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Mobile Radio Link Adaptation by Radio Channel State Prediction

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Introduction

Applying the channel state prediction in 3G mobile communication networks [1, 2] allows securing a maximum spectral efficiency of the channel under the required error rate.

The paper deals with the selection analysis of the optimum sampling period of the radio channel signal envelope [3] and prediction interval adaptation using Kalman filter to achieve minimum channel state prediction error. Results of radio channel state prediction simulations performed in Matlab® are applicable in optimization of adaptation parameters of a real communication system [4].

Simulation of Kalman filter as radio channel state predictor

Kalman filter enables parameters prediction also for non-stationary signals [5, 6] using all information about the measured signal from the start of measurement or signal reception. The predictor applies a filter with a recursive structure. Kalman filter belongs to adaptive predictors because its coefficients are adapted in each step so as to provide optimal estimate of the signal. The predictor performs two repeatedly changing steps – prediction (time update) and correction (measurement update).

Algorithm for radio channel state prediction using Kalman filtering

Using the Kalman filter method, the following steps are performed in each simulation step:

- Based upon the specified sampling period of the radio signal envelope f_{sampl}, a set of input samples $Z(n)$ is generated over the time T;
- Based on the input data $Z(n)$, Kalman filter predicts the future state of the radio signal envelope $\tilde{I}(n+L)$, where L denotes the prediction range, i.e. the number of future samples for which the prediction is defined;
- The prediction error is evaluated using the formula $\varepsilon_{(n+L)} = \tilde{I}_{(n+L)} - Z_{(n+L)}$, i.e. calculating the difference between the predicted value and the real one of the radio signal envelope level;
- Prediction error is evaluated after the time T (adaptation period) elapses, in our simulation T is the size of the UMTS time slot, i. e. 0.667 ms;
- Optimal setting of the prediction range L_{scale}, i.e. the defined time of prediction, and radio channel envelope sampling frequency f_{sampl} to guarantee the required prediction error level ε_{allow}.

To be able to objectively evaluate obtained simulation results, the first simulations were carried out without adaptation of parameters of the prediction range L_{scale}, with sampling frequency of the radio signal envelope f_{sampl}. The parameters L_{scale} and f_{sampl} were constant during simulation. Two sampling frequencies of the radio signal envelope were chosen (f_{sampl} = 12 kHz and 24 kHz), for which the best quality of prediction, i.e. the lowest value of the prediction error was achieved [7] (Fig. 1).

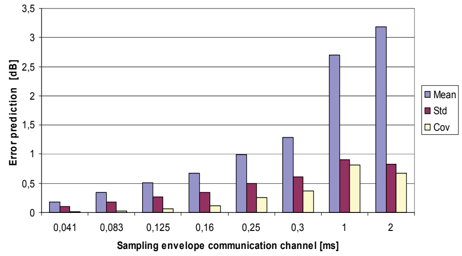

Fig. 1. Mean value, standard deviation and covariance of the prediction error versus radio channel envelope sampling period

With regard to simultaneous utilization of predictors in the link adaptation loop it is important to know properties of the predictor with Kalman filter also for various prediction intervals, i.e. prediction range L_{scale}. The received signal processing, generating of the related TPC link adaptation command and its transmission through the control channel takes certain time, hence the control station works with a relatively out-dated information about the radio channel state.

Elimination of the total delay n_{total} is the main objective of implementation of prediction methods for radio channel state estimation into transmission power control algorithms. To simulate real system, for sampling frequency f_{sampl}= 12 kHz, the UMTS time window period was chosen, i.e. $L_{scale} = 0.667$ ms (a sufficiently large prediction range). The prediction range for sampling frequency f_{sampl}= 24 kHz was chosen as the period between two subsequent samples of the radio signal envelope, i.e. $L_{scale} = 0.041$ ms (minimum prediction error). In this way, limits for the simulation without adaptation have been obtained, that can be further compared with results from simulation with prediction range adaptation (FSPRA and VSPRA algorithms).

From simulations results that the smaller is the sampling period of the radio signal envelope, the better prediction is achieved [8]. A drawback of a small radio signal envelope sampling period consists in hardware demands for computation unit and prediction possibility over a very small prediction interval; this lowers its applicability in the link adaptation loop. It is quite complicated to carry out real-time simulation using sampling frequency 24 kHz to guarantee the required QoS criterion in various types of communication environment and for various speeds of the mobile terminal.

Similar results can be achieved using methods for optimal tuning of the prediction range L_{scale} and the sampling frequency f_{sampl} (algorithms FSPRA and VSPRA with adaptation).

Fixed step prediction range adaptation

Realization of the *Fix Step Prediction Range Adaptation* (FSPRA) algorithm consists in guaranteeing minimum value of the adaptation criterion ε_{error} by changing the prediction range parameter L_{scale}.

The FSPRA algorithm is based upon evaluation of the current value of prediction error ε_{error} and consecutive increasing/decreasing of the prediction range L_{scale} by a fix adaptation step L_{step}. In our case, the prediction range step corresponds to time between two subsequent samples of the radio signal envelope, which corresponds to the sampling period of the radio signal fading envelope.

To objectively compare simulation results, the mobile station moved in heterogeneous environment. Because the environment parameters depend on the time-varying mobile station velocity, the system has to periodically update the adaptation process with the period of the UMTS time window, i.e. every 0.667 ms. Simulation was performed for two sampling frequencies of the radio signal envelope f_{sampl} = 12 kHz and 24 kHz. The required prediction error value was ε_{allow}= 1 dB.

Variable step prediction range adaptation

The Variable Step Prediction Range Adaptation algorithm *(VSPRA)* is the second method for optimal changing of the prediction range parameter L_{scale} in order to minimize the adaptation criterion value ε_{error}. The main principle of the prediction range adaptation block with variable step is based upon evaluation of the current value of the prediction error ε_{error} for the given prediction range, as well. Two parameters were introduced, affecting the prediction range change ΔL_{scale} based on the evaluation of the current value of the prediction error ε_{error}.

The qualitative parameter $\varphi_{trend}(n+L)$ characterizes the prediction error change trend and can achieve three distinct values $\varphi_{trend}(n+L) = \langle -1,0,1 \rangle$ describing the trends of the prediction range ΔL_{scale}, namely decrease, without change and of growth.

Another qualitative parameter is the *change weight* $\phi_\Delta(n+L)$ with values from the interval $\langle 0,1 \rangle$ where $\phi_\Delta(n+L) = 0$ indicates that the new prediction range equals the previous one $L_{scale}(n+L) = L_{scale}(n+L-1)$, i.e. the prediction range change $\Delta L_{scale} = 0$, and vice versa, the value 1 indicates the highest possible slope of the prediction range change. The change weight $\phi_\Delta(n+L)$ is directly proportional to the current prediction error ε_{error}. The resulting prediction range value L_{scale} is defined as follows

$$L_{scale}(n+L) = L_{scale}(n+L-1) + \left(\phi_\Delta(n+L) \cdot L_{step}\right) \cdot \varphi_{trend}(n+L). \qquad (1)$$

The objective evaluation of simulations requires securing equal conditions, hence also in these simulations the mobile station moved in a heterogeneous environment. The adaptation process was periodically updated with the period of UMTS frame time window (0.667 ms). Simulation was carried out for two sampling frequencies of the radio signal envelope f_{sampl} = 12 kHz and f_{sampl} = 24 kHz. Required value of the prediction error was again ε_{allow}= 1 dB.

Evaluation of simulation results

Results of the radio channel state prediction simulation without prediction range adaptation, with fix step adaptation (*FSPRA algorithm*) and with variable step adaptation (*VSPRA algorithm*) are compared in Fig. 2 using cumulative distribution function CDF.

Comparison of FSPRA and VSPRA adaptation algorithms shows reduction of the prediction error ε_{error} when using the variable step prediction range adaptation

(VSPRA). The using of parameters $\varphi_{trend}(n+L)$ and $\phi_{\Delta}(n+L)$ contributed to the global reduction of the prediction error ε_{error} and to keeping the allowed prediction error ε_{allow}. The difference in prediction error of the VSPRA algorithm for the two sampling frequencies 12 kHz and 24 kHz was 0.35 dB. If this difference value is acceptable, a lower sampling frequency can be used (f_{sampl} = 12 kHz) which considerably reduces the real computational load of the algorithm and thus also the time needed for selection of the prediction range for the transmission of a new UMTS window. In simulations, an ideal feedback channel for information transmission into the transmitter is supposed.

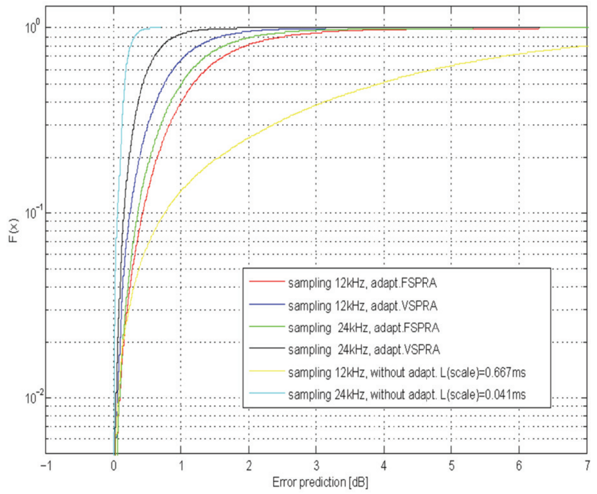

Fig. 2. Comparison of the prediction error CDF of a system without prediction range adaptation and with adaptation algorithms FSPRA and VSPRA

Prediction gain of the predictor depends on the prediction error [8–10]. Achieved results for adaptation algorithms FSPRA and VSPRA are compared on Fig. 3. The largest prediction gain $G_{(L)}$ was achieved using the VSPRA algorithm with sampling frequency f_{sampl} = 24 kHz. The prediction range $L_{scale}(n+L)$ is updated with the period of the UMTS time window 0.667 ms.

From the simulation results comparison (Fig. 3) concludes that algorithms in which a small prediction error is achieved (VSPRA with sampling frequencies 12 and 24 kHz), work with relatively small prediction ranges in time when the mobile station moves at the highest speed. According to the prediction range adaptation algorithm the prediction range is selected one sample ahead, to guarantee the required prediction error.

Comparison of simulation results with respect to their application in the radio channel to guarantee optimal prediction gain for a sufficiently large prediction range is in Fig. 4.

The algorithm that uses the sampling frequency $f_{sampl} = 24$kHz without prediction range adaptation achieves the best results in terms of the prediction gain $G(L)$ and on the contrary, it allows predicting the radio channel envelope state for a very small time $L_{scale} = 0.041$ ms, which corresponds to the time period between two subsequent samples of the radio signal envelope. Elimination of the time delay n_{total} is minimal.

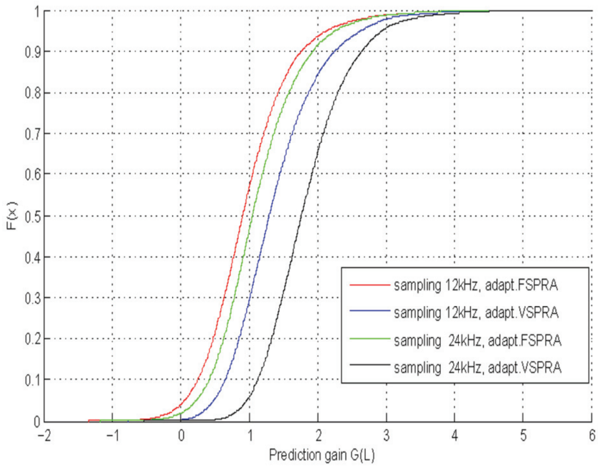

Fig. 3. Comparison of prediction gain CDF of adaptation algorithms FSPRA and VSPRA

Another drawback of algorithms without prediction range adaptation lies in the fact that the prediction range is fixed during the whole simulation. This means that the algorithm uses a small prediction range even if the mobile station is moving at a small speed (the coherent time of the radio channel is large) and thus does not eliminate the time delay in processing information needed for power control.

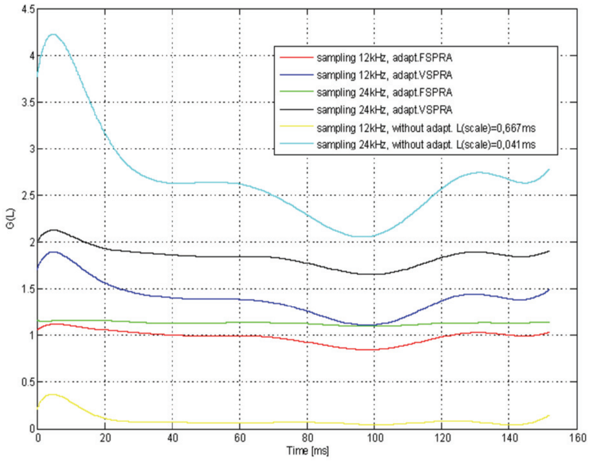

Fig. 4. Prediction gain – versus - simulation time: comparison of algorithms

Conclusions

Optimal setting of the predictor‘s prediction range L_{scale} and sampling period of the fading signal envelope is solution to the problem of channel coherent time, when small value of the coherent time brings very frequent changes of the fading envelope values. If the mobile station moves at high speed, the prediction error grows and the adaptation module reduces the prediction range L_{scale} thus improving the signal fade estimate. If the value of the coherent time channel grows, the mobile station moves at a smaller speed and the adaptation module increases the prediction range L_{scale} so as to ensure the required prediction error ε_{allow}.

Acknowledgments

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The paper explains the prediction range adaptation and optimal setting of the sampling period of the radio signal envelope to guarantee optimal quality and capacity of the radio channel. The developed algorithms FSPRA and VSPRA provide optimal setting of the prediction range with respect to the mobile station motion. Both algorithms are compared with the algorithm without adaptation. Efficiency of algorithms and their contribution to minimization of the radio channel state prediction error, optimal prediction gain for a sufficiently large prediction range with respect to execution speed of the adaptation algorithm are evaluated. The paper focuses on using the Kalman filter to predict the radio signal fading envelope and potential implementation in the transmitter power control loop. Ill. 4, bibl. 10 (in English; abstracts in English and Lithuanian).

P. Žiačik, V. Wieser. Mobiliojo radijo ryšio kanalo būsenos prognozavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 8(114). – P. 27–30.

Pateikiamas optimalią kokybę ir radijo kanalo talpą garantuojančio radijo signalo prognozuojamas veikimo nuotolis ir optimalūs nustatymai reikiamu laikotarpiu. Analizuojami FSPRA ir VSPRA algoritmai, įvertinantys mobiliojo ryšio stoties padėtį, nusako optimalius prognozuojamo veikimo nuotolio parametrus. Pateikti algoritmai yra palyginti tarpusavyje bei su nepristaikančiuoju algoritmu. Pateiktas algoritmo efektyvumas, radijo kanalo būsenos prognozavimo klaidų mažinimo būdai ir kt. Daugiausia dėmesio skiriama radijo signalo būsenai prognozuoti Kalmano filtru. Il. 4, bibl. 10 (anglų kalba; santraukos anglų ir lietuvių k.).