BER and SIR Based Hybrid Link Algorithms Performance in Mobile Radio Channel

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Abstract. *In the next generation of mobile communication networks (B3G) the using of effective handling of radio resources is supposed (channels, power and transmission rate) with simultaneous delivery of required services, in which the quality of service (QoS) is guaranteed. In this article we have described and simulated new BER based, SIR-frame based and SIR-slot based link adaptation algorithms. Algorithms were designed to increase efficiency of data transmission among user equipment and base stations (uplink) expressed by throughput and the outage probability for each link. Simulation results of hybrid adaptation (power and modulation BPSK, QPSK, 16-QAM, 64-QAM) are compared and expressed as data throughput and outage probability for different simulation environments (pedestrian channel with mobile subscriber speed 10 km/s and vehicular channel with speed 120 km/h).*

Keywords

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

1. Introduction

The main goal of our work is to achieve higher efficiency of data transmission between user equipment (mobile station MS) and base station (BS) (uplink) by adding new modulation schemes to the transmission chain. The transmission chain was designed according to the 3GPP specification for UMTS system, which is based on WCDMA [1, 3, 8]. It is possible to use higher modulation schemes in the data transmission and to offer new odds to increase efficiency of data transmission and save system resources [9]. The HSDPA (High Speed Downlink Packet Access) is an example of using 16-QAM in real WCDMA system [11, 12]. Simulation model was created in the Matlab and Simulink environment [10]. Designing new link adaptation algorithms and comparing them by several parameters is possible.

2. Simulation Model

The described model with decentralized link control is focused on the reduction of interference in the mobile radio channel. The model of the WCDMA mobile radio network consists of an optional number of base stations, which serve to trace mobile stations ("served MSs") [6]. In each cell also other mobile stations ("non-served MSs") are generated, which cause intercell and intracell interference. OVSF codes for served mobile stations are from the same branches of the code tree. On the contrary, OVSF codes from different branches are chosen for non-served mobile stations (better cross-correlation functions [5, 7]). The most important parameter of the simulation is the test environment [3], which makes possible to test designed algorithms in various conditions and compare their efficiency. The benefit of simulation model is the possibility to record every moment of actual channel conditions, mobile stations movement, part of used Pseudo-random binary sequence (PN code) and then acts accordingly [7]. This allows repeating the same simulation conditions with modified or new algorithms. The comparison of results is also simpler.

3. Link Adaptation Algorithms

The simulation model supports three types of algorithms (Fig. 1). The first one, BER-frame based algorithm, was designed according to 3GPP specifications but new modulation schemes (BPSK, 16-QAM and 64-QAM [4]) were added. The changing of modulation scheme is according to actual bit error rate (BER) after each frame transmission.

The second one, SIR-frame based algorithm, is focused on increasing the efficiency of data transmission by adding more complicated actual modulation scheme decision mechanism according to actual signal to interference ratio (SIR) and modulation scheme is changed after each frame transmission. In SIR-slot based algorithm the modulation scheme is changed after each slot transmission.

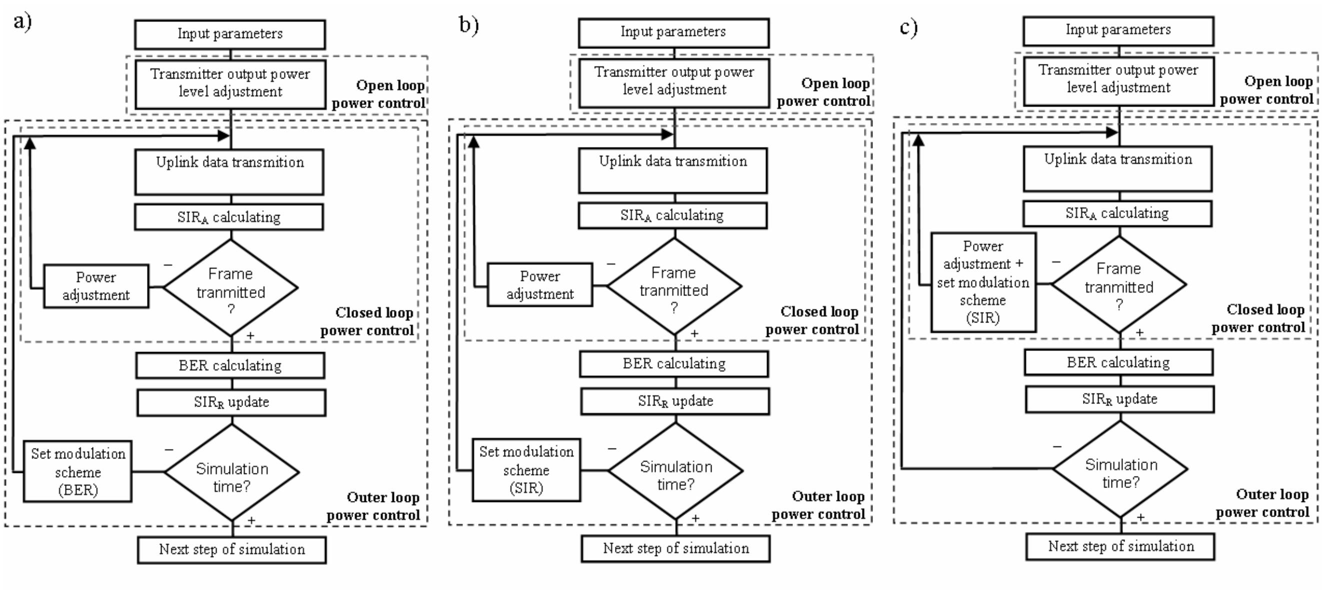

Fig. 1. a) BER-frame based algorithm b) SIR-frame based algorithm, c) SIR-slot based algorithm

3.1 BER-Frame Based Algorithm

Basic link adaptation algorithm (Fig. 1a) was derived from 3GPP specification for UMTS system [1]. Input parameters are initial (actual) modulation scheme MOD_A and required one, MOD_R. The Open loop power control (OpLPC) sets up the initial output power for the mobile station transmitter P_{MS_out} [dBm]:

$$P_{MS\_out} \geq P_{BS\_out} - \left(L_{PATH-LOSS} + L_{RAYLEIGH} + L_{SHADOW}\right) \quad (1)$$

where P_{BS_out} [dBm] is the power of Dedicated Physical Control Channel, $L_{PATH-LOSS}$ [dB] is the path loss of selected environment, $L_{RAYLEIGH}$ [dB] is the Rayleigh fading represented by Clark's model [4] and L_{SHADOW} [dB] is log-normal shadow fading. Simulation results of time slots transmission among MSs and appropriate BSs are as follow: actual BER (BER_A), intracell and intercell interference and actual SIR (SIR_A) values. The Closed loop power control (CLPC) is used for MS transmission power adjustment after time slot transmission. It can be expressed by the following part of the algorithm program code:

```
if(SIR_A ≥ SIR_R) then P_MS_out – ΔP
else if (SIR_A < SIR_R) then P_MS_out + ΔP
end;
```

where ΔP [dB] is the power control step. The Outer loop power control (OuLPC) adjusts the required SIR value (SIR_R) of used modulation scheme or it is able to set the higher-order (lower-order) modulation scheme after the frame transmission. SIR_R value is adjusted according to the following part of the algorithm program code:

```
if (BER_A > BER_R) then
      if (P_MS_out = P_MS_max) then set
            lower-order modulation
            scheme as MOD_A and set
            appropriate SIR_R
      else SIR_R + ΔSIR
      end;
end;
```

where ΔSIR [dB] is SIR control step of predefined size. On the other side, BER_A could be lower as (or equal to) the required BER (BER_R):

```
if (BER_A ≤ BER_R) then
      if (P_MS_out = P_MS_max) then SIR_R - ΔSIR
      else SIR_R + ΔSIR. Set higher-
      order modulation scheme as
      MOD_A according to SIR_A
      end;
end;
```

The algorithm continues at the uplink data transmission block (Fig. 1a.) until all required frames are transmitted.

3.2 SIR-Frame Based Algorithms

The initialization, the OpLPC and the CLPC parts of the SIR-frame based algorithm are the same as those in the BER-frame based algorithm. OuLPC adjusts SIR_R value of used modulation or can set the higher-order (lower-order) modulation scheme after frame transmission according to SIR_A. This can be expressed by the next part of the algorithm program code:

```
if (BER_A > BER_R) and (P_MS_out = P_MS_max) then set lower-order modulation scheme as MOD_A
else if (SIR_A > SIR_R_act – ΔSIR) and (SIR_A < SIR_R_act + ΔSIR) then do not change MOD_A
else if (SIR_A ≤ SIR_R_act - ΔSIR) then set lower-order modulation scheme as MOD_A
else if (SIR_A ≥ SIR_R_act - ΔSIR) then set higher-order modulation scheme as MOD_A
end;
```

where SIR_{R_act} [dB] is the required SIR for actual modulation scheme. The adjusting of modulation scheme is according to actual radio channel conditions (Non-forced algorithm). SIR_R is adjusted according to:

```
if (BER_A > BER_R) then
        if (MOD_A ≤ MOD_R) then SIR_R + ΔSIR
        else SIR_R - ΔSIR
        end;
end;
```

On the other side, BER_A could be lower as (or equal to) the BER_R:

```
if (BER_A < BER_R) then
        if (MOD_A = MOD_R) then keep SIR_R in
                the actual values (+/-ΔSIR)
        else if (MOD_A > MOD_R) then SIR_R - ΔSIR
                else SIR_R + ΔSIR
                end;
        end;
end;
```

The algorithm continues at the uplink data transmission block (Fig. 1b.) until all required frames are transmitted.

We have organized SIR-frame based algorithms into the following groups:

1. Non-forced - the modulation scheme is adjusted by the successive changing of SIR_R value.
2. Forced - the modulation is changed by forced switching. We have developed four methods of forced modulation switching:

- Forced Soft – if BER > BER_R, $P_{MS\_out} < P_{MS\ max}$ and MOD > MOD_R then SIR_R is continuously (soft) decreased by ΔSIR value, but if $P_{MS\_out} = P_{MS\ max}$ the modulation scheme is forced switched to more robust one.
- Forced Hard – if BER > BER_R, $P_{MS\_out} < P_{MS\ max}$ and MOD > MOD_R then the modulation is switched to MOD_R. The second condition is the same as in forced soft algorithm.
- Forced Soft Return and Forced Hard Return - in these algorithms we have developed the tool for return of modulation to the requested one (MOD_R), if the channel is rapidly changing (the transmission is longer or the mobile speed is higher). On the other side, if MS achieved the requested modulation scheme, BER > BER_R and $P_{MS\_out} < P_{MS\ max}$, the MOD_R is locked in specified interval (MOD_R +/- optional safety interval) until one of the inequalities is broken. This OuLPC condition is used to keep the required modulation scheme as long as possible and limits too often modulation schemes switching.

3.3 SIR-Slot Based Algorithms

The initialization, OpLPC parts of the SIR-frame based algorithm are the same as in the BER-frame based algorithm. CLPC also can set the higher-order (lower-order) modulation scheme after time slot transmission (Slot-based algorithm):

```
if (BER_A > BER_R) and (P_MS_out = P_MS_max) then set lower-order modulation scheme as MOD_A
else if (SIR_A > SIR_R_act - ΔSIR) and (SIR_A < SIR_R_act+ ΔSIR) then do not change MOD_A
else if (SIR_A ≤ SIR_R_act - ΔSIR) then set lower-order modulation scheme as MOD_A
else if (SIR_A ≥ SIR_R_act - ΔSIR) then set higher-order modulation scheme as MOD_A
end;
```

The adjusting of modulation scheme depends on the actual radio channel conditions. The transmission power of MS is adjusted as follows:

```
if (SIR_A > SIR_R) then
        if (SIR_A > SIR_R + ΔSI) then P_MS_out- ΔP
        end;
else if (SIR_A ≤ SIR_R) then  P_MS_out + ΔP
end;
```

where ΔSI [dB] is the safety interval, which keeps SIR_A over the SIR_R of used modulation scheme, and ΔP [dB] is the power control step. In OuPCL, the values of SIR_R and MOD_R are adjusted according to:

```
if (BER_A > BER_R) then
        if (P_MS_out = P_MS_max) then set lower-
                    order modulation scheme
                    as MOD_A
        else if (MOD_A ≤ MOD_R) then SIR_R + ΔSIR
                else SIR_R - ΔSIR
                end;
        end;
```

On the other side, BER_A could be lower as (or equal to) the BER_R:

```
if (BER_A ≤ BER_R) then
        if (MOD_A = MOD_R) then keep SIR_R in
                actual values (+/-ΔSIR)
                if SIR_A achieved SIR_R of lower-
                order modulation then set
        initial required modulation
        else if (P_MS_out = P_MS_max) then
                if (MOD_A ≤ MOD_R) then set
                        lower-order modulation
                        scheme as MOD_A
                else if (MOD_A > MOD_R) then
                                SIR_R - ΔSIR
                        else    SIR_R + ΔSIR
                        end;
                end;
        end;
end;
```

The algorithm continues at the uplink data transmission block (Fig. 1c.) until all required frames are transmitted.

4. Simulations

The important parameters of simulation are shown in Tab. 1. The simulator was designed to save all parameters of uplink radio channel and mobile stations when the first simulation is finished. Next simulations can use saved parameters with different algorithms. This property ensures comparability of simulation results [10].

Common parameters	Network	Number of cells	Cells' type	Antennas' type	Cells' radius	Downlink frequency	Uplink frequency
		9	Micro	360° coverage	470 m	1 945 MHz	2 135 MHz
	Base stations	P_{BS_max}	P_{BS_min}	Sensitivity	System losses	Interference	FEC
		25dBm	-50dBm	-120dBm	2dB	from ~10 MS	None
	Mobile stations	P_{MS_max}	P_{MS_min}	Sensitivity	MOD_R	SF	BER_R
		20dBm	-50dBm	-125dBm	16QAM	8/16/32/64	10^{-6}
	Test environments and common parameters	Short-term fading	Shadow fading	Frame / Slot / Simulation time	Available mod. schemes	Max. L1 data speed	
		Clark's model	12dB (average)	10ms / 0.667ms / 1000 ms	BPSK QPSK 16QAM 64QAM	480/240/120/60 kbit/s 960/480/240/120 kbit/s 1920/960/480/240 kbit/s 2880/1440/720/360 kbit/s	

Algorithms	Type	Model of test channel	Environment	Average speed
	BER-frame based	Pedestrian A&B Vehicular A	Low Range Outdoor Suburban Outdoor	10km/h 120km/h
	SIR-frame based (Non-forced)			
	SIR-frame based (Forced Soft)			
	SIR-frame based (Forced Hard)			
	SIR-frame based (Forced Soft Return)			
	SIR-frame based (Forced Hard Return)			
	SIR-slot based			

Tab. 1. Model and simulation parameters.

5. Results

We have compared algorithms by two parameters: modified data rate R_{mod} and satisfied user outage probability P_{out_su} [3]. Modified data rate is average data rate with regard to satisfied user:

$$R_{\mathrm{mod}} = \frac{\sum N_{b\_\mathrm{mod}}}{t_{sim}} \tag{2}$$

where N_{b_mod} is the number of correct transferred bits except time interval t_{err} :

$$t_{err} = \sum_{i=1}^{M} t_{0,042\_i} \tag{3}$$

where M is the number of time intervals $t_{0,042\_i}$ [s]. The duration of the time interval $t_{0,042\_i}$ is $0{,}042 t_{sim}$ with $\mathrm{BER} > \mathrm{BER_R}$. The time interval $t_{0,042\_i}$ is set by satisfied user requirement [3], in which the user is satisfied, if he is not interrupted. The session is interrupted if $\mathrm{BER} > \mathrm{BER_R}$ during the time longer than t_{dropp}:

$$t_{dropp} = \max\left(5, \frac{10}{R_t \cdot \mathrm{BER_R}}\right) \tag{4}$$

We supposed (for real time services) mean session duration 120 sec [3], so t_{dropp} is 5/120 = 0.042 %. The second result of simulations is the probability of outage with regard to satisfied user P_{out_su}:

$$P_{out\_su} = \frac{t_{err}}{t_{sim}} \tag{5}$$

The results of simulations are shown in Fig. 2-5.

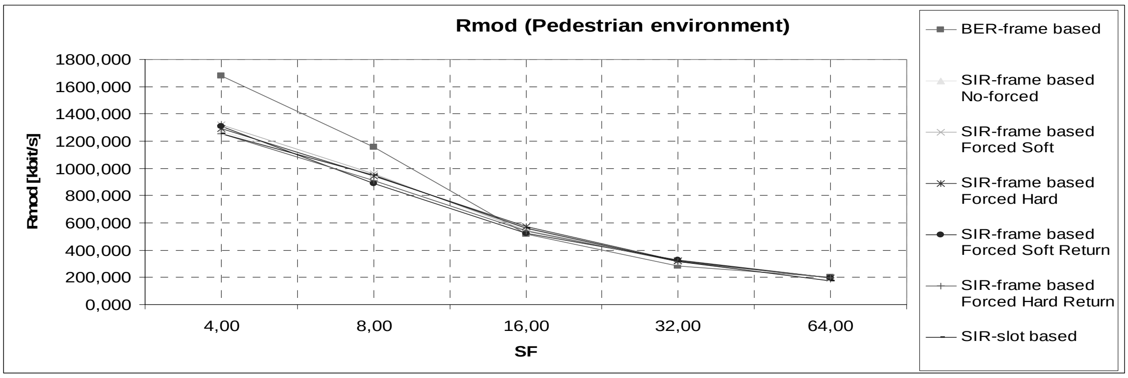

Fig. 2. R_{mod} – Pedestrian environment.

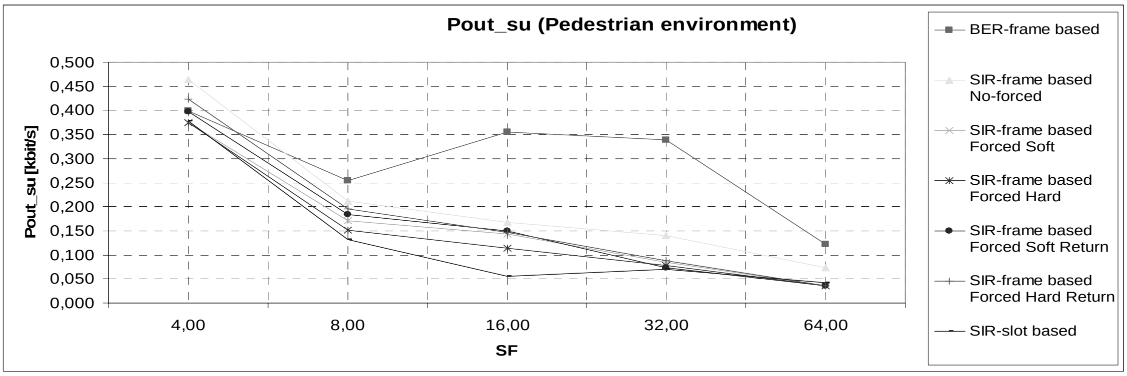

Fig. 3. P_{out_su} – Pedestrian environment.

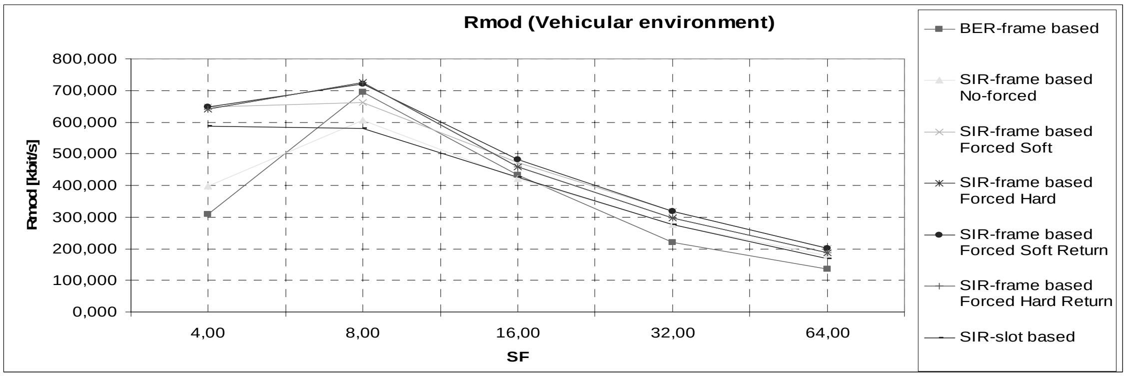

Fig. 4. R_{mod} – Vehicular environment.

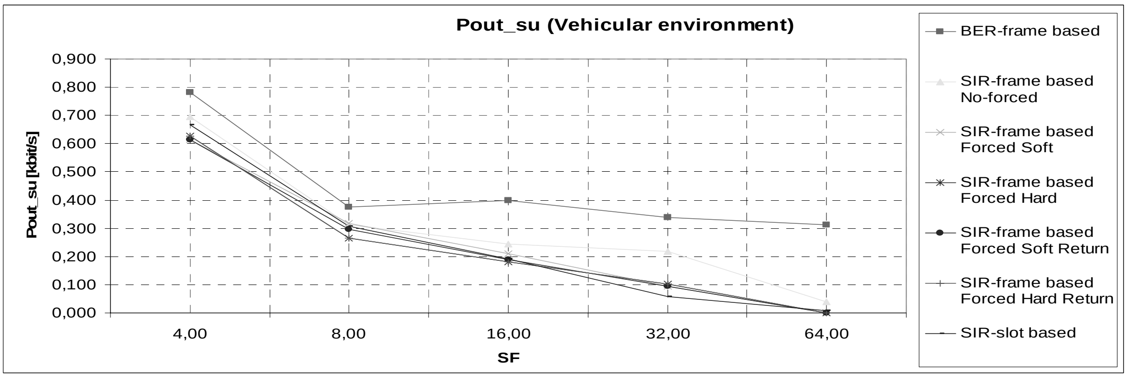

Fig. 5. P_{out_su} – Vehicular environment.

6. Conclusion

The simulation results show that the data rate is almost the same for each link adaptation algorithm in Pedestrian and Vehicular environment (Fig. 2 and 4). The variance from medium data rate is small for each spreading factor SF of OVSF code, but the probability of outage with regard to satisfied user is evidently lower for more sophisticated link adaptation algorithms (Fig. 3 and 5). The placement of actual modulation scheme control block to the closed loop power control (SIR-slot based algorithm) almost immediately allows the change of modulation (required SIR) according to the actual channel state (radio channel fading). According to this property, the user equipment should not transmit data with higher-order modulation, if the radio channel state is insufficient. In the case, when the channel state is changed from the sufficient state to the insufficient one after the first slot transmission, only the data contained in the second time slot are lost. The third time slot is transmitted by using lower-order modulation scheme (and the data from the second slot can be restored by using channel and source decoder [7] or by using ARQ method [2, 9]). We suppose that information about uplink channel state is available immediately.

With SF=8 and Pedestrian environment, the R_{mod} was at interval from 900 kbit/s to 1190 kbit/s for simulated algorithms. The achieved P_{out_su} of SIR-slot based algorithm (P_{out_su} = 0.13) is almost half of this in BER-frame based algorithm (P_{out_su} = 0.25). With SF=16 (SF=32) and Pedestrian environment P_{out_su} was increased for SIR-based algorithm. This was caused by algorithm behavior, which was not able to solve the problem with increasing BER fast enough and a lot of wrong transmitted bytes were concentrated in larger blocks. These blocks are considered as outage. Other hybrid link adaptation algorithms brought sequential improvement against BER-based algorithm. It means that we achieved lower transmit latency (because wrong received time slots needn't to be transmitted again) and higher radio channel efficiency. The similar situation can be seen for other SF and the Vehicular environment (Fig. 2-5.).

Our next goal is making our model more realistic with regard to transmission delays (information about radio channel state) and to wrong transmitted data recovery capacity.

Acknowledgements

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