Effects of Dominant Other-Sector Interference on Multi-Antenna HSDPA Performance

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***Abstract* — Link level SINR simulation results and network level sector throughput simulation results that quantify the benefit of dual antenna MMSE reception in a macrocellular HSDPA system are provided. The dual antenna RAKE receiver serves as baseline reference. Link-level simulation results are confirmed by a novel analytical expression that in flat Rayleigh fading and for uncorrelated rx antenna branches provides spatial interference suppression mean SINR gain as a function of the *dominant other-sector interference ratio* (DIR).**

It is shown that the MMSE receiver's spatial interference suppression gain depends heavily on the amount of experienced DIR. The higher the DIR the higher is the SINR gain. Nevertheless, seen on network level SINR gain turns into moderate sector throughput gain, well below 50%. This is due to the fact that high DIR situations are rare in the investigated macrocellular scenario. Moreover, dynamic range limitations hinder translation of the full SINR gain into sector throughput.

***Keywords*:** Dominant other-sector interference, DIR, HSDPA, MMSE, spatial interference suppression.

1. Introduction

Physical layer enhancements such as a second *receive* (rx) antenna, and a *minimum mean square error* (MMSE) receiver are currently considered to increase the sector throughput of the *high speed downlink packet access* (HSDPA) system [1]. The spatial interference suppression capabilities of a dual rx antenna MMSE receiver, performing *optimum combining* (OPC) over the antenna branches, is the focus of the following investigation. The dual rx antenna RAKE receiver, performing *maximum ratio combining* (MRC) over the antenna branches, serves as baseline reference. The key question is: How much gain can be obtained from spatial interference suppression? On link level gain can, for example, be measured as a mean *signal to interference plus noise ratio* (SINR) advantage. On network level gain can be measured in the form of a sector throughput advantage. In either case, the achievable gain is directly related to the amount of spatially coloured other-sector interference present in the modelled scenario. In case the other-sector interference is predominantly experienced as *additive white Gaussian noise* (AWGN), hardly any spatial interference suppression gain will be available as MRC and OPC are identical for white noise [2].

While Section 2 introduces the macrocellular simulation framework, Section 3 derives an analytical expression for the mean SINR gain as a function of the *dominant interference ratio* (DIR). Simulated and analytical results are presented and discussed in Section 4.

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2. Simulation Framework

The hexagonal cell layout from [3], where the centre base station site is surrounded by two rings of interfering sites, is adopted throughout the following. Each site counts three sectors, leading to a total of 57 sectors. The main lobes of the directional sector antenna elements are oriented as indicated by the solid arrows in Figure 1. Using quasi-static Monte Carlo simulations, SINR and sector throughput statistics are collected for users uniformly distributed in the shaded area of the centre cell. Due to cell symmetry, statistics collected in other parts of the centre cell are identical. Using the geometry based other-sector interference model from [4] a user's average interference situation is not directly described through the user's physical location, but via two user parameters, the *line of sight angle of connection* (AoC), and the *cell geometry-factor* (G-factor). The AoC is measured in the azimuth plane as indicated in Figure 1. The G-factor is defined as the ratio of the small area mean received power of the strongest sector (serving sector) and the small area mean received power sum of all other interfering sectors. *Small area mean* refers to the

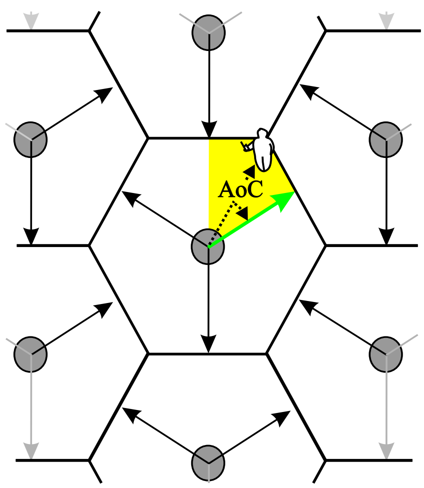

Figure 1: Excerpt from cellular set-up.

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expectation over multipath fading. Assuming that pathloss and shadow fading from all sectors at one base station site are identical, these two user parameters can accurately describe the power ratios from the most dominant interfering sectors [4].

The ratio of the strongest other-sector interferer to the small area mean received power sum of all remaining other-sector interferers is referred to as DIR. The shadow fading averaged DIR, as encountered in the centre cell area, is displayed in Figure 2 (a). It can be seen that very dominant interference is received from neighbouring sectors at the same base station site. Figure 2 (b) displays the encountered DIR distribution. Its mean lies at approximately 0 dB. Generally, the accurate representation of dominant other-sector interference is crucial to determine the benefit of the dual rx antenna MMSE receiver, as the DIR relates to the degree of spatial colouring which may be exploited in the spatial interference suppression process.

The complete quasi-static Monte Carlo simulations concept is displayed in Figure 3. Using a joint AoC-G distribution [4] the network simulator, initially presented in [5] and [6], assigns an AoC-G parameter pair to every new user entering the system. In the sequel the network simulator retrieves every user's time evolving SINR performance by indexing into an SINR trace database. This database contains a trace for every possible AoC-G pair. The underlying radio propagation channel is modelled with the stochastic correlation based *multiple input multiple output* (MIMO)

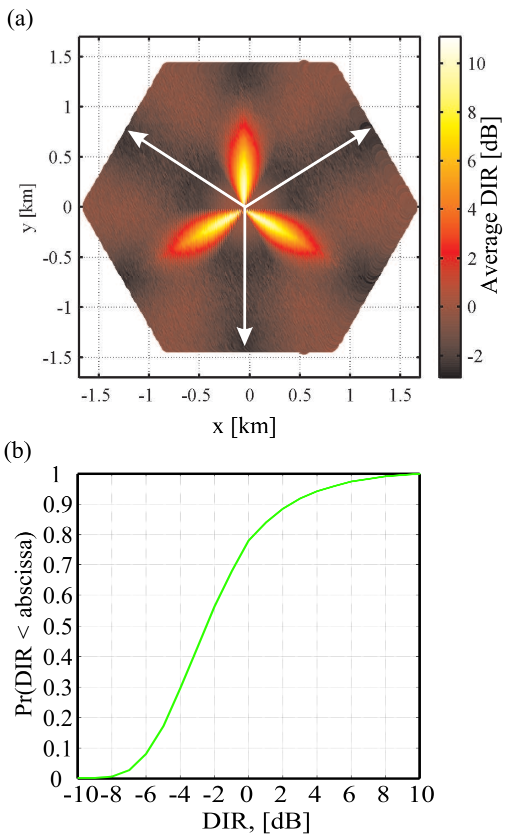

Figure 2: (a) DIR as encountered in the centre cell, when averaged over shadow fading, and (b) DIR distribution.

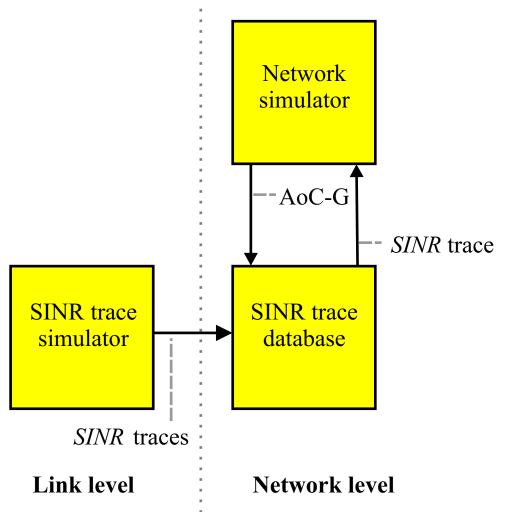

Figure 3: Quasi-static Monte Carlo simulation concept.

channel simulator presented in [7][1]. Having a model for every user's SINR performance the network simulator executes the standard HSDPA procedures – channel quality reporting, link adaptation, packet scheduling, data transmission, turbo decoding, CRC check, ACK/NACK signalling, and packet retransmission [5], [6]. An overview of the main simulation parameters is provided in Table 1.

Parameter	Setting
MIMO channel simulation	
Power delay profile	Flat Ray., PeA, VhA
Rx power azimuth spectrum	360° uniform
Horizontal rx antenna spacing	0.5 wavelength
SINR trace simulation	
Carrier frequency	2 GHz
Chip rate	3.84 Mc/s
Other sector interference model	OWNP2, [4]
HS-DSCH sector power ratio	0.7
Spreading factor	16
Mobile terminal speed	3 km/h
Channel/rx-covariance estimation	Ideal
Network simulation	
Number of multicodes	15
Traffic model	FIXED, 800 kbits, [6]
Max. number of queued users	10
Modulation schemes	QPSK, 16 QAM
Effective code rate	0.2 to 0.9 in 0.1 steps
Link adaptation criterion	10% packet error prob.
Link adaptation/scheduling delay	6 ms
Packet scheduling algorithms	RR, PF
PF specific settings	Filter length 100, init. 128 kb/s
HARQ algorithm	Incremental redundancy

Table 1: Simulation parameter settings.

[1]The software was developed as part of the European Union's IST-2000-30148 I-METRA project <www.ist-imetra.org>.

3. ANALYTICAL EXPRESSION

To benchmark and validate the simulation results the spatial interference suppression gain of MMSE over RAKE in terms of mean SINR is derived. For simplicity a frequency flat Rayleigh fading channel with decorrelated rx antenna elements is assumed. Only one flat Rayleigh fading interfering sector is received. All other interfering sectors are experienced as a single AWGN source.

The serving sector's multipath fading signal power per rx antenna branch is given by

$$P_{sig} = |h_1|^2 \cdot \overline{P}_{sig} \quad , \tag{1}$$

where $|h_1|$ is a Rayleigh fading variable with a mean power of one. $\overline{P}_{sig}$ represents the small area mean received signal power. Similarly the dominant interfering sector's signal power per branch is given by

$$P_{dom} = |h_3|^2 \cdot \overline{P}_{dom} \quad , \tag{2}$$

where $|h_3|$ is a Rayleigh fading variable independent of $|h_1|$, and $\overline{P}_{dom}$ marks the small area mean received power of the dominant interfering sector.

The remaining AWGN interference power per branch is given by $\frac{\overline{P}_{dom}}{DIR}$, so that the overall interference plus noise power is

$$P_{int} = |h_3|^2 \cdot \overline{P}_{dom} + \frac{\overline{P}_{dom}}{DIR} \quad , \tag{3}$$

and its multipath mean is

$$\overline{P}_{int} = \overline{P}_{dom} \cdot \left(1 + \frac{1}{DIR} \right) \quad . \tag{4}$$

The ratio of mean signal power to mean interference power can thus be written as

$$\frac{\overline{P}_{sig}}{\overline{P}_{int}} = \frac{\overline{SNR}}{DIR+1} \quad , \tag{5}$$

where it is used that the *mean signal to AWGN ratio* $\left(\overline{SNR}\right)$ can be expressed as

$$\overline{SNR} = \overline{P}_{sig} \cdot \frac{DIR}{\overline{P}_{dom}} \quad . \tag{6}$$

3.1. Mean SINR for Dual Rx RAKE

The following derives an approximation for the mean SINR of the dual rx RAKE receiver performing MRC over the rx antenna branches. It is denoted $\overline{SINR}_{2RAKE}$.

After combining the mean signal power, $\overline{P}_{sig\_2RAKE}$, is four times the mean single branch power [8, p. 572], *i.e.*

$$\overline{P}_{sig\_2RAKE} = 4 \cdot \overline{P}_{sig} \quad . \tag{7}$$

The multipath fading interference power after combining emerges from the sum of the interference powers per branch.

$$P_{int\_2RAKE} = \left(|h_3|^2 + |h_4|^2\right) \cdot \overline{P}_{dom} + 2 \cdot \frac{\overline{P}_{dom}}{DIR} \quad , \tag{8}$$

where $|h_4|$ is another Rayleigh fading variable. The multipath mean interference power is

$$\overline{P}_{int\_2RAKE} = 2 \cdot \overline{P}_{int} \quad . \tag{9}$$

The $\overline{SINR}_{2RAKE}$ can be expressed using an approximation for the mean of the ratio of two random variables X and Y, *i.e.* [9, p.147]

$$\begin{aligned} \mathrm{E}\left\{\frac{Y}{X}\right\} &\approx \left(\frac{\mathrm{E}\{Y\}}{\mathrm{E}\{X\}} + \mathrm{Var}\{X\} \cdot \frac{\mathrm{E}\{Y\}}{(\mathrm{E}\{X\})^3} \right) \\ &\approx \frac{\mathrm{E}\{Y\}}{\mathrm{E}\{X\}} \cdot \left(\frac{\mathrm{E}\{(X)^2\}}{(\mathrm{E}\{X\})^2} \right) \end{aligned} \quad , \tag{10}$$

where $\mathrm{E}\{\cdot\}$ and $\mathrm{Var}\{\cdot\}$ indicate mean (expectation) and variance respectively. With (10) the approximation for the mean SINR writes

$$\overline{SINR}_{2RAKE} = 2 \cdot \frac{\overline{P}_{sig}}{\overline{P}_{int}} \cdot \frac{\mathrm{E}\left\{ \left(\left(|h_3|^2 + |h_4|^2\right) \cdot \overline{P}_{dom} + 2 \cdot \frac{\overline{P}_{dom}}{DIR} \right)^2 \right\}}{\left(\mathrm{E}\left\{ \left(|h_3|^2 + |h_4|^2\right) \cdot \overline{P}_{dom} + 2 \cdot \frac{\overline{P}_{dom}}{DIR} \right\} \right)^2} \quad , \tag{11}$$

which after taking the expectations and under the usage of (5) turns into

$$\overline{SINR}_{2RAKE} = \overline{SNR} \cdot \left(\frac{(DIR)^2 + 2 \cdot (DIR+1)^2}{(DIR+1)^3} \right) \quad . \tag{12}$$

Looking at the asymptotic behaviour, *i.e.*

$$\lim_{DIR \downarrow 0} \overline{SINR}_{2RAKE} = 2 \cdot \overline{SNR} \quad , \tag{13}$$

$$\lim_{DIR \uparrow \infty} \overline{SINR}_{2RAKE} = 0 \quad , \tag{14}$$

shows that if the dominant interferer's power goes to zero, the mean SINR approaches the mean SNR times the dual branch combining gain. If the dominant interferer's power, however, approaches ∞, the mean SINR approaches zero.

3.2. Mean SINR for Dual Rx MMSE

Based on [10, (18)] the SINR pdf after dual antenna MMSE with OPC over the rx antenna branches writes

$$\begin{aligned} \mathrm{pr}\left(SINR_{2MMSE}\right) = &- \frac{(1+2 \cdot DIR)}{2 \cdot DIR \cdot \overline{SNR}} \cdot e^{\left(\frac{-SINR_{2MMSE} \cdot (1+2 \cdot DIR)}{\overline{SNR}}\right)} \\ &+ \left(\frac{1}{2 \cdot DIR \cdot \overline{SNR}} + \frac{1}{\overline{SNR}} \right) \cdot e^{\left(\frac{-SINR_{2MMSE}}{\overline{SNR}}\right)} \end{aligned} \quad . \tag{15}$$

Thus its mean SINR, $\overline{SINR}_{2MMSE}$, can be expressed as

$$\overline{SINR}_{2MMSE} = \int_0^{+\infty} \left(\begin{array}{l} SINR_{2MMSE} \\ \cdot\, \mathrm{pr}\left(SINR_{2MMSE}\right) \end{array} \right) \cdot dSINR_{2MMSE} \quad , \tag{16}$$

which, after solving the integral and some simplification, turns into

$$\overline{SINR}_{2MMSE} = \overline{SNR} \cdot \left(\frac{2 + 2 \cdot DIR}{1 + 2 \cdot DIR} \right) \quad . \tag{17}$$

Considering the asymptotic behaviour, *i.e.*

$$\lim_{DIR \downarrow 0} \overline{SINR}_{2MMSE} = 2 \cdot \overline{SNR} \quad , \tag{18}$$

$$\lim_{DIR\uparrow\infty} \overline{SINR}_{2MMSE} = \overline{SNR} \quad , \tag{19}$$

shows that if the dominant interferer's power goes to zero, the mean SINR approaches the mean SNR times a dual branch combining gain as obtained for the RAKE receiver. If the dominant interferer's power, however, approaches ∞, the mean SINR approaches the mean SNR on one branch. This means that one degree of freedom is used up for dominant interference suppression.

3.3. Spatial Interference Suppression Benefit

Based on the mean SINR results from (12) and (17) the spatial interference suppression gain of the dual rx MMSE receiver is as a function of DIR given as

$$\frac{\overline{SINR}_{2MMSE}}{\overline{SINR}_{2RAKE}} = \frac{\overline{SNR}\cdot\left(\frac{2+2\cdot DIR}{1+2\cdot DIR}\right)}{\overline{SNR}\cdot\left(\frac{(DIR)^2+2\cdot(DIR+1)^2}{(DIR+1)^3}\right)} = \frac{2\cdot(DIR+1)^4}{6\cdot(DIR)^3+11\cdot(DIR)^2+8\cdot(DIR)+2} \quad . \tag{20}$$

Looking once more at the asymptotic behaviour, *i.e.*

$$\lim_{DIR\downarrow 0} \frac{\overline{SINR}_{2MMSE}}{\overline{SINR}_{2RAKE}} = 1 \quad , \tag{21}$$

$$\lim_{DIR\uparrow\infty} \frac{\overline{SINR}_{2MMSE}}{\overline{SINR}_{2RAKE}} = \infty \quad , \tag{22}$$

it can be seen that at low DIR hardly any interference suppression gain can be obtained while the gain increases without bound for a DIR going to ∞.

4. Discussion of Results

To show the strong dependency of the obtainable mean SINR on the experienced DIR, link level SINR statistics are collected for a variety of DIR situations. Mean SINR gain ratios as obtained in a flat Rayleigh fading and a weakly frequency selective *Pedestrian A* (PeA) fading environment are plotted in Figure 4. Additionally, the analytical approximation from (20) is included in Figure 4.

It can be seen that the analytical approximation is able to predict the gain ratio even for complex scenarios that occur in connection with the hexagonal grid macrocellular set-up from [3].

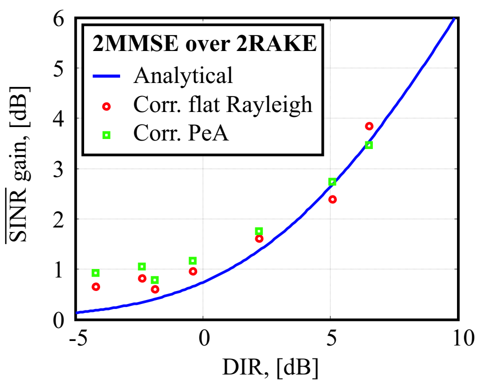

Figure 4: Mean SINR gain as a function of DIR.

However, for low DIR < 0 dB the simulated gains appear to be higher than the prediction. This can be explained by the fact that the prediction assumes that all interfering sectors, besides the strongest, are experienced as a single AWGN source. In the simulations, however, spatially coloured multipath fading interference is received from a total of four interfering sectors [4].

The post scheduling SINR statistics as experienced over the whole sector area are displayed in Figure 5.

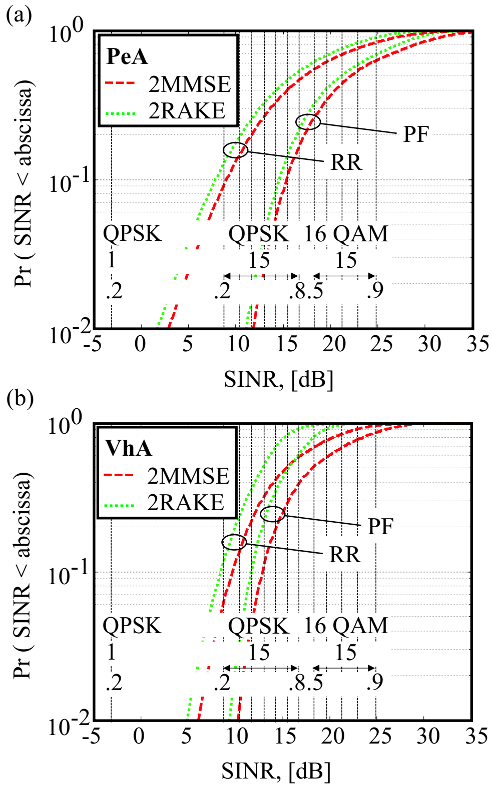

Figure 5: Post scheduling SINR statistics as encountered over the sector area.

The statistics are collected in a PeA, as well as in a *Vehicular A* (VhA) fading environment. A *round robin* (RR) and a *proportional fair* (PF) packet scheduling strategy are used. The vertical grid indicates the modulation scheme, the number of multicodes, and the effective coding rate that is supported under the 10% packet error probability link adaptation constraint. The upper most and lower most vertical grid line approximately indicate the HSDPA system's dynamic range. The corresponding mean SINR results are displayed in Table 2.

	VhA		PeA	
	RR	PF	RR	PF
$\overline{SINR}_{2MMSE}$, [dB]	18.57	21.47	22.84	27.31
$\overline{SINR}_{2RAKE}$, [dB]	13.70	16.55	20.67	24.97
$\overline{SINR}$ gain, [dB]	4.87	4.92	2.17	2.34
$\overline{SINR}$ gain, [%]	207	210	65	71

Table 2: Mean post scheduling SINR results seen over sector area.

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Looking at the SINR statistics for the PeA environment in Figure 5 (a) and at the lower tail SINR statistics for the VhA environment in Figure 5 (b) it becomes apparent that the dual rx MMSE receiver shifts the mean SINR upwards while approximately maintaining the slope. Diverting the view to the upper tails in Figure 5 (b), it can be seen that the MMSE receiver may additionally boost the SINR peaks.

While the general upwards shift is primarily due to the MMSE receiver's spatial other-sector interference suppression capabilities, the boost of the upper tails in the frequency selective fading VhA environment is attributed to the MMSE receiver's own-sector *inter path interference* (IPI) suppression capabilities.

Figure 6 displays the corresponding network level sector throughput performance. Comparing the sector throughput gains, ranging from 13% to 45%, with the mean SINR gains in Table 2, ranging from 65% (2.17 dB) to 210% (4.92 dB), it becomes apparent that the in parts impressive mean SINR gains do not fully translate into sector throughput gains. This is explained revisiting the SINR statistics in Figure 5. In the PeA environment of Figure 5 (a) the general SINR operation point of the system is relatively high due to little own-sector IPI. This leads to a situation where many users operate very high up in the HSDPA system's dynamic range already with dual rx RAKE receivers. Improving the SINR through an MMSE receiver brings no further throughput improvement for the 10% best users under RR scheduling and for the 30% best users under PF scheduling, as they are hard limited by the HSDPA system's dynamic range.

In the VhA environment from Figure 5 (b) the SINR operation point is generally lower due to an increased own-sector IPI level. Not as many users are hard limited through the system's dynamic range. However, also in this situation the most impressive SINR gains relate to higher order 16 QAM modulation, where they translate less efficiently into throughput [6, Fig. 1 (c)].

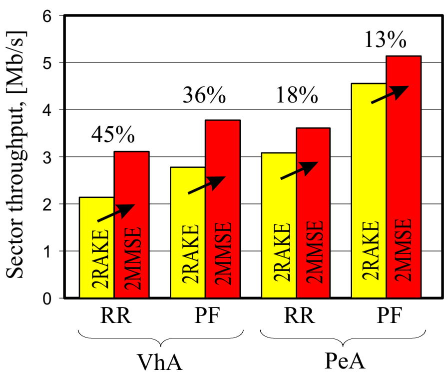

Figure 6: Sector throughput results.

5. Conclusion

The effect of dominant other-sector interference on multi-antenna HSDPA performance was investigated. For a flat fading environment simulations and analytical derivations showed that the higher the dominant other-sector interference, the more mean SINR gain is obtainable from spatial interference suppression.

In a standard hexagonal grid macrocellular scenario other-sector spatial interference suppression paired with own-sector IPI suppression was shown to relate to mean SINR gains in the order of 65% to 210%. Due to dynamic range limitations those mean SINR gains cannot to the full extent be translated into sector throughput gains. Sector throughput gains were found to merely range from 13% to 45%.

Besides assuming ideal channel estimation the MMSE receiver performance simulations additionally assumed ideal knowledge of the received interference covariance. Less own- and other-sector MMSE interference suppression gain is thus expected to be available in case of non ideal interference covariance knowledge.

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