Performance of Advanced Hybrid Link Adaptation Algorithms in Mobile Radio Channel

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Abstract. *The fast power adaptation is essential for WCDMA based mobile radio networks, as 3G UMTS. Although the first version of UMTS has been released in 1999 (Release 99) evolution was not finished yet. Quality of Service (QoS) and user data rate (e.g. HSDPA and HSUPA) are continuously increasing from release to release. Even though link adaptation frequency (1500 times per second) seems to be enough to span accidental fadings of mobile radio channel, used link adaptation algorithm is based on non-actual information about mobile radio channel state, which causes transmitter reaction delay to the actual channel state. Usage of appropriate prediction method to estimate near future channel state seems to be valuable step to improve hybrid link adaptation algorithm. In this article we have described and simulated the new SIR-slot based advanced link adaptation algorithms. Algorithms were designed to increase efficiency of data transmission among user equipment and base stations (uplink) for different simulation environments (pedestrian channel with mobile subscriber speed 5 km/h, 15km/h and vehicular channel with speed 45 km/h).*

Keywords

Next generation mobile networks, link adaptation algorithm, prediction methods, uplink data transmission efficiency, hybrid adaptation.

1. Introduction

The one of the latest 3G UMTS Release 05 (already active in the field) has brought advanced downlink data transmission HSDPA (High-Speed Downlink Packet Access) service, where the highest theoretical L1 data speed is above 10 Mbps. HSDPA implementation includes (H-ARQ) Hybrid Automatic Repeat Request, AMC (Adaptive Modulation and Coding), fast cell search, and advanced receiver design and prepared UMTS Release 06 includes MIMO (Multiple-Input Multiple-Output) communication [3]. In the reverse (uplink) direction the HSUPA (High Speed Uplink Packet Access) is available from Release 06. HSUPA implementation includes higher-order modulation, shorter TTI (Transmission Time Interval), H-ARQ etc. Theoretical L1 uplink data rate is above 5.75 Mbps [4]. The new specified services proofs, that the evolution of 3G is still in progress, straightforward to LTE (Long Term Evolution) and there is an aim to achieve data rates and network throughput which will be interesting in comparison to fixed data networks. Even if, HSDPA/HSUPA implementation includes a lot of new modern techniques, these are working with certain traffic delay. We see the solution of this problem in using of appropriate mobile radio channel state prediction method [1, 5].

2. Mobile radio channel prediction model

The prediction of mobile radio channel is based on observed impulse responses, where one of the limiting factors is the estimation error. We assume, that channel can be approximated as time invariant over a block of symbols, because the broadband symbol rate is much higher in comparison with the channel fading rate (time variation of channel during the estimation interval increases estimation error) [1].

The principle of basic prediction model is depicted on fig. 1, where relations between transmitter and receiver can be seen. Outer loop power control (OuLPC), located in receiver, adapts (based on BER) required SIR$_R$ $\gamma_i^t(t)$ to keep required QoS^t. The receiver calculates error $e_{\gamma i}(t)$, what is the difference between required SIR$_R$ $\gamma_i^t(t)$ and actually achieved (measured) SIR$_A$ $\hat{\gamma}_i(t)$. Measurement of SIR$_A$ $\hat{\gamma}_i(t)$ is done in block F_i, where suitable filter is located. Input signal to block F_i includes fragment of valid signal, interference from other transmitters and noise $e_i^{AWGN}(t)$.

The mobile radio channel gain $G_i(t)$ [dB], interferece $I_i(t)$ [dB] and fragment of transmission power $\delta_i^p(t)$ [dB] are represented by block named environment. Second output of F_i is information about actual received signal power level $p_i(t)$, which is also input of prediction block P_i. Predictor P_i includes own internal memory $\vec{M}$ to store actual and previous power level samples of received signal $[p_i(t-1),..., p_i(t-m)]$, where m is memory size. P_i output is predicted sample (estimation of future mobile radio channel state) $\hat{p}_i(t+L)$, where L is the prediction interval. Presented model uses fixed power step Δp to control transmitter output power level, therefore P_i output is difference $\dot{d}_i(t)$ between required power level $p_i^t(t)$ and estimated $\hat{p}_i(t+L)$ one. Error $e_{\gamma i}(t)$ and difference $\dot{d}_i(t)$ are transformed according to predefined rules to the TPC (Transmitter Power Control) command $s_i(t)$ in the block R_i. Transmitted TPC command can be affected by error $e_i^s(t)$ in backward control channel. The TPC command is decoded in block D_i (closed loop power control (CLPC)). It is obvious, that loop power control accuracy depends on traffic delay (n_p samples) of TPC command delivery and $\hat{\gamma}_i(t)$ measurement delay (n_m samples). The block R_i always causes one sample delay (time to process TPC command), therefore the total delay of one power control cycle n_{total}:

$$n_{total} = 1 + n_p + n_m \tag{1}$$

The main goal of predictor is to eliminate total delay n_{total}, what can by done by estimation of mobile radio channel n_{total} samples in advance [1, 5].

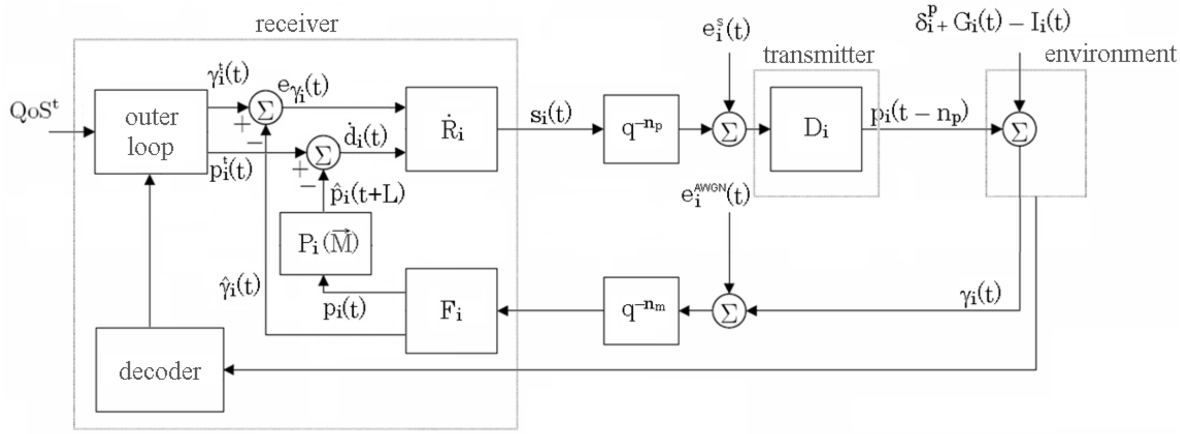

Fig. 1. Principle of basic prediction model

3. Advanced hybrid link adaptation algorithm

The designed hybrid link adaptation algorithm (fig. 2.a) is based on standard link adaptation algorithm used in UMTS/FDD system [6]. Hybrid link algorithm also includes adaptive modulation schema, coding schema control and decision about power step is based on actual SIR [7]. Required fixed power step is sent in every time slot. OpLPC sets up initial power for UE P_{UE_out} [dBm]:

$$P_{UE\_out} \geq P_{BS\_out} - (L_{PATH-LOSS} + L_{RAYLEIGH} + L_{SHADOW}) \tag{2}$$

where P_{BS_out} [dBm] is the output power of uplink control channel (UCCH) channel (measurement is done on control channel, because its format and parameters are not changed during connection), $L_{PATH-LOSS}$ [dB] is the path loss of selected environment, $L_{RAYLEIGH}$ [dB] is the Rayleigh fading loss [7] and L_{SHADOW} [dB] is log-normal shadow fading loss. CLPC is used for UE transmission power adjustment after time slot transmission. Decision is based on comparison of SIR$_A$ and required SIR$_R$. If SIR$_A$ is greater or equal to SIR$_R$, then transmitter power is decreased (power control step ΔP [dB]). On the contrary, if SIR$_R$ is greater than SIR$_A$, power is increased:

```
if ($SIR_A$ > $SIR_R$) then
    if ($SIR_A$ > $SIR_R$ + $\Delta SIR$) then $P_{MS\_out}$ - $\Delta P$
    end;
else if ($SIR_A$ ≤ $SIR_R$) then  $P_{MS\_out}$ + $\Delta P$
end;
```

where ΔSIR [dB] is the safety interval, ΔP [dB] is the power control step. Advantage of proposed hybrid link algorithm lies in possibility to control modulation a coding schema of uplink data channel (UDCH). In the case of bad mobile radio channel condition, the coding schema is updated as the first one and modulation schema as the second one. Simplified algorithm code:

```
if      ($SIR_A$ ≤ $SIR_{R\_act}$ - $\Delta SIR$)
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        if    ($P_{MS\_out}$ == $P_{MS\_max}$)
            if    ($COD_A$ is not the strongest available) then set stronger coding scheme as $COD_A$
            elseif ($COD_A$ is the strongest available) then set lower-order modulation scheme as $MOD_A$
        end;
elseif ($SIR_A \geq SIR_{R\_act} - \Delta SIR$)
        if    ($COD_A$ is the weakest available) then set higher-order modulation scheme as $MOD_A$
        elseif ($COD_A$ is not the weakest available) set weaker coding schema as $COD_A$
elseif ($SIR_A > SIR_{R\_act} - \Delta SIR$) and ($SIR_A < SIR_{R\_act} + \Delta SIR$) then do not change $MOD_A$ and $COD_A$
end;
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Information about momentary used transmission schema in UDCH is sent through control channel [8].

The Outer loop power control (OuLPC) adjusts required SIR_R to keep required QoS.

Advanced hybrid link adaptation schema includes prediction methods, where near future channel state is estimated and this forecast is used to control power level (power step value). The advanced hybrid link adaptation algorithm flow diagram is depicted on the figure 2 [13].

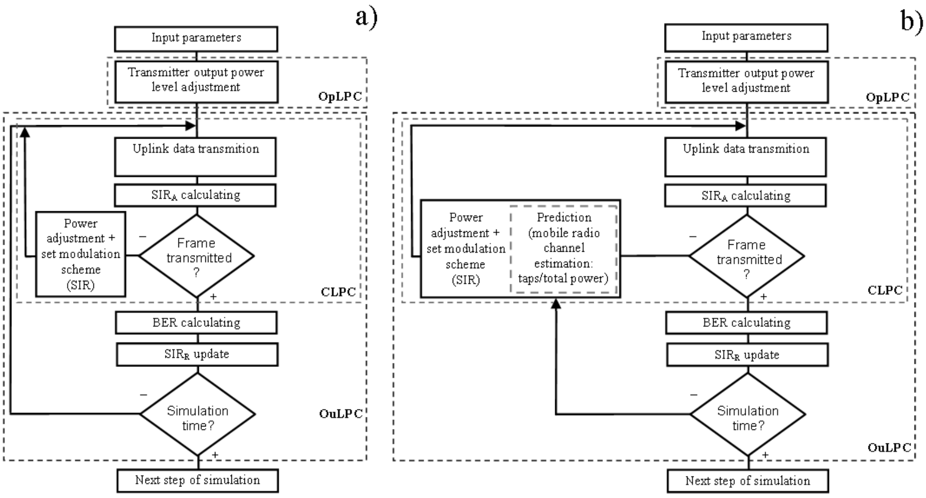

Fig. 2. a) Hybrid link adaptation algorithm [7, 9] b) Advanced hybrid link adaptation algorithm

4. Prediction methods

There are several suitable mobile radio channel state predictors, deeply described in [1]. The simplest one, is the sub-sampled direct linear FIR (Finite Impulse Response) predictor of total mobile radio channel power, which performance is not sufficient to be used at higher UE equipment velocity (e.g. acceleration of UE increases the number of deep fadings of mobile radio channel [1]):

$$\hat{h}(t+L\,|\,t)=\varphi(t)\theta\,. \tag{3}$$

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

$$\varphi(t)=[h(t),h(t-\Delta t),\ldots h(t-(N-1)\Delta t)]. \tag{4}$$

Where $h(t)$ denotes complex valued observation, Δt denotes time spacing between samples and N is the number of predictor coefficients. Prediction error is given by:

$$\varepsilon_c(t)=h(t)-\hat{h}(t\,|\,t-L). \tag{5}$$

Prediction error has zero mean and therefore the minimum mean square error MMSE criteria to find predictor coefficients, will be equal to the variance:

$$\sigma^2_{\varepsilon c}=E\left\{|\varepsilon_c(t)|^2\right\}. \tag{6}$$

Predictor's performance is expressed by a predictor gain $G(L)$:

$$G(L)=10\log_{10}\frac{E\left[(h-E[h])^2\right]}{E[\varepsilon_c]}. \tag{7}$$

Efficient total power prediction used in simulations can be seen as the sum of the squared magnitude of the *M* taps predictions [1, 2]:

$$\hat{p}(t+L)=\sum_{k=1}^{N}\left|\hat{h}_k(t+L)\right|^2 . \tag{8}$$

The prediction interval L depends on the time spacing Δt between observed channel samples $y(t)$, therefore if there is a request to increase prediction interval, input samples have to be subsampled.

The effect of observed samples subsampling against prediction gain $G(L)$ is not high in the case of low transceiver velocity. With increasing transceiver velocity the number of deep fadings is rising and designed subsampled predictor gain $G(L)$ is getting low. The subsampling of input samples causes lost of details at higher velocity, what can be eliminated by using iterative FIR predictor.

The adaptive iterative predictor reduces complexity because only one predictor has to be adapted for any prediction range. The proposed iterative predictor is less sensitive to errors with assumptions made in the filter model [1]. The principle of iterative predictor lies in reuse of already predicted samples to predict another one (up to interval of prediction). General model of *L*-step predictor can be described [1]:

$$\hat{h}(t+L\,|\,t)=\varphi(t)\hat{\theta}(t+L\,|\,t). \tag{9}$$

Required prediction range is obtained in *m*-iterations, where *m* is divider of *L*, therefore subsampled predictor memory φ is extended into the future using predicted values:

$$\begin{aligned}\varphi(t+km\,|\,t)=[\hat{h}(t+km\,|\,t),\ldots h(t+m\,|\,t),h(t),\ldots\\ \hat{h}(t+T-km)]\end{aligned} . \tag{10}$$

Where $k\in\langle 1,2\ldots T\rangle$ and T denotes the size of regressor. FIR predictor used for prediction of time varying system has time varying coefficients, therefore the output of the iterated one-step predictor is:

$$\begin{aligned}&\hat{h}(t+m\,|\,t)=\varphi(t)\ \hat{\theta}_m(t+m\,|\,t),\\ &\hat{h}(t+2m\,|\,t)=\varphi(t+m\,|\,t)\ \hat{\theta}_m(t+2m\,|\,t),\\ &\qquad\vdots\\ &\hat{h}(t+L\,|\,t)=\varphi(t+L-m\,|\,t)\ \hat{\theta}_m(t+L\,|\,t).\end{aligned} \tag{11}$$

Where $\hat{\theta}_m(t+km\,|\,t)$ denotes an *m*-step predictor with coefficients extrapolated *km* steps ahead [1].

5. Simulation model assumptions

Mathematical model used in simulation includes WCDMA based base station (receiver only), mobile station (transmitter only), mobile radio channel model and hybrid link adaptation block (Transmitter Power Coding and Modulation Control - TPCMC command related blocks). The block diagram of simulation model is depicted on the fig. 3. Presented model does not include downlink control and data transport channels, but continuous random data stream is generated in *information source* block. There is only one uplink *errorless control channel* created to transport feedback TPCMC command. Downlink data stream is secured in *channel coder,* after that *spread* (data stream is converted to chip rate 3.84 Mchip/s over the selected spreading factor) and *scrambled* (PN code). The last block - transmitter block in the row is *digital modulator* and output *amplifier* [10, 12]. Output samples are complex sample $\dot{x}_i(t)=i_i(t)+jq_i(t)$ at chip rate, where absolute value of complex sample represents nominal digital output power level $p_i^r(t)=|\dot{x}_i(t)|$.

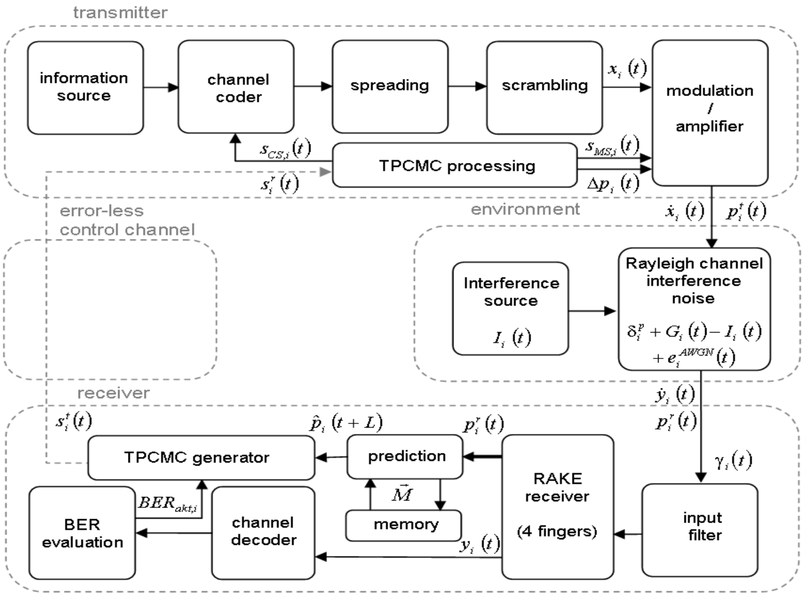

Fig. 3. WCDMA based transmitter / receiver block diagram

Inner cell interference $I_i(t)$ is represented by AWGN at required level. Rayleigh mobile radio channel model $G_i(t)$ is based on the Clark's statistical model of mobile radio channel [6]. The environment block includes fragmentation of transmitting signal δ_i^p.

Received signal $\dot{y}_i(t)$ is filtered and resampled in *input filter* block. Main received signal processing is done in the *RAKE receiver*, where four main taps are traced. RAKE receiver finger includes demodulator, delay block, descrambling block and despreading block. Tracked paths are weighted and combined to one data stream $y_i(t)$, which is decoded in *channel decoder*. The block *BER evaluation* compares received data stream with sent delayed data stream (logical connection is not depicted, this process is running in background of simulation). The *prediction* block inputs represent information about total received power level $p_i^r(t)$ (or taps received power level). Estimation of future channel state $\hat{p}_i(t+L)$ and actual BER ($BER_{akt,i}$) is used to create appropriate TPCMC command. Transmitted TPCMC command includes transmitter power step value $\Delta p_i(t)$, required coding schema $s_{CS,i}(t)$ and required modulation schema $s_{MS,i}(t)$.

Presented simulation model simplifications have no influence to the achieved prediction gain. One of the model advantages is the possibility of simulation repetition with the same mobile radio channel behavior (including initial state and changes). Therefore prediction methods can be compared under the same simulation conditions.

6. Results

Simulation has been run for 100 frames (stabilization of power loop control parameters takes 20 frames). UE transmitted test data pattern (random data source). Simulation results were achieved with spreading factor 8 and convolution coder 1/2. Mobile radio channel model was set to pedestrian (velocity range: 5km/h and 15km/h) or vehicular (velocity range: 45km/h) [11]. Interference level average value was set to -48 dBm, what represents maximum output power level boundary condition for UE (UE maximum output power level = 33dBm and minimum output power level = 15dBm). Both algorithms were compared (fig. 2), where advanced hybrid link adaptation algorithm with non-adaptive power prediction (TPCMC $n_{total}=1$) and advanced hybrid link adaptation algorithm with adaptive iterative prediction (TPCMC $n_{total}>1$) were added into the simulation model. The non-adaptive total power prediction interval L was set to 1 (1 time slot), because TPCMC command processing and traffic delay was set to 1 time slot at presented model. The prediction interval L at iterative prediction was set from 2 to 10. The L is equal to the number of iterations to estimate mobile radio channel state at required time slot. There was a fixed number of predictor coefficients $N=6$ used for both predictors. The achieved average L1 data BERs at various UE velocity are depicted in graph on the fig. 4. The link adaptation algorithm efficiency can be expressed through the average difference between SIR$_R$ and SIR$_A$: $e_{SIR}=E[SIR_R-SIR_A]$, where simulation shows that acceptable are values of $|e_{SIR}|<3dB$.

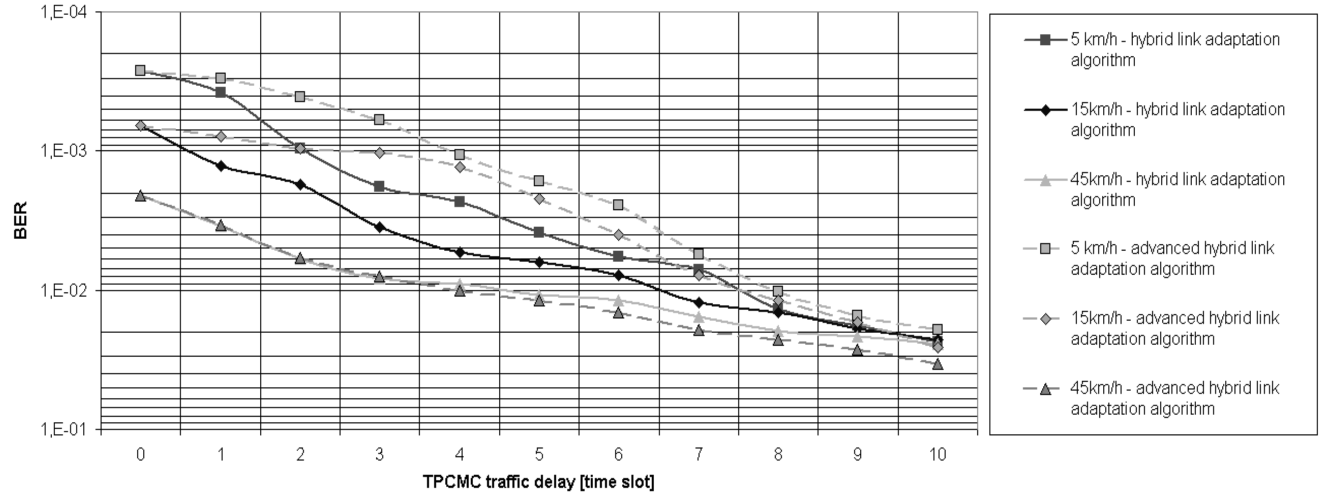

Fig. 4. Average L1 data BERs at various MS velocity and TPCMC traffic delay

During simulations were achieved values: minimum $|e_{SIR}|>0.1dB$ (TPCMC $n_{total}=0$) and maximum $|e_{SIR}|<1{,}72dB$ (TPCMC $n_{total}=10$), what confirms that link adaptation algorithms parameters were set properly. Very important indicator of prediction performance is achieved prediction gain. The advanced hybrid link adaptation algorithm with power prediction achieved maximum prediction gain $G(1\ time\ slot) = 3.61dB$ (5km/h pedestrian), but increasing of TPCMC traffic delay (length of prediction) causes the decreasing of prediction gain. Simulation of advanced hybrid link adaption algorithm in vehicular environment under UE velocity 45km/h shows that used prediction performance is insufficient to achieve lower L1 BER. Achieved gain values were bellow 0.5dB.

7. Conclusion

The simulation results depicted on the fig. 4 shows, that application of appropriate mobile radio channel prediction methods is meaningful. The maximum improvement was observed in the pedestrian environment (5km/h) when TPCMC was delayed about three time slots ($n_{total} = 3$): Hybrid link algorithm achieved average bit error rate $BER = 1.813.E - 03$ in comparison with average $BER = 0.602.E - 03$ of advanced hybrid link algorithm. Simulation also shows that presented advanced hybrid link algorithm is not powerful enough to increase high data rate (e.g. decrease BER, because all wrong transmitted data block have to be retransmitted) at higher UE velocity (vehicular velocity range and environment) in comparison with required computation and memory requirements. Average L1 data BER was not decreased, even at higher TPCMC n_{total} BER was increased. Even if performance of used power prediction is not sufficient to keep high data rate at high UE velocity, there is still space to improve prediction methods to achieve valuable results, e.g. adaptive iterative prediction can be used to estimate several samples, where the short-term prediction interval can be used to generate TPCMC command and long-term to estimate trend of mobile radio channel.

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