_{i=0}^{M} a_i y[n-i] + w[n]; $$

M is the order of AR process, $a_i$ FIR filter coefficients, and the linear prediction equation is given by:

$$\hat{y}[n] = \sum_{i=1}^{M} a_i y[n-i];$$

This predictor is the linear least-squares (LLS) estimator is a random process $y[n]$ is wide-sense stationary (WSS) and $w[n]$ is a zero-mean additive white Gaussian noise (AWGN). If $y[i]'s$ are jointly Gaussian, this LLS estimator becomes the optimal minimum mean-square error (MMSE) estimator [6-7-8].

In general, at time $n$, we want to predict a future, i.e., $\hat{y}[n+1], \ldots, \hat{y}[n+j]$ is based on $y[n-1], \ldots, y[n-M]$.

The AR process order $M=1$ or 2, the general prediction equation is:

$$\hat{y}[n+j] = c_1 y[n-1] + c_2 y[n-2] $$

where $j \geq 0$ determines how far ahead the predictor will tell the future.

In order to obtain the prediction coefficients $c_1'\text{'s}$, the Yule-Walker equation is proposed, in the two-pole case,

$$E(\hat{y}[n+j] - y[n+j], y[n+k]) = 0; \quad k=1, 2; \quad (8)$$

Which can be written in the form of

$$E(\sum_{l=1}^{2} c_l y[n-l], y[n-k]) = E(y[n+j], y[n-k])$$

for $k=1,2.$ ; \quad (9)

Using the covariance function of $y[n]$, $K_{yy}[m] = E(y[n], y[n+m])$:

$$\sum_{l=1}^{2} c_l K_{yy}[k-l] = K_{yy}[k+j];$$

(10)

for $k=1,2.$

Which is a matrix equations to solve for $c_i$'s in the two-pole case as follows:

$$\begin{bmatrix} K_{yy}[0] & K_{yy}[1] \\ K_{yy}[1] & K_{yy}[0] \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} = \begin{bmatrix} K_{yy}[1+j] \\ K_{yy}[2+j] \end{bmatrix}; $$

(11)

A simple way to obtain an estimate of $K_{yy}[m]$, $\hat{K}_{yy}[m]$ is to use the sample correlation function from some of the past data numbers. In our case, $\hat{K}_{yy}[m]$ is to update each time using the last N data from $y[n-N+1]$ to $y[n]$. The number N of the past data used in the sample correlation function depend on the coherence time $\tau$ of the process that we deal with. When N ~ $\tau$, we expect an accurate estimation for the covariance function.

5. Channel Adaptation

In this work, we consider schemes that use controls of power and data transmission rate [10][11][12][13]. We define a finite number of data transmission rate states according to the number of the past data used in the sample correlation function. First State, $r_1 \equiv M_1$ and $r_1$; Second State, $r_2 \equiv M_2$, $r_2$; then $r_N$ (data rate state) = $M_i$ (modulation symbol size ) and $r_i$ (code rate). See figure Nº6. A specific code rate and modulation symbol size, which differ from state. The schemes
are designed to be appropriate for the signal attenuation interval of that state that will yield the bit error rate (BER) to less than or equal to the BER target. When signal attenuation is predicted to cross over the boundary between different states, we implement a discrete change of the code rate and/or the size symbol. Within each state, continuous power control is implemented every second to compensate for the signal attenuation over HAAP earth-path so as to keep a received signal-to-noise ratio (SNR) constant.

For example, let us determine the signal attenuation boundaries in case of adaptive code M-QAM modulation, we have the average probability of symbol error of uncode M-QAM,

\[
P_e = 4Q\left(\frac{3 E_{av}}{M - 1} \frac{1}{N_0 \alpha^2}\right);
\]

(12)

The amplitude attenuation of the received signal, and Q(x) is a Q-function. Using the upper bound of the Q-function, we get,

\[
P_e \leq 2\exp\left(\frac{3 E_{av}}{2 N_0 \alpha^2} \frac{1}{M - 1}\right);
\]

(13)

Which should be less than the BER target. Solving this for \(\alpha\) with the equality gives us the lower boundary of state “i”, \(\alpha_i\), for each M= 2, 4, 16, 64,…If we try \(E_{av}/N_0 = 25\) dB \(P_e = 10^{-3}\), we can build four M-QAM states according to the boundaries of signal attenuation as follows:

<table>
<thead>
<tr>
<th>State</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(0 &lt; \alpha &lt; 0.22) dB (64 QAM)</td>
</tr>
<tr>
<td>2</td>
<td>(0.22 &lt; \alpha &lt; 9.2) dB (16 QAM)</td>
</tr>
<tr>
<td>3</td>
<td>(9.2 &lt; \alpha &lt; 12.3) dB (4 QAM)</td>
</tr>
<tr>
<td>4</td>
<td>(12.3 &lt; \alpha &lt; 12.3 + X) dB (BPSK)</td>
</tr>
</tbody>
</table>

Table N1, Adaptive Code for error probability.

Where X is determined by the maximum power compensation margin that the system can endure before reaching the power amplifier saturation point. In the HAAP case, the second zone (SAC) expands from the UAC to 76.5-90.5 km, and angles of elevation range from 15\(^\circ\) to 30\(^\circ\); the power amplifier works at the saturation point, then power control is truncated, avoiding to maintain a received SNR constant, then adaptive coding rate must be used.


The adaptive Coding is illustrated by block diagram in figure Nº4, [14][15] Data to be transmitted are generated by data source and encoded using one of the M punctured convolutional codes and interleaver convolutional. The forward channel is composed of the modulator, the physical channel and demodulator. In order to implement the adaptive coding scheme, it is necessary to use a return channel. Once the channel state has been estimated, a decision is made by predictor and it changes the code, and the corresponding messages are sent to the encoder and locally to the decoder. We consider forward error correction (FEC), in which only error correction is performed. The FEC procedure maintains a constant system throughput; though, in channels with high error rates, complex codes are required to keep the probability of uncorrected errors below a prescribed limit.

7. FEC Procedure

In some types of communications, such as voice and video transmission and retransmissions are not allowed. For these systems, the return channel is used only to transmit the channel state estimation from the receiver to the transmitter, and the error control is achieved by FEC procedure. [8]

The adaptive error protection is obtained by changing the code rates. For practical purposes, it is desirable to modify the code rate without changing the basic structure of encoder and decoder. Punctured convolutional codes (RCPC) are ideally suited for this application, and Interleaver Convolutional is also used to mitigate burst errors.[11][15]

They allow almost a continuous change of the code rates whereas decoding is done by the same decoder. The punctured codes used in our scheme have a range of code rates from 1/2 to 7/8. Table N1: Adaptive Code for error probability, BER target \(P_e = 10^{-3}\).

8. Graph of the results obtained by simulation in Matlab

Figure No. 5 shows the data from simulations provided HAAP channel model for a day of heavy rain, prediction and the result has credibility with the statistics taken by Burgeño and Vilar.

Figure Nº5. Results of the simulation prediction of data signal received during moderate rain.

Figure N6, shows the data from simulations of the channel prediction HAAP with deep and long fading planned for a day of heavy rain, his prediction and the resulting depth error when

\(j = 0\) \(j = 3\).
In this paper, we have characterized HAAP channels at high frequencies (Ka-band) with weather-induced impairment (developed channel prediction and adaptation methods are included). The rain attenuations have been modelled as random processes log-normally distributed. We have proposed a variable-rate and variable-power MQAM modulation technique, which adapts to the channel variation. Adaptive coding appears to be a promising method for error control on channels with time-varying statistics. The code parameters are selected according to the actual channel state, this state changes to maintain a BER target. The proposed scheme is formed with Convolutional Punctured plus Interleaver Convolutional (See figure N°8). The attractiveness of the adaptive coding method is clearly demonstrated by comparison to a non-adaptive scheme designed for the worst channel state. The results show an interesting mitigation proposal for the weather impairment channels. Finally an alternative technique is proposed for use in CDMA services integrated ground-based high altitude platform type HAAP.

References

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