

Prediction Method for Channel Quality Indicator in LEO mobile Satellite Communications

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Abstract— CQI(Channel Quality Indicator) is an essential indicator for AMC(Adaptive Modulation and Coding) technique in terrestrial mobile system. Due to the long delay, and fast movement of LEO satellite, CQI prediction is necessary to ensure effective AMC in LEO mobile satellite communication system. The complete procedure and problem encountered when doing AMC in satellite system are introduced and the difficulties of prediction are analyzed. In order to obtain meaningful and feasible CQI prediction results, a complete prediction scheme is proposed. For different evaluation angles and different UE speeds, Hallen's long-range prediction model and a modified smooth-ARIMA (Autoregressive Integrated Moving Average) are chosen to be applied in this scheme. Simulation results show that the prediction performance is very well with the proposed method, which can surely guarantee AMC performance.

Keywords— AMC, CQI Prediction, LEO Satellite, Long Range Prediction

I. INTRODUCTION

LEO mobile satellite system is very promising due to shorter transmission delay and smaller pathloss compared with GEO satellite system. It can obtain global coverage with several satellites. But the signal transmission situation is quite different from terrestrial system. The combination of LEO satellites and terrestrial mobile communication is a quite big challenge.

AMC (Adaptive Modulation and Coding) [1],[2] is utilized in many terrestrial systems such as LTE and HSPA. It is an important method to improve system's capacity and data transmission efficiency. CQI (Channel Quality Indicator) [3] is calculated by UEs according to the downlink reference signals, and is sent back to eNodeB to be an indicator for AMC. But in LEO mobile satellite communication system, satellite channels' propagation delay will cause trouble for AMC. The signals carrying CQI are all outdated when arriving at eNodeB. So CQI prediction is of great needs to guarantee AMC performance.

Many existing prediction models are feasible for short-range prediction in terrestrial system, such as ARIMA (Autoregressive Integrated Moving Average)[4], long-range prediction proposed by Hallen[5], Kalman filter[6], etc. The prediction parameter includes CQI[4], Doppler shift[6],

channel matrix. All these models do prediction according to the input data sequence's autocorrelation. Their prediction ability are limited when doing long-range prediction much longer than the sequence' autocorrelation time. Therefore, in LEO mobile satellite system, to guarantee AMC performance, the received CQI data's application method and the prediction model's selection are all necessary to be taken into consideration.

In this paper, in order to solve the encountered problem when doing AMC in satellite system, several existing prediction models are compared. A existing model and a proposed modified model are selected to obtain meaningful and feasible CQI prediction results.

In Section II, LEO mobile satellite communication system and the procedure and problem of CQI transmission in AMC are introduced in details. Section III gives the concrete analysis for satellite channel quality, and existing prediction models' limitation. In Section IV, the proposed prediction scheme is introduced, including introducing a modified ARIMA model, and the model selection for various transmission situation. Section V shows the simulation result. A summary for this paper can be seen in Section VI.

II. LEO MOBILE SATELLITE COMMUNICATIONS SYSTEM

A. Satellite Propagation Link Model

In LEO mobile satellite communication systems, there are several satellites serving the system, working alone or together. In this paper, we only consider the situation that a UE is served by one LEO satellite without inter-satellite cooperation.

In one LEO satellite system, double-hop is the main transmission mode. The double-hop mode comprises two signal paths: one is from the starting UE, forwarded by a satellite, and finally arrives at the destination ground station; the other one is from the ground station, forwarded by a satellite similarly, and finally arrives at the destination UE. The complete process can be seen in Fig. 1. For example, in Iridium system, as the orbit altitude is relatively low, the double-hop transmission delay is about 10ms. In LEO system, typical delay of this double-hop model is 20-80ms. The influence of delay is the interest in this paper.

B. Adaptive Modulation and Coding (AMC)

Adaptive modulation and coding (AMC) is an advanced technique to enhance data rate and make full use of channel capacity by applying different, adaptive modulation order schemes. It has been applied in many terrestrial systems. In terrestrial LTE system, UE reports CQI to eNodeB and eNodeB uses it to do AMC. UE calculates CQI based on the downlink reference signals' SNR, and feedback to eNodeB via uplink channel. After receiving CQI, eNodeB will allocate suitable downlink MCS based on the CQI and the resource distribution conditions. Overall, AMC is a strictly close loop process.

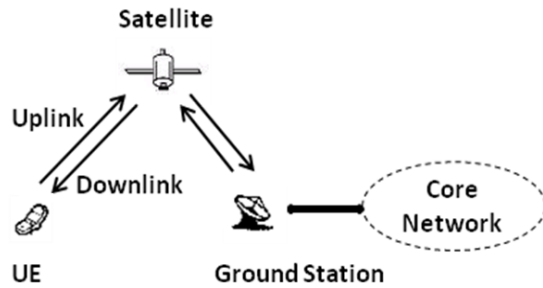


Figure 1. Double-hop model of satellite system

C. AMC in LEO Satellite System

In LEO mobile satellite communication system, AMC is also needed to improve system performance. The main difficulties for AMC are the fast variation of channel environment and the long transmission delay. The CQI data received by ground station for selecting proper MCS are outdated, and can not reflect real channel quality.

In order to guarantee AMC effectiveness, prediction is necessary for LEO mobile satellite system. As the prediction of channel quality of LEO satellite is not that much discussed in previous art, this paper wants to offer a heuristic idea.

III. SATELLITE CHANNEL QUALITY MODEL AND PREDICTION MODEL

A. Satellite Channel Quality Model

As introduced before, in LEO satellite system, the key channel parameters needed to be taken into consideration includes: Doppler frequency shift caused by satellite, Doppler spread caused by UE movement, the double-hop transmission delay.

In this paper, we assume that the large Doppler frequency shift can be detected accurately and corrected without deviation.

Models introduced by Loo[7], Lutz[8], and Corazza[9] are all commonly used satellite channel models. In this paper, a statistic model introduced in [10] is employed, which is a detailed satellite channel model based on Loo[7]. The model

considered small scale fading and large scale fading for channel quality analysis. [10] used three-state model to describe direct signal: LOS conditions, moderate shadowing conditions, deep shadowing conditions. The transformation principle between these three states is a Markov chain. In each state, the detailed shadow fading situation varies under log-normal distribution, and with different distribution parameters for each state. The small scale fading is of Rician distribution. The signal's variation can reference to Fig. 2 [10]. It can be seen that channel quality's variation includes fast variations, slow variations, and very slow variations, which are corresponding to small scale fading in Rician distribution, large scale fading in log-normal distribution, and large scale states in a Markov chain.

B. Prediction Model

In LEO mobile satellite communication system, ground station will receive CQI data feed backed by UE. One CQI data can be received every TTI (1ms) when doing periodic feedback. The received CQI sequence is employed to do prediction.

According to the channel quality model above, CQI sequence comprises regularity and randomness. Prediction can be viewed as a filter to give a future result by using the inner regularity of the sequence and avoiding the influence of randomness as much as possible. Different prediction models may use different properties of the sequence and may have different prediction ability. In general, the short-range prediction performance is much better than long-range prediction. The limitation of a prediction model is more and more obvious as the predict-range getting longer, which may cause great impact on the AMC decision.

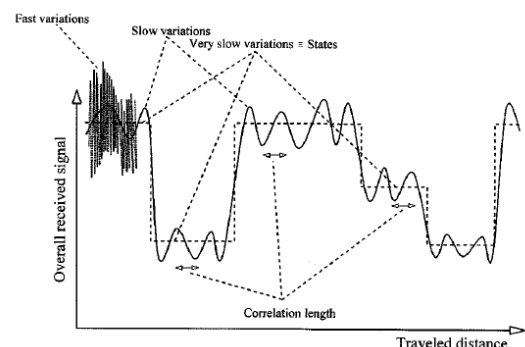


Figure 2. Different rates of change of the various received signal components

Two prediction models are considered in this paper. ARIMA [4] is a commonly used prediction model in terrestrial system. Hallen's long-range prediction [5] is introduced for the specific situation in this paper.

1) Autoregressive Integrated Moving Average (ARIMA)

ARIMA is a widely used channel quality prediction model. In terrestrial mobile system has already applied this

model to predict CQI in 1TTI (1ms) range[4]. Here is definition of ARIMA (p,d,q) model:

$$\hat{z}_t(l) = E_t[\hat{z}_{t+l}] = \sum_{j=1}^{l-1} \phi_j \hat{z}_t(l-j) + \sum_{j=l}^{p+d} \phi_j \tilde{z}_{t+l-j} - \sum_{j=l}^q \theta_j a_{t+l-j} \quad (1)$$

Assume that received CQI state sequence is $z_t, z_{t-1}, z_{t-2} \dots$. In Eq.1, $\hat{z}_t(l)$ stands for the minimum mean square error prediction for l steps ahead of t . Assume μ as z_t sequence's average value, and a_t stands for the interference impulse. It has $\tilde{z}_t = z_t - \mu$. This model has been utilized in terrestrial with good performance[4], and has a relative low computation complexity, and can output result in time.

Due to the heavy dependence on sequence autocorrelation, the prediction performance decreases quickly when the prediction range is becoming longer than autocorrelation time. In this paper, the needed prediction range is 40ms, as the TTI=1ms, 40 step predictions are needed under this situation. According to Eq. (1), 40-step prediction will bring about huge computation quantity, also with much longer process delay. Meanwhile, when the prediction range is long enough, the output of this model will be the sequence's average value, which loses the value of prediction[11].

2) Long-range prediction[5]

Long-range prediction is firstly derived by Hellan. This method is based on AR model, and uses down sampled input data sequence as the prediction input. If the down sample frequency f_s satisfies Eq. (2), where f_d is the maximum Doppler shift, the prediction can be done for a relative long-range with little information loss. The prediction range can be as long as several times of sequence autocorrelation time, up to around one wavelength [5].

$$f_s \geq 2 f_d \quad (2)$$

This method has a relative same computation complexity with ARIMA. But after downsampling, the input data's interval becomes larger, for example, 5ms, then the prediction step will reduce to 8, which is much smaller than 40 steps for ARIMA model and the computation complexity decreased consequently.

C. Channel Autocorrelation Analysis

According to the analysis above, these prediction models' parameters and prediction ability rely on the input sequence autocorrelation time. Therefore, it is necessary to analysis the CQI data, or channel quality autocorrelation time before prediction.

In LEO mobile satellite system, the maximum Doppler spread is as follows:

$$f_{dm} = \frac{v}{c} f_c \cos \theta \quad (2)$$

Where v is the speed of UE, c is the speed of light, f_c is the frequency of carrier, θ is the angle between UE movement direction and the radio waves incident direction.

The signal correlation time is:

$$t_c = \frac{0.423}{f_{dm}} = \frac{0.423}{\frac{v}{c} f_c \cos \theta} = \frac{0.423c}{v f_c \cos \theta} \quad (3)$$

If S-band is used in this system, assume it has $f_c=2.4\text{GHZ}$, then:

$$t_c = \frac{0.423}{8v \cos \theta}, L_c = \frac{0.423}{8 \cos \theta} \quad (5)$$

A few correlation time and maximum Doppler shift are calculated in Table 1.

TABLE 1. CORRELATION PARAMETERS

θ (°)	V(m/s)	fdm(HZ)	tc (ms)
10	3	23.64	17.89
	10	78.77	5.37
	30	236.44	1.79
40	3	18.38	23.01
	10	61.30	6.90
	30	183.83	2.30
80	3	4.17	101.50
	10	13.89	30.45
	30	41.67	10.15

According to Table 1, influenced by different UE speed and evaluation angle, the signal's correlation time and length are quite various.

IV. CQI PREDICTION METHOD IN LEO MOBILE SATELLITE COMMUNICATIONS

From the analysis above, it seems that when θ is large and v is small, there is possibility to obtain decades milliseconds' correlation time for prediction. Common prediction model, such as ARIMA is able to do good prediction. When θ is small and v is large, the correlation time is too short for directly prediction. A proper prediction method should be selected carefully for the latter situation. In the following discussion, both prediction performance and computation complexity are taken into consideration.

When the data autocorrelation time is longer than prediction range, ARIMA can be applied to do a 40-step prediction. But taking the complexity into consideration, since ARIMA does prediction step by step, the 40-step prediction brings about so much complexity and process delay to the system. If Hallen's long-range prediction is applied in this situation, prediction step can be minimized. For example, when evaluation angle equals 80° , and UE speed equals 3m/s, the minimum sample

rate is about 8HZ. Assume that the sample rate is 100HZ, than prediction can be done with the data interval equals 10ms, and a 4-step is enough to obtain good performance.

When the data autocorrelation time is shorter than prediction range, as introduced before, Hallen's long-range prediction model can do prediction in this situation. But also taking complexity into consideration, when evaluation angle equals 40° , and UE speed equals 30m/s, the minimum sample rate is about 366HZ, which resulting the downsampled data interval is less than 3ms. If sample rate f_s equals 500HZ, than a 20-step prediction has to be done, thus also bringing about high complexity and delay. So when f_s is large, it's also improper to use Hallen's long-range prediction model.

Actually, downsampling is some kind of losing data inner discipline. If we want to increase the sample rate to lower complexity, the inner discipline must be made use of to guarantee the prediction performance. In this paper, we propose to average the data sequence in the sample interval, not just take the data on sample point. The average can take advantage of the non-sample point data's information and smoothing away the noise influence to some extent, then enhancing the prediction performance. This new method is referred as **smooth-ARIMA** model in the following simulation.

The prediction scheme is proposed as follows:

1. Model Selection:

1) When evaluation angle θ is large and UE speed v is small:

The data autocorrelation time is longer than prediction range: Hallen's long-range prediction is applied.

2) When evaluation angle θ is small and UE speed v is large:

When data autocorrelation time is a little shorter than prediction range: Hallen's long-range prediction is applied.

When data autocorrelation time is much shorter than prediction range: Smooth-ARIMA is applied.

2. Determine the prediction model's parameters according to the evaluation angle and UE speed.

3. Do prediction using the selected model.

V. SIMULATION AND ANALYSIS

The prediction results are obtained with different parameters in Table 2, including different elevations, different UE speed. Since the prediction model has relationship with data autocorrelation time, the parameter UE speed is selected to ensure the data autocorrelation time is shorter than, almost equal to, longer than the prediction range.

TABLE 2. SIMULATION PARAMETERS

Elevation ($^\circ$)	UE Speed (m/s)	Prediction Range (ms)
40,80	3, 30	40

Fig. 3 gives the prediction result for autocorrelation time longer than prediction range and the sample rate is larger than

minimum sample rate limitation. It shows that all the three prediction models do prediction very well.

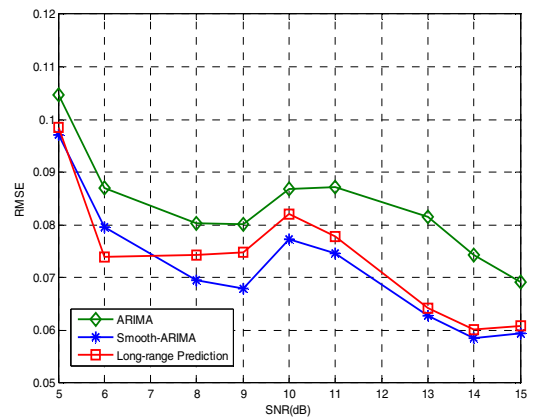


Figure 3. Prediction performance when $\theta=80^\circ$, $v=3\text{m/s}$, sample rate = 100HZ

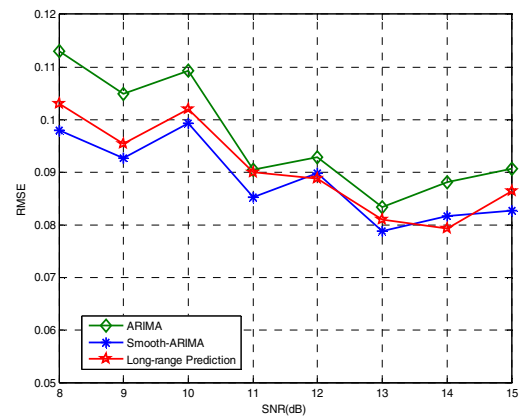


Figure 4. Prediction performance when $\theta=40^\circ$, $v=3\text{m/s}$, sample rate = 100HZ

Fig. 4 gives the prediction result for autocorrelation time a little shorter than prediction range and the sample rate is larger than minimum sample rate limitation. It shows that the performance of downsampling or smoothing every 10ms is better than 40-step ARIMA model.

Fig. 5 gives the prediction result for autocorrelation time much shorter than prediction range and the sample rate is larger than minimum sample rate limitation. It shows that the performance of downsampling and smoothing are almost the same.

Fig. 6 gives the prediction result for autocorrelation time much shorter than prediction range and the sample rate is smaller than minimum sample rate limitation. It shows that the performance of downsampling drop significantly, and smooth ARIMA are almost the same as large sample rate.

From the simulation above, it is obvious that our proposed scheme can do prediction on every specific situation.

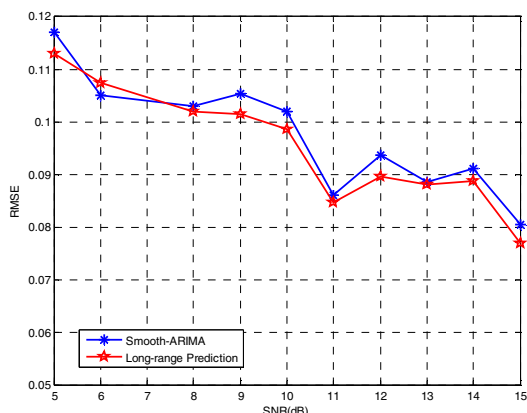


Figure 5. Prediction performance when $\theta=40^\circ$, $v=30\text{m/s}$, sample rate = 500HZ

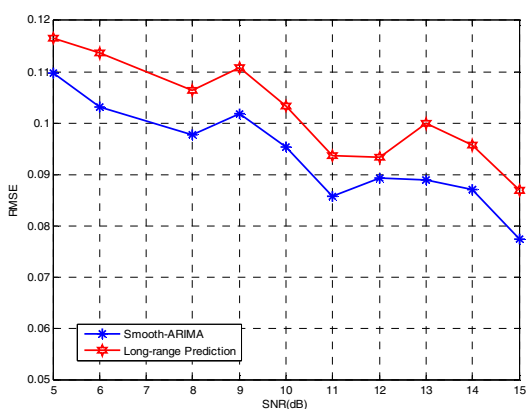


Figure 6. Prediction performance when $\theta=40^\circ$, $v=30\text{m/s}$, sample rate = 100HZ

VI. CONCLUSION

The problem encountered when doing CQI prediction for AMC in LEO mobile communication system is discussed in this paper. In order to obtain feasible and rational prediction result to guarantee AMC performance, by using different prediction model and different parameters, a complete prediction scheme is proposed in this paper. By considering both the performance and complexity, a new smooth-ARIMA model is proposed in this paper for the situation that evaluation angle is small and UE speed is large. Hallen's long-range prediction model and a new proposed smooth-ARIMA model are selected to do prediction in different situation. Simulation results show that the prediction performance is very well with the proposed method. A conclusion can be drawn that the proposed complete CQI prediction scheme can surely guarantee AMC performance.

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