Performance of Predictor Based Link Adaptation Algorithms

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Abstract. *The presented paper deals with the link adaptation algorithms in mobile radio access networks based on Wideband Code Division Multiple Access (WCDMA). The mobile radio channel has a significant impact on the transmitted signal between User Equipment (UE) and Base Station (BS). The character of environment (e.g. number of received reflections) and increasing UE velocity cause unfavorable signal fadings, which have a major impact on the received signal. Due to this fact and the principle of WCDMA, fast power adaptation is essential for mobile radio access networks based on WCDMA. The prediction of mobile radio channel near-future state is one of the possible approaches how to span its unfavorable state. According to this assumption, we have improved the basic link adaptation algorithm (used to control properties of transmitter) to predictor based link adaptation algorithm. This contribution comprises the performance of basic link adaptation algorithm and predictor based algorithms, which support both variable (multi-bit) and fixed (single-bit) power steps to modify transmitter output power level. The link adaptation algorithms were simulated under various average UE velocities in urban environment. New algorithms were designed to increase the efficiency of data transmission in uplink direction.*

Keywords

WCDMA based mobile radio access networks, link adaptation, prediction methods, mobile radio channel.

1. Introduction

Improvements of the link adaptation algorithm of the mobile radio access network based on WCDMA proposed in this paper are based on the 3GPP recommendation for Universal Mobile Telecommunication System (UMTS) mobile radio network, what evolution is still in progress. The worldwide trend of the mobile radio networks usage changes the ratio between the voice based services and the data based services [1]. Thus, the trend of evolution is ongoing in the same direction [2]. Evolution of UMTS system is divided into the steps named Releases. Every release defines new techniques and technologies, what increase the quality of provided services with the guaranty of backward UE compatibility [3]. The proposed optimization of basic link adaptation (BLA) algorithm of radio access network based on WCDMA is also designed by this presumption. Therefore designed and used simulation models of mutual interference in the mobile radio access network environment, as well as limitations (e.g. boundaries of the solution) are defined according to the 3GPP recommendations for UMTS/FDD [4], [5].

The fast power control is essential for the mobile radio access networks based on WCDMA. The link adaptation is affected by the signal processing delays, Transmitter Power Control (TPC) command generation delays and traffic delays (TPC delivery through feedback control channel). There are several techniques used to achieve maximum spectral efficiency of the mobile radio access network based on WCDMA, e.g. usage of the advanced transmitting procedures (Hybrid Automatic ReQuest for retransmission (H-ARQ)), Adaptive Modulation and Coding (AMC) procedures, etc. [6], [15]. The techniques above correct negative effect of Mobile Radio Channel (MRCH), when transmitted signal is already affected [13]. The prediction of MRCH near-future state may be used to improve efficiency of Closed Loop Power Control (CLPC) by delimitation of delays in TPC delivery [11], [16].

2. Basic Link Adaptation Algorithm

The basic link adaptation algorithm, which includes all power control loops (Open, Closed and Outer) used for simulation of CLPC efficiency is depicted in Fig. 1 [7]. Open loop power control (OpLPC) defines the ability of the UE transmitter to set its initial output power when a UE is accessing the network. CLPC defines the ability of the UE transmitter to adjust its output power in accordance with received TPC commands (TPC are transmitted over the feedback dedicated control channel (DCCH)), in order to keep the received uplink Signal-to-Interference Ratio (SIR_A) at a given SIR target (SIR_R). Outer loop power control (OuLPC) is used to maintain the quality of communication at the level of agreed Quality of Service (QoS), while using as low power as possible. The uplink outer loop power control is responsible for setting a target SIR in the BS for each individual UE [3].

As was mentioned above, processing of the received signal, generation of the TPC command and transmission over the feedback DCCH cause delays (n_{total} time slots), what lead to the transmission of non-actual (delayed) TPC command. This causes unsuitable transmitter output power level changes, which do not fit to the actual MRCH state.

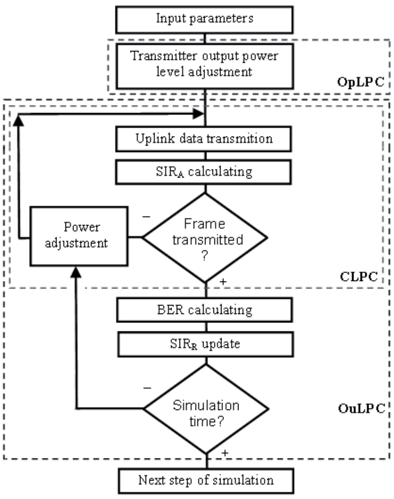

Fig. 1. Basic link adaptation algorithm.

Optimized handling of the power step Δp is additional advantage of the prediction methods used to predict the MRCH future state. CLPC defined in the 3GPP specifications uses the fixed single-bit power step Δp^{1b} based on the reported MRCH state (expressed through SIR), although constant value is too rough to span deep fadings. Δp^{1b} can be replaced by the multi-bit variable power step Δp^{nb}, when the appropriate prediction method is implemented into CLPC. Therefore the Δp^{nb} values depend only on the estimation of the MRCH state. On the other hand, disadvantage is obvious: the Δp^{nb} step needs n times higher channel capacity to be transmitted over the DCCH channel as the Δp^{1b} step needs.

3. Prediction Methods

The linear prediction of a the discrete-time signal is a powerful tool, which can be used either for the prediction of the future total MRCH channel state or for the prediction of the dominant single tap state. Used concept is based on the sub-sampled direct FIR (Finite Impulse Response) prediction, where future samples of the total MRCH state are predicted as follows [8]:

$$\hat{h}(t+L\,|\,t)=\varphi(t)\theta \tag{1}$$

where $\hat{h}$ is an estimated value, L denotes a prediction interval, the column vector θ = $[\theta_1 \ldots \theta_B]^T$ represents the float valued predictor coefficients and $\varphi(t)$ is a row vector of past channel samples:

$$\varphi(t)=[h(t),h(t-\Delta t),\ldots h(t-(M-1)\Delta t)] \tag{2}$$

where $h(t)$ denotes the float valued observation, Δt denotes a time spacing between the samples and M is a number of the predictor coefficients. The predictor's performance is expressed through a predictor gain $G(L)$ [9]:

$$G(L)=10\log_{10}\frac{E\left[(h-E[h])^2\right]}{E[\varepsilon_c(t)]} \tag{3}$$

where $\varepsilon_c(t)$ is a prediction error:

$$\varepsilon_c(t)=h(t)-\hat{h}(t\,|\,t-L). \tag{4}$$

The prediction error has zero mean. Therefore the minimum mean square error method (MMSE) is used to find the predictor coefficients [8].

The power prediction of Q monitored dominant complex valued MRCH taps ($h_{tap(q)}(t)$) is another approach how to estimate MRCH state. Efficient total power prediction can be seen as the sum of the squared magnitudes of the predicted Q complex valued taps (multipath quadratic predictor) [8]:

$$\hat{p}(t+L)=\sum_{q=1}^{Q}\left|\hat{h}_q(t+L)\right|^2. \tag{4}$$

The prediction interval L depends on the time spacing Δt between the observed channel samples $h_{tap(q)}$. Therefore input samples have to be subsampled whenever is necessary to increase the prediction interval. The subsampling of input $h_{tap(q)}$ vectors decreases resolution, what leads to poor prediction performance (i.e. the predictor is not able to trace deep fadings) if the MRCH state becomes very unfavorable (urban environment with the high density of radio waves reflectors and high UE velocity) [15].

Therefore we have considered the implementation of the third prediction method based on the adaptive iterative total power predictor, which can be used instead of training of several non-adaptive predictors for the different prediction intervals L. The adaptive iterative predictor reduces system complexity because only one predictor has to be adapted for any prediction interval. The proposed iterative predictor with assumptions made in the model filter is less sensitive to errors. The principle of iterative predictor is based on the reusing of predicted samples to predict the next one. The general model of the L-step predictor can be described [8]:

$$\hat{h}(t+L\,|\,t)=\varphi(t)\hat{\theta}(t+L\,|\,t). \tag{5}$$

The required prediction range is obtained in m-iterations, where m is the divider of L. Therefore subsampled predictor memory φ is extended into the future because of the predicted values usage. The input vectors $h_{tap(m)}$ are not subsampled and the resolution of the input samples does not decrease while L increases. Reused estimated samples contain prediction errors, which affect estimation in the following iterations.

4. Predictor Based Link Adaptation

The proposed predictor based link adaptation (PBLA) algorithm is depicted in Fig. 2. There is a new block of prediction which extends the power adjustment block in comparison with the basic link adaptation algorithm (Fig. 1). The position of the predictor in algorithm refers to the estimation of MRCH state in every time slot (one time slot = 10/15 ms). We have designed three variations of PBLA according to the implemented prediction method [7]:

- *Linear direct FIR PBLA algorithm* – the linear FIR prediction method was used for direct estimation of the total MRCH state. Appropriate downsampling of observed MRCH state samples was used to achieve requested prediction interval $L = n_{total}$. According to the results achieved in the simulation of the predictor performance (described in detail in [7]), the predictor memory $\overrightarrow{M}$ size was set to 512 samples and the number of predictor coefficients $B = 12$.
- *Multipath unbiased quadratic PBLA algorithm* – the complex valued quadratic predictor was implemented in every RAKE receiver's finger [14]. The sum of estimated paths samples composes estimated total MRCH state. The average prediction error is extracted from every estimated sample (unbias). The predictor's parameters are: $sizeof(\overrightarrow{M})$ = 512 samples, B = 8 coefficients and $L = n_{total}$.
- *Iterative multipath unbiased quadratic PBLA algorithm* – the iterative variation of previous PBLA algorithm. The number of iterations $m = L = n_{total}$.

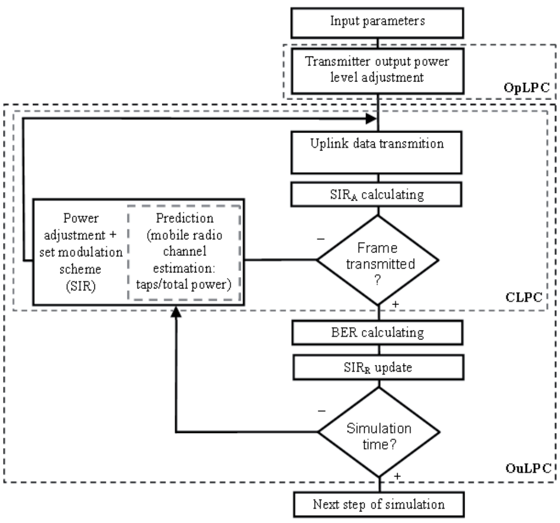

Fig. 2. Predictor based link adaptation algorithm.

The raw output of the predictor represents estimated values of the MRCH state at L. Estimated values need to be transformed into the useful information, because the functionality of CLPC is based on the actual SIR (SIR_A). Therefore we have defined two qualitative parameters of the estimated MRCH state:

- *Trend of change* $\upsilon(t+L)$, which is defined as follows:

$$\upsilon(t+L) = \begin{cases} 1 \quad (increase), & \dfrac{d\hat{h}(t+L)}{dt} > 0 \\ 0 \quad (no\ change), & \dfrac{d\hat{h}(t+L)}{dt} = 0 \\ -1 \quad (decrease), & \dfrac{d\hat{h}(t+L)}{dt} < 1 \end{cases} \qquad (6)$$

where $\dfrac{d\hat{h}(t+L)}{dt}$ is the numerical differentiation.

- *Normalized weight of change* $\psi(t+L)$ is the float based value from the range $\langle 0, 1)$, where $\psi(t+L) = 0$ indicates no change and values close to 1 report the maximal steepness of the change. In the case of the poor predictor performance (i.e. insufficient $G(L)$), the value $\psi(t+L) = 1$.

An example of dependencies between the estimated values of the MRCH state and both qualitative parameters $\upsilon(t+L)$ and $\psi(t+L)$ is depicted in Fig. 3.

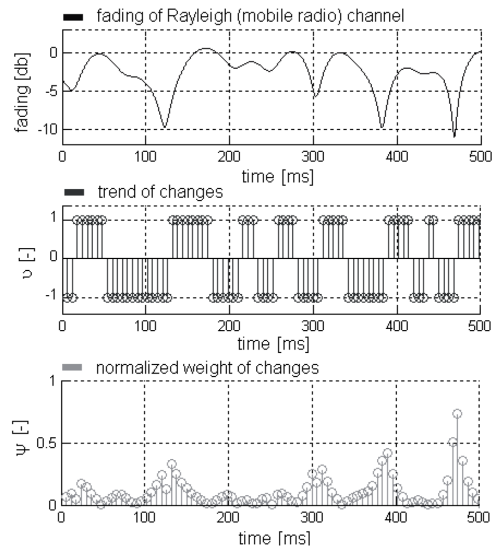

Fig. 3. Fading, trend and normalized weight of changes.

The performance of the predictor is considered as poor in all simulations described below if $G(L) < 0.1$dB (then $\psi(t+L) = 1$). The value $\psi(t+L) = 1$ refers to an error state and both qualitative parameters of the MRCH state are silently discarded in CLPC.

The WCDMA based transmitter/receiver block diagram of the simulation model is depicted in detail in Fig. 4. The block diagram describes interactions between transmitter, environment (i.e. model of MRCH) and receiver. The feedback DCCH channel used for the transmission of the TPC commands is simulated as an error-less control channel. Also the simplification of the observed MRCH samples gathering has been used. The samples are not obtained from analysis of the pilot bits transmitted in the uplink control channel, but directly from the model of MRCH. The simulation model is valid for all proposed PBLA algorithms, including simulation of the performance of the basic link adaptation algorithm (but prediction related blocks (*prediction* and *memory*) are excluded).

Designed simulation model (Fig. 4) is focused on the simulations of uplink communication. Therefore the model does not emulate different uplink control and data transport channels. Both types of channels are replaced with a continuous random data stream generated in the *information source* block (i.e. a control data are not necessary in the uplink direction). There is only one downlink *error-less control channel* created, which is used to transport feedback TPC command $s_i(t)$. The uplink data stream processing is following: the *channel coder* adds redundancy to secure transmitted data, the *spreading* spreads data stream in the spectrum (conversion to the chip rate 3.84 Mchip.s^{-1} over the selected spreading factor), *scrambling* with specified PN sequence, the *digital modulation* (QPSK) and the transmitter output power *amplifier* [4], [5]. The output samples are complex valued samples $x_i(t) = i_i(t) + jq_i(t)$. Absolute values of the complex valued samples represent nominal digital output power level $p^t_i(t) = |x_i(t)|$. The *interference source* $I_i(t)$ is represented by AWGN at level which leads to the required conditions in the *environment*. The model of Rayleigh's MRCH $G_i(t)$ is based on the Clark's statistical model [8]. The *environment* block also includes a fragmentation of transmitting signal δ_i^p. Received complex valued signal $y_i(t)$ is filtered in the *input filter* block. Main received signal processing is done in the *RAKE receiver*, where four main taps are traced (including information about every tap condition). Every RAKE receiver finger includes all standard blocks (demodulation, delay removing, descrambling and despreading). Dominant signal paths processed in the RAKE receiver fingers are weighted and combined into the one data stream $y_i(t)$, which is decoded in the *channel decoder*. The block *BER evaluation* evaluates an error ratio of the received data stream. The *prediction* block is used in the case of PBLA algorithm. Inputs of predictor represent the information about the received power level $p_i^r(t)$ (or total received power level). All predictor output values: $\upsilon(t+L)$ and $\psi(t+L)$, actual SIR and $BER_{akt,i}$ are used to form appropriate TPC command $s_i(t)$ (which carries appropriate power step value $\Delta p_i(t)$).

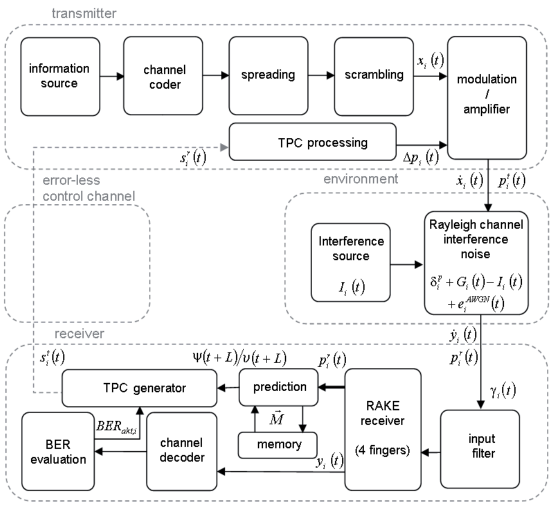

Fig. 4. WCDMA based transmitter/receiver block diagram.

It is important to notice, that the design of the simulation model allows to repeat the simulations with the same UE (e.g. direction of movement, changes in velocity) and the MRCH behavior (e.g. fadings). This makes comparison of achieved results possible and also easier.

5. Simulation Results

The BLA algorithm and the proposed PBLA algorithms were compared according to results achieved in simulations with the following main properties:

- the TPC transmission delay $n_{total} = n_{processing} + n_{traffic}$ was set to 3 time slots (i.e. 2 ms), where $n_{processing} = 2$ time slots and $n_{traffic} = 1$ time slot,
- $\Delta p^{1b} = \pm 0.5$ dB based on $\upsilon(t+L)$; $\Delta p^{3b} \in \langle 0;\ \pm 0.25;\ \pm 0.5;\ \pm 0.75;\ -1.0 \rangle$ dB based on $\upsilon(t+L)$ and $\psi(t+L)$,
- the average UE velocity $\bar{v}$ was gradually increased in 5 km.h^{-1} steps from 5 km.h^{-1} up to 50 km.h^{-1},
- the urban mobile radio environment and the MRCH model parameters ($G_i(t)$) were set in conformance with the parameters of pedestrian A/B and vehicular A/B channels defined in [12],
- the length of simulation was set to 1 500 time slots (excluding OpLPC).

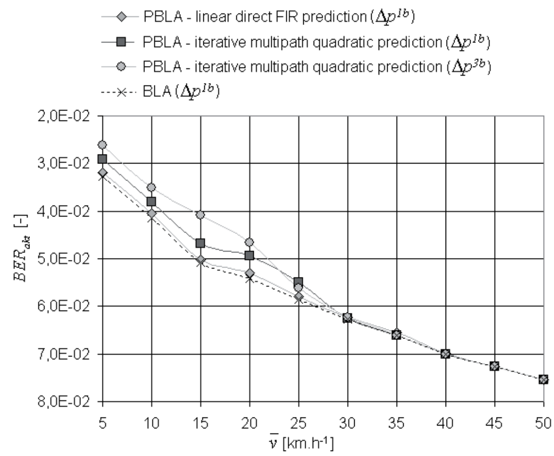

Fig. 5. BER_{akt} of simulated PBLA and BLA algorithms.

The total values BER_{akt} achieved in the simulations are depicted in Fig. 5. The BER_{akt} of BLA represents the lowest boundary which can be achieved with the PBLA algorithms. This occurred at higher $\bar{v}$ because of the weak predictor performance (i.e. $\psi(t+L) = 1$). The iterative multipath quadratic PBLA algorithm with Δp^{3b} achieved the lowest BER_{akt}. The results show, that advance of the MRCH prediction (i.e. elimination of n_{total}) was meaningful if $\bar{v} \le 30$ km.h^{-1}. If $\bar{v} > 30$ km.h^{-1}, achieved BER_{akt} values are very similar for all proposed PBLA algorithms because of an insufficient predictor performance. The BER improvement achieved with the PBLA algorithms is depicted in Fig. 6.

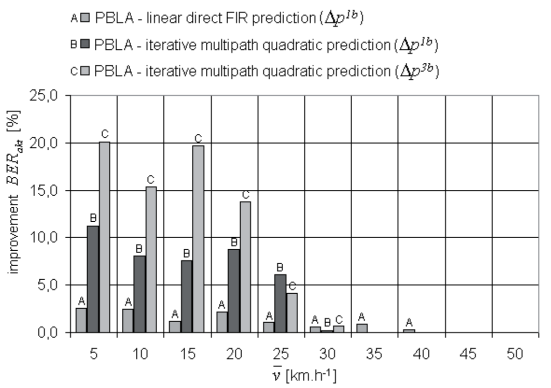

Fig. 6. Reduction of BER_{akt} for simulated PBLA algorithms.

The value of $G(L=3)$ achieved in the simulations with the PBLA algorithms is depicted in Fig. 7. The weak performance of the linear direct FIR predictor confirms the maximum achieved value $G(L=3) = 2.74$dB if $\bar{v} = 5$ km.h^{-1}. This also refers to the low percentage reduction of BER_{akt} in Fig 6.

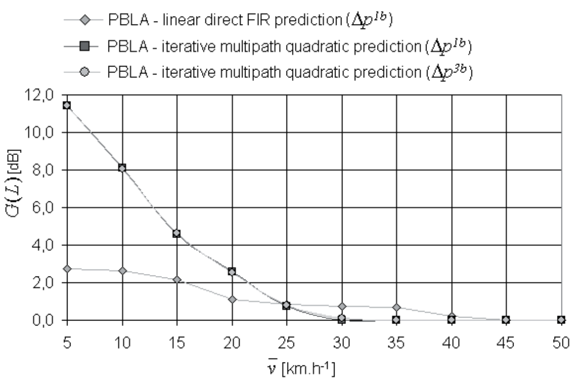

Fig. 7. $G(L=3)$ values of simulated PBLA algorithms.

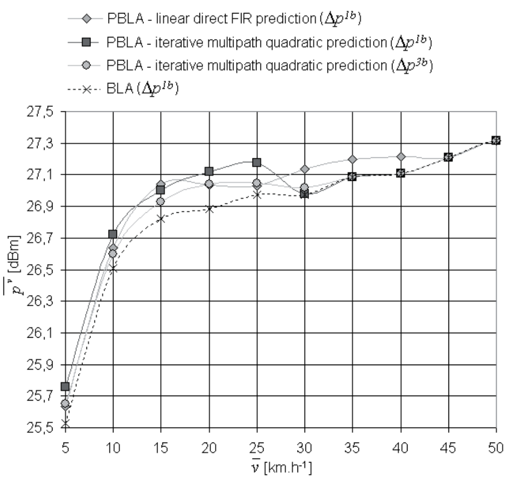

Fig. 8. $\overline{p^v}$ of simulated PBLA and BLA algorithms.

The performance of both iterative multipath quadratic PBLA with Δp^{1b} and the iterative multipath quadratic PBLA with Δp^{3b} is the same, because of the same parameters of predictors. The difference in achieved percentage reduction of BER_{akt} is caused by different transmitter power control step, where variable Δp^{3b} provides more efficient transmitter output power control (Fig. 6).

More efficient handling of the transmission power p^v in iterative multipath quadratic PBLA with Δp^{3b} is depicted in Fig 8. Justification of Δp^{3b} usage is obvious, because the iterative multipath quadratic PBLA algorithm with Δp^{3b} achieved the lowest BER_{akt}, and the average p^v ($\overline{p^v}$) is lower than for the other PBLA algorithms with Δp^{1b}.

The last worth parameter which may express performance of the proposed algorithms, represents the achieved average actual SIR $\bar{\hat{\gamma}}$ (Fig. 9). Very close dependency between the average $\overline{p^v}$ and $\bar{\hat{\gamma}}$ can be observed when trend of achieved values is compared (Fig. 8 and Fig. 9).

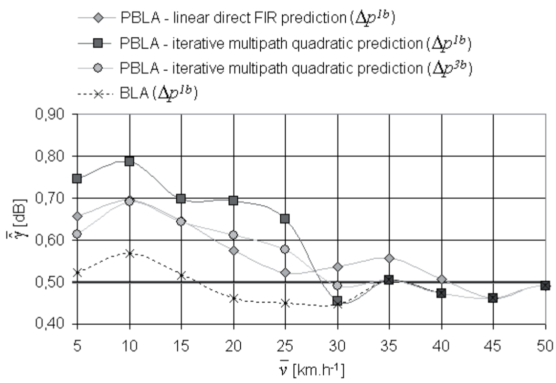

Fig. 9. $\bar{\hat{\gamma}}$ of simulated PBLA and BLA algorithms.

The main aim of OuLPC of any simulated link adaptation algorithms is to get $\hat{\gamma}$ as close to the requested SIR target γ^t as possible ($\gamma^t = 0.5$ dB in all simulations, highlighted in Fig. 9). According to the simulation results, compensation of n_{total} causes that the proposed PBLA algorithms generate the TPC command based on the estimation of MRCH with side effect: increase of average p^v. Therefore it is meaningful to search for compensation of higher $\overline{p^v}$, which iterative multipath quadratic PBLA algorithm with Δp^{3b} provides.

6. Conclusion

We have compared the performance of basic link adaptation algorithm and predictor based algorithms in simulations under the various average UE velocities in the urban environment. The most interesting simulation results (depicted in Fig. 6) show significant improvement of BER_{akt} when appropriate prediction method is used in CLPC to generate the TPC commands. The performance of predictors highly depends on the UE velocity $\bar{v}$ and the achieved results show that the prediction is meaningful for values $\bar{v} \leq 30$ km.h^{-1} (urban environment and pedestrian/vehicular MRCH properties). The prediction method is not switched off in the case of higher $\bar{v}$, but there is a mechanism implemented to avoid inadequate TPC command generation when the predictor has weak performance. The simulation results also point to the fact, that the average transmitted power p^v was increased (the higher interference to the other active UEs) when the prediction of the MRCH state was applied. The variable three bits power step Δp^{3b} instead of the fixed single bit Δp^{1b} was implemented into the iterative multipath quadratic PBLA to reduce this unfavorable side effects. The variable power step Δp^{3b} also efficiently manages both qualitative parameters derived from the MRCH estimation. The iterative multipath quadratic PBLA with Δp^{3b} achieved the highest ratio between used resources and achieved bit error rate (the maximum achieved BER_{akt} improvement was 20.2 % at $\bar{v} = 5$ km.h^{-1}). The proposed PBLA algorithms were designed to utilize benefits of the short-term prediction of MRCH. The insufficient performance when $\bar{v} > 30$ km.h^{-1} is the main disadvantage of the proposed algorithms, what opens a wide space for further development of the link adaptation algorithms.

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