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A Modified ARIMA Model for CQI Prediction in LTE-based Mobile Satellite Communications

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***Abstract*—LTE-based mobile satellite communication system is a combination of terrestrial LTE system and satellite communication techniques, which aims at improving the current LTE system's technical specifications for better service quality. AMC (Adaptive Modulation and Coding) technique is applied in current LTE system to improve system capacity and data transmission efficiency. CQI (Channel Quality Indicator), which is measured by UE, is an essential indicator for AMC process. However in satellite system, the said data received by eNodeB are all outdated due to the long delay caused by satellite link. So there exists need for predicting CQI data in advance. ARIMA (Autoregressive Integrated Moving Average Model) is a good choice for predicting CQI in terrestrial system, but its prediction ability is limited when prediction length is too long in satellite communication system. To solve this problem, a prediction scheme is proposed in this paper. This method predicts CQI states, instead of predicting the specific CQI values, and provides the reference CQI for AMC. A modified ARIMA model is applied for reducing the prediction complexity and delay. Simulation shows that the proposed method can realize CQI prediction with acceptable RMSE performance.**

I. INTRODUCTION

AS the satellite communications has the characteristics of wide downlink broadcast coverage, not sensitive to ground situations, wide frequency band, good communication quality and other advantages, it has been gradually paid much more attention. If combined with satellite techniques, current LTE [1] system will surely obtain new leap forward. However, taking the satellite communications' long signal transmission delay and other features into account, existing terrestrial LTE technology implementation requires some changes accordingly.

AMC (Adaptive Modulation and Coding) [2][3] is utilized in terrestrial LTE system. It selects appropriate modulation and coding scheme (MCS) to improve system's capacity and data transmission efficiency. The selection is dynamic, depending on the channel's changes over time. An essential indicator of channel quality is CQI (Channel Quality Indicator) [1][4], which is calculated by UEs according to the downlink reference signals, and is sent back to eNodeB.

In satellite systems, for AMC process, the long delay caused by satellite link will lead to the result that CQI signals will arrive at eNodeB after a long period of time. In other words, the data used in AMC process for MCS selection are generated a long time before. If adjustment is carried out based on these overdue data, when channel's situation becomes better, power and frequency resource will be wasted. On the contrary, when channel's situation becomes worse, unnecessary HARQ process may be triggered off, thus wasting time resource similarly. Therefore, in order to improve AMC efficiency, it is significant to predict the CQI data which really represents the channel's situation when AMC instruction arrives at the destination UE.

Recent research about CQI prediction in terrestrial systems mostly focus on time series prediction model, such as exponential smoothing model [5][6], moving average algorithm [7], or ARIMA (Autoregressive Integrated Moving Average Model) [8][9]. Also some other parameters, for example SINR, can be revised to obtain more accurate CQI values [10]. Also the feedback rate of CQI [11] can be considered for better system capacity. Among these algorithms, ARIMA owns the merits of high accuracy and simple implementation structure, which also performs very well in terrestrial systems [8]. But due to the long delay of satellite transmission link, ARIMA cannot be applied in the system directly. As a result, a meaningful prediction method must be proposed in order to provide rational results for effective AMC adjustment.

Based on the above, taking the long delay in LTE-based mobile satellite communication system into account, a prediction scheme is proposed in this paper. The said scheme can provide rational result for AMC by replacing the prediction of specific CQI values with prediction of CQI states during a period of time. A modified ARIMA model is applied when predicting CQI states, thus reducing the hardware implementation and realization complexity. The idea of exponential smoothing algorithm is employed in the said modified algorithm, and forced feedback is added.

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Prediction formula is simplified, thus allowing it possible to use low-order model to do prediction other than high-order model and improving calculation speed.

In Section II, LTE-based mobile satellite communication system and the process of CQI transmission in AMC adjustment are introduced in details. Also the application problem is put forward. In Section III, a CQI prediction scheme is presented. And a modified ARIMA algorithm is proposed for the said prediction method. In Section IV, simulation of the modified ARIMA model is presented. Section V gives the summary for the whole paper.

II. LTE-BASED MOBILE SATELLITE COMMUNICATIONS

Satellite communication systems use satellites as relay stations to transmit signals, and communicate between different ground stations. High-orbit GEO satellite communication system is able to achieve seamless coverage of the ground, and its coverage is always much larger than the general mobile communication systems. At the same time, GEO system is not sensitive to the situations on the ground, which will help to provide coverage for a large area where business quantity is low. If current LTE [1] system can combined with satellite techniques, it is possible to obtain a leap forward for LTE.

A. Satellite Transmission Model

In satellite communication systems, there exist two transmission modes, including single-hop and double-hop. Typical application in satellite systems is double-hop mode, which will be the basic model for this paper's analysis. The double-hop model comprises two signal paths: one is from the starting UE, forwarded by a GEO satellite, and finally arrives at the destination ground station; the other one is from the ground station, forwarded by a GEO satellite similarly, and finally arrives at the destination UE. The complete process can be seen in Fig. 1. In GEO system, typical delay of this double-hop model is 540ms [12]. So in order to make use of GEO techniques in LTE system, this long time delay must be taken into account.

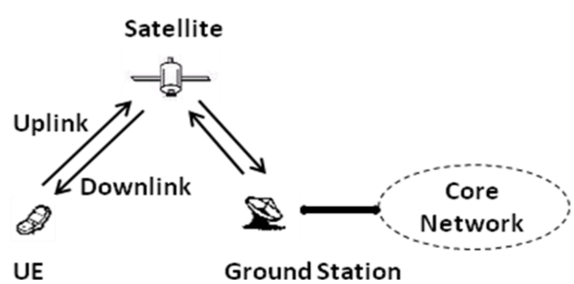

Fig. 1. Double-hop model of satellite system

B. Adaptive Modulation and Coding

Adaptive modulation and coding (AMC) is an advanced technique aiming at improving users' data transmission rate and average cell throughput. Interference can be greatly reduced by applying different, adaptive high order modulation schemes, which is a replacement of the traditional scheme which relying on changing transmission power. AMC has been widely used in current communication systems. Fig. 2 shows normal structure of an AMC communication system. LTE standard also introduces AMC which is described in detail in TS 36.213 [3]. Similarly, in LTE-based mobile satellite communication system, AMC is also needed to improve system's capacity, data transmission rate, and users' signal quality.

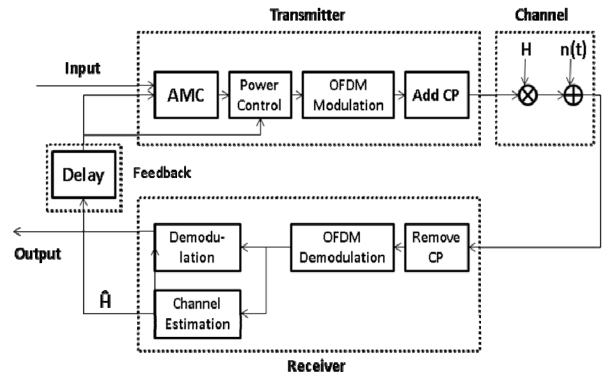

Fig. 2. AMC communication system

In terrestrial LTE system, in order to help make use of AMC by eNodeB, UE has to report CQI. TS 36.213 gives the mapping relationship of CQI index and modulation and coding scheme (MCS). UE calculates CQI based on the downlink reference signals, 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. Then UE gets AMC orders and does uplink transmission. Overall, AMC is a strictly close loop process.

If employing AMC technique in a satellite system, the long time delay caused by satellite channel cannot be neglected which leads to the result that the CQI data eNodeB received are all outdated data after a long time. Therefore, it is significant to predict CQI which really works when AMC order arrives at UE, thus allowing the improvement of AMC efficiency.

C. CQI Prediction in LTE-based Mobile Satellite Communications

The key difference of CQI transmission procedure between LTE-based mobile satellite communication system and terrestrial LTE system is that in former system CQI has to be forwarded by satellites and sent to ground station, while in latter system CQI is just transmitted to eNodeB directly. The uplink and downlink paths are quite different so that many environment features the signals experienced have changed greatly, such as transmission delay and Doppler frequency shift. CQI signals will be greatly affected due to these changes. As said before, satellite double-hop model owns 540ms transmission delay. In other words, the CQI signal which received by ground station represents the channel condition of 270ms before. Then ground station has to use these data to determine the MCS for the UE in 270ms later. As a result, the ground station has to use the received data to predict the possible CQI data of 540ms long.

As for CQI data reported in fixed period, UE will report the CQI data which measured by UE itself to eNodeB every same time interval. For example, in land LTE system, CQI can be calculated in every TTI (1ms). Then the ground station will receive a sequence with 1ms as interval. If the ground station wants to predict meaningful CQI, it has to do a 540-step prediction, which is definitely not possible for most of the time series prediction models. Therefore, this paper wants to put forward a sensible CQI prediction scheme to solve the said problem.

III. CQI Prediction Scheme for LTE-based Mobile Satellite Communications

ARIMA is a widely used time series prediction model which performs well in current terrestrial LTE system. However, when prediction time length is too long, it is hard for ARIMA to give a meaningful result. The multi-step prediction result will tend to the average value. But in satellite system, it is necessary to do multi-step prediction. So the traditional prediction scheme for land system will not work in this satellite situation. In order to solve the said problem, a meaningful prediction scheme is proposed in this paper.

A. *CQI Prediction Scheme*

[13] has mentioned that for satellite wide band system, channel fading conditions will always stay stable for quite a long time. So it is acceptable to consider these stable data to be in one state and classify all data into several states. Within each state, the channel fading condition is considered unchanged.

Given the GEO satellite channel discussed here owns the feature of slowly changing, it is acceptable to believe that in several TTIs, signal fading conditions almost stay in a small range with slightly fluctuation. There is no dramatic change between small and big fading during such period of time. As for CQI sequence, because CQI is the channel quality indicator, it is also acceptable to believe that during several TTIs, most CQI date stay in a small range with slightly fluctuation. There is no dramatic change of the specific CQI values. Hence, we can learn from [13] in which the channel fading situations are divided into states. The states classification of CQI value according to the changes is also reasonable.

Consequently, the prediction for specific CQI values can be replaced with the prediction for CQI states. And a reference CQI value can be obtained from the predicted state for AMC application. The said scheme gives up the prediction for specific CQI value. Since each state can be viewed as the statistical result of CQI values within several TTIs, the state sequence's time interval and the correlation time are both longer. For example, if 100 TTIs are mapped to one state, prediction for 540ms can be revised to predict the state in 500ms-600ms with only 6 steps prediction. As the number of prediction step is reduced significantly, the meaningful prediction can be realized.

B. *Modified ARIMA Model for CQI Prediction*

[13] classified the CQI values into 3 states, and regarded the transition between different states as a Markov process. Since the transition probability between different states must be obtained in advance by large number of statistic, it makes this model not suitable for real time prediction. As ARIMA algorithm works well in terrestrial LTE system, it is still employed for CQI state prediction in LTE-based mobile satellite communication system in this paper.

Basic formula of ARIMA model is Eq. (1).

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

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 also has $\tilde{z}_t = z_t - \mu$.

Since GEO satellite channel is special for its very stable environment, the order of ARIMA model is always higher than that applied in terrestrial system. As for normal land system, channel environment changes quickly, so the order of ARIMA model is always low due to the short correlation, such as AR(2) [9]. As the implementation complexity is directly related to the model's order, the hardware and resource expense will become much higher in satellite system than that of land system. In order to reduce the said expense, modifications of traditional ARIMA model, such as cutting down the model's order and predigestion of the prediction formula, are indeed needed.

So as to improve low-order model's performance, the idea of exponential smoothing algorithm [5] is introduced into this modified model. Exponential smoothing algorithm is a typical time series prediction model with retrospective property. The key difference between high-order ARIMA model and low-order ARIMA model is the data window size which decides how many data will be taken into account for prediction. If we want to use low-order model to achieve similar prediction performance compared with high-order model, while the window is small, introducing the retrospective property could possibly improve the prediction performance.

Here is a modification of traditional ARIMA model to solve the said problem.

Model input:

$$z_t, z_{t-1} \dots z_{t-p}, \hat{z}_t \tag{2}$$

Model output:

$$\hat{z}_t(l) = (1 - \frac{\alpha}{l})\hat{z}_{ARIMA(p,d,q)} + \frac{\alpha}{l}\hat{z}_t \tag{3}$$

In Eq. (3), $\hat{z}_{ARIMA(p,d,q)}$ stands for the traditional ARIMA one step prediction output with $z_t, z_{t-1} \dots z_{t-p}$ as input. l stands for the number of prediction steps. α stands for smoothing constant. $\hat{z}_t$ stands for the prediction result for the moment t which is already obtained earlier.

With the modification presents above, the prediction can be done with low-order model which greatly reduce the implementation complexity and processing delay.

The said modified algorithm has p actual received state data, and one pre-predicted state data which can be viewed as a forced feedback. The modification leads to the result that the output $\hat{z}_{t+1}$ comprises the information in the past, $z_t, z_{t-1}, \dots z_{t-p}, \hat{z}_t$. Similarly, $\hat{z}_t$ comprises the information of $z_{t-1}, z_{t-2}, \dots z_{t-p-1}, \hat{z}_{t-1}$. $\hat{z}_{p+1}$ comprises the information of $z_p, z_{p-1}, \dots z_1$. The initial state has $\hat{z}_p = z_p$. Eventually, a conclusion can be drawn that the result $\hat{z}_{t+1}$ comprises the information of $z_t, z_{t-1}, \dots z_1$, which is a representation of the said retrospective property.

A schematic diagram of this modified model can reference to Fig. 3.

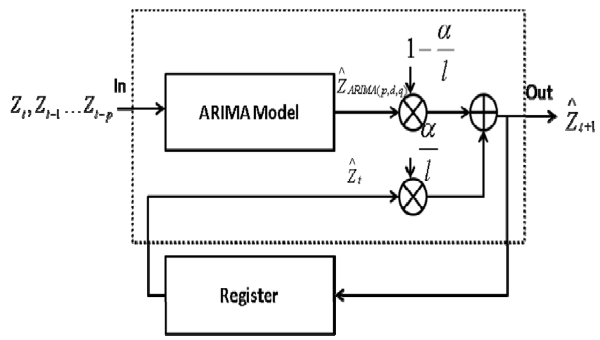

Fig. 3. Modified ARIMA model implementation structure

Table I is a rough comparison of computation complexity between traditional ARIMA model and the modified model with the assumption of d=0.

TABLE I
COMPUTATION AMOUNT OF TRADITIONAL AND MODIFIED ARIMA MODEL

	Complex Addition and Subtraction Quantity	Complex Multiplication and Division
Traditional ARIMA(p,d,q) One-step Prediction	p+q	p+q
Modified ARIMA(p,d,q) One-step Prediction	p+q+1	p+q+2
Traditional ARIMA(p,d,q) L-step Prediction	2^{L-2}(p+q)	2^{L-2}(p+q)
Modified ARIMA(p,d,q) L-step Prediction	p+q+1	p+q+2

It is clear that the modified model can reduce the implementation complexity compared with the traditional ARIMA model. Since the computation quantity is greatly reduced, the calculation speed is consequently improved.

IV. SIMULATION

Simulation is done for the said modified ARIMA model in link level. CQI data are reported in fixed period 1ms. Apply RMSE (root mean square error) as the measurement standard.

Here is the comparison of traditional ARIMA(6,0,10) and modified ARIMA(2,0,0) model.

Fig. 4 gives the state prediction performance comparison of modified ARIMA(2,0,0) model, ARIMA(6,0,10) model, ARIMA(2,0,0) model. It shows that the low-order modified ARIMA model performs a little worse than that of traditional high-order ARIMA model. Thus may be caused by the reduction the model order. Even though the forced feedback is added, the modified model data weight distribution is surely worse than the high-order model. But the performance doses not differ very much. Additionally, compared with the same order model, the modified model does a little better. The figure proves that the modified model can achieve similar prediction accuracy.

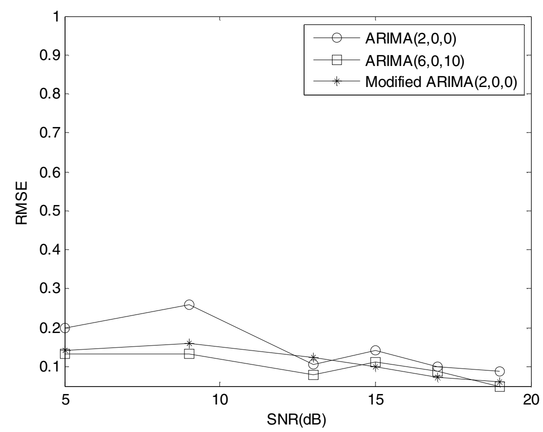

Fig. 4. State prediction performance

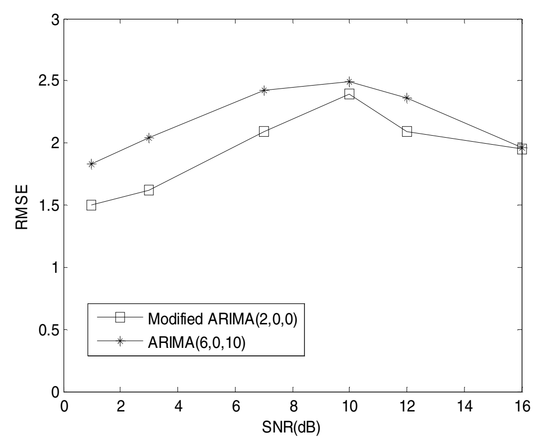

Fig. 5. Reference CQI performance

Fig. 5 shows the RMSE performance of the equivalent reference CQI predicted by modified ARIMA(2,0,0) and ARIMA(6,0,10). There isn't so much significant difference between the two results. The modified model even performs a little better. That implies that we can use the modified low-order model to do prediction other than the high-order model.

V. CONCLUSION

The necessity of CQI prediction for effective AMC adjustment in LTE-based mobile satellite communications is detailed discussed in this paper. A prediction scheme is proposed to solve the problem that traditional time series model cannot realize meaningful prediction due to the very long delay in satellite environment. The said scheme replaces the specific CQI data prediction with the CQI state prediction. A modified ARIMA model is also put forward to achieve low implementation complexity and short process delay. The idea of exponential smoothing algorithm is merged into the modified model. Forced feedback is added to introduce retrospective property and the prediction formula is simplified to enhance process speed.

The analysis of the computation quantity shows the modified model can greatly reduce the implementation complexity and process delay. Simulation gives a clear conclusion that the modified model can achieve similar accurateness compared with traditional model. Therefore, a summary can be drawn that the proposed scheme is applicable for LTE-based mobile satellite system and CQI state can be predicted quickly and accurately. The scheme can offer better reference for AMC adjustment in satellite environment.

This paper focuses on the proposal of the prediction scheme. As for the detailed state classification method and the consideration of the length of one state, there is not so much discussion. The said problems will be considered in our future research.

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