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On the Dynamics of Link Adaptation Updating Periods for Packet Switched Systems

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Abstract. Link Adaptation is an adaptive radio link technique that selects a transport mode, from a set of predefined modes of varying robustness, depending on the channel quality. One of the parameters that has to be defined when considering the application of Link Adaptation is the updating period which indicates how often a decision is made on the transport mode to use. This paper analyses the Link Adaptation performance for various updating periods under different operating conditions affecting the channel quality dynamics.

Keywords: Link Adaptation, updating periods, packet switched systems.

1. Introduction

Link Adaptation (LA), initially developed as a 3G technique [1], has been identified as a key technology for evolved GSM systems such as Adaptive Multi-Rate (AMR) codec, General Packet Radio Services (GPRS) and Enhanced Data rates for GSM Evolution (EDGE). The basis of LA is to assess the channel conditions and then use a transport mode, from a set of predefined options, which is optimised for these conditions. The benefits of LA have already been proven for circuit switched [2] and packet switched cellular systems [3, 4].

The LA performance depends on the accuracy of the channel quality measurements and the ability of the system to adapt to channel quality variations. This ability is determined by the LA updating period, which defines how regularly a decision is made on the most suitable transport mode. The adjustment of the LA updating period presents a trade off between signalling load, number of mode changes and ability to quickly adapt to sudden channel quality variations. A LA updating period could be considered as optimum if it maximises performance while minimising the signalling load and number of mode changes. If the channel quality presents a smooth variation there is no need for a short LA updating period as it will unnecessarily increase the signalling load. Therefore, the duration of the LA updating period should be established according to the dynamics of the channel quality variation. These dynamics are dependent on various parameters of a mobile system, e.g. load. The impact of different updating periods for voice services in a packet switched system was analysed in [1]. In [1] the LA algorithm was designed to interact with Power Control which would respond to short term variations in the channel quality while LA would respond to long term variations. A study of the LA updating period for packet data transmissions has been reported in [4]. However, this study was confined to a particular set of operating conditions. This paper extends that study by investigating the optimum LA updating periods for varying operating parameters affecting the channel quality dynamics. System parameters such as load, diverse traffic sources and mobile speeds are considered in this analysis. The study has been conducted for packet data transmissions in a GPRS-like system.

2. Simulation Models

Prior to transmission, GPRS data packets are segmented into smaller data blocks across the different GPRS logical layers, with the final logical unit being the Radio Link Control (RLC) block. An RLC block is then transmitted over four bursts in consecutive TDMA frames [5]. In order to vouch for high simulation accuracy and to account for sudden channel quality variations, an event-driven simulator working at the burst level has been implemented. The simulator models the dynamic behaviour of the channel quality in terms of the Carrier to Interference Ratio (CIR).

2.1. System Model

A cellular network of equally sized 3-sector macro cells, with a cluster size equal to four, has been considered. The network models the first and second tier of co-channel interferers. Each sector has been assigned two carriers. Mobility has been modelled, within each sector, but no handover has been considered between sectors. The boundary effects have been removed by using a wrap-around technique. Pathloss is predicted using the Okumura-Hata model. The shadowing has a log normal distribution with a standard deviation of 6dB and a decorrelation distance of 20 metres. Fast fading has also been included in the system level simulations as explained in Section 2.3. No Power Control or Frequency Hopping mechanisms have been implemented. The simulator studies the downlink performance. The system load is varied by changing the number of users in the system. Each user will exist for the complete duration of the simulation. A single slot allocation strategy has been implemented by means of a random allocation scheme. Users are assigned channels in a First Come First Served basis and the channel is kept until all its data has been correctly transmitted. An ARQ protocol, following the GPRS specifications, has been implemented to request the retransmission of erroneous blocks. A perfect feedback of the ARQ report with no RLC block looses has been assumed. Although the current GPRS standard does not contemplate mode changes for retransmissions, it has been considered here so that results are not conditioned by GPRS limitations.

2.2. Traffic Modelling

Two different traffic sources have been considered for this study, WWW browsing and email, with the traffic type evenly distributed among users at 50%. Both traffic sources have been implemented as an ON/OFF model. For both traffic models, the transmission of a new packet cannot start until the previous transmission has finished, i.e. all the data has been correctly received. The active transmission time will hence depend on the link quality conditions. More details on the traffic sources can be found in [6]. No channel partition has been applied between the two services and results are collected individually for each type of traffic from the central cell.

2.3. System to Link Level Interface

In order to reduce the complexity of system level simulations, the effects at the physical layer are generally included by means of Look-Up Tables (LUTs). Simplified LUTs, as the ones

Table 1. GPRS coding schemes parameters.

Scheme	Code rate	Payload	Data rate (kbits/s)
CS1	1/2	181	9.05
CS2	≈2/3	268	13.4
CS3	≈3/4	312	15.6
CS4	1	428	21.4

used in [4], map the mean CIR over the four bursts used to transmit an RLC block to quality metrics such as the Block Error Rate (BLER). However, the combined effects of convolutional coding and interleaving make the block errors dependent not only on the mean block quality but also on the quality distribution among the four bursts used to transmit an RLC block. To accurately model block errors, more detailed LUTs have been developed. These LUTs map the mean burst quality and the standard deviation of the quality over the four bursts used to transmit an RLC block to a corresponding BLER. The burst quality is represented by means of the Bit Error Rate (BER). To extract the BER, the mean CIR is estimated in each burst. The BER is then obtained, through a random process, by means of a first LUT representing the cumulative distribution function (cdf) of the BER for the given mean CIR. The interest of this procedure is to model the effect of fast fading on the burst quality through a random process thereby including the fast fading at the system level. More details on the LUTs can be found in [6].

3. Link Adaptation

The GPRS radio interface defines four channel Coding Schemes (CSs), CS1 to CS4, for the packet data traffic channels [5]. Each scheme has been designed to provide different resilience to propagation errors under unfavourable radio conditions. The different error correction capability of each CS makes the payload transmitted in an RLC block dependent on the CS used (see Table 1). Therefore, the different CSs offer a trade-off between throughput and coding protection, paving the way for the application of Link Adaptation to GPRS.

The basis of LA is to assess the channel conditions and then use a CS that is optimised for these conditions. In this work, an optimum CS is the one that maximises the throughput defined as:

$$\text{Throughput} = R_{\text{CS}} * (1 - \text{BLER}_{\text{CS}}) \tag{1}$$

with R_{CS} and BLER_{CS} being the data rate and BLER respectively for a given CS. The LA switching thresholds define the boundaries between the regions where each CS is optimum. Traditionally, these boundaries are represented by a single point corresponding to a mean block quality value (e.g., mean CIR [4]). In this work, the boundaries are defined as a collection of points each representing a combination of mean and standard deviation of burst quality values [6].

The LA algorithm will use the quality measurements over the previous reporting period to decide on the optimum CS. The mean burst quality and the standard deviation of the burst quality over a block for each transmitted block during the last reporting period will be filtered to get the quality measurements necessary for the LA algorithm. A filter with a rectangular shape has been applied throughout. In this paper, a fixed initial coding scheme, CS4, has been selected at the beginning of each new data transmission.

4. Simulation Results

This section analyses the LA performance for different updating periods under various operating conditions. In particular, the effect of the system load, mobile speed and traffic source, on the LA performance for the different updating periods, is here studied. Four different updating periods have been considered: 20 ms, 60 ms, 100 ms and 200 ms. 20 ms is the shortest possible updating period as it corresponds to the transmission time of an RLC block.

As indicated in Section 3, a LA updating period could be regarded as optimum if it maximises throughput while minimising the signalling load and number of CS changes. The performance will then be measured by means of the cdf of the user throughput, the average user throughput and the number of CS changes per second. Other useful parameters are the proportion of RLC blocks received with an optimal CS and the proportions of right-side and wrong-side failures. A right-side failure corresponds to the case where a user is using a non-optimal CS but one robust enough for correct reception. For the wrong-side failure, the current CS is not robust enough.

In order to ensure results with relative errors below 1%, each simulation scenario (i.e., a given combination of load, mobile speed and updating period) simulates at least the transmission of 30 million RLC blocks in the central cell.

4.1. Effect of Load

The throughput performance under increasing traffic loads for users moving at 50 km/h and receiving WWW traffic is illustrated in Figure 1. The considered loads of 8, 16, 24 and 36 users per sector represent an average channel occupancy of 20%, 45%, 67% and 93% respectively.

The results show that, for all updating periods, the performance decreases as the load increases. The increase in the proportion of wrong and right side failures and the decrease in the proportion of blocks transmitted with the optimal CS as the load increases can be regarded as the main factors contributing to this behaviour (Figure 2).

Under every load considered, an updating period of 20 ms increases the number of samples experiencing low bit rates. However, it can also be observed that this updating period gives the best throughput to a percentage of samples and that this percentage varies with the load. With 8 users per sector, this percentage is around 77%, whereas this value is reduced to around 50% when the load is increased to 36 users per sector. Figure 2 shows that the decrease in the proportion of blocks transmitted with the optimal CS as the load increases is similar for both updating periods. However, with an updating period of 20 ms the increase in the proportion of wrong-side failures as the load increases is more significant than with an updating period of 100 ms. A wrong-side failure may have a significant impact in the throughput as it represents the case where a block has been transmitted with a CS not robust enough and therefore there is a high probability that the block has to be retransmitted. The performance with updating periods of 60 ms, 100 ms and 200 ms is quite similar for users experiencing low throughputs. Only for higher throughputs there is an advantage for using shorter LA updating periods. For these throughputs, the performance decreases as the updating period increases. However, as shown in Figure 3 longer updating periods also reduce the number of CS changes with the

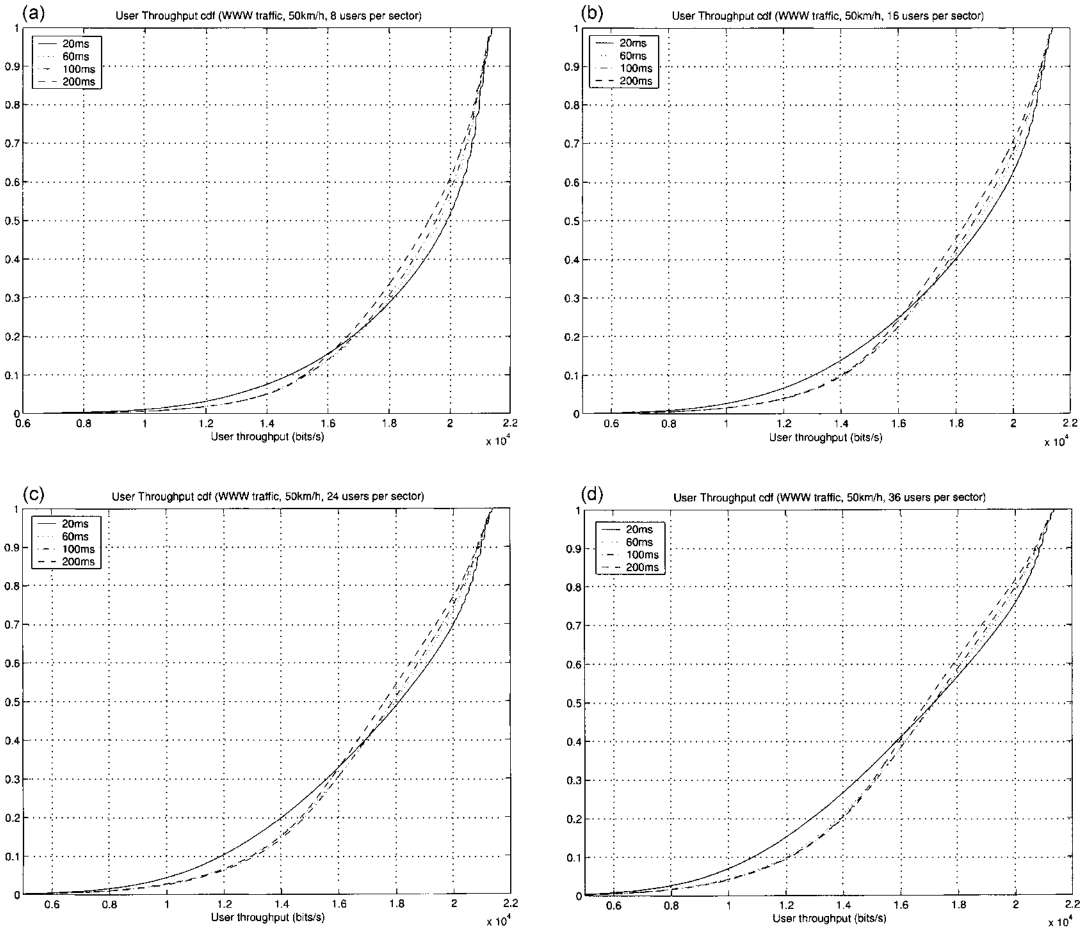

Figure 1. User throughput cdf for various loads (WWW traffic, 50 km/h): (a) 8 users per sector; (b) 16 users per sector; (c) 24 users per sector; (d) 36 users per sector.

associated reduction in the signalling load. The selection of the LA updating period offers then a trade-off between performance and signalling load, with varying effects under different loads.

In terms of the average user throughput an updating period of 20 ms provides a poorer performance than an updating period of 60 ms (Table 2). The difference in performance becomes more apparent with increasing loads. The performance is very similar, in this case, for updating periods of 60 and 100 ms, but it decreases for the 200 ms case.

If the aim when implementing an LA algorithm is to guarantee that 95% of the samples will experience the highest possible minimum throughput, an updating period of 20 ms clearly underperforms the other updating periods for all the considered loads. For example, an updating period of 20 ms gives a throughput of greater than 11.28 kbits/s for 95% of the samples, with 16 users, while an updating period of 100 ms provides a throughput of greater than 12.57 kbits/s (Table 2).

The analysis of the dynamics of the LA updating periods under different loads suggests that for high loads, the benefit of using an updating period of 20 ms is questionable. For low and medium loads, this updating period provides the best throughput for a significant number

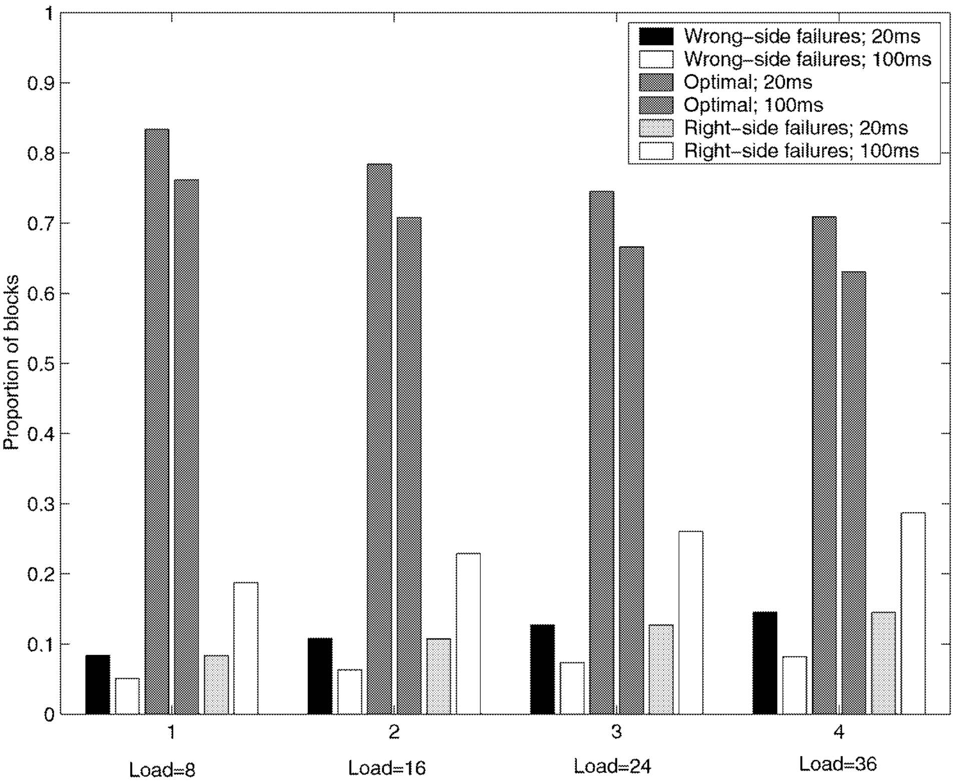

Figure 2. Optimal, right and wrong side failures for updating periods of 20 and 100 ms and various loads.

Table 2. Average user throughput and minimum throughput for 95% of the samples in kbits/s for different LA updating periods (WWW traffic, 50 km/h).

Up. period	20 ms		60 ms		100 ms		200 ms	
	Avg.	Min	Avg.	Min	Avg.	Min	Avg.	Min
Load = 8	18.81	12.95	18.83	13.87	18.77	13.98	18.63	13.97
Load = 16	17.94	11.28	18.04	12.41	17.99	12.57	17.86	12.47
Load = 24	17.21	10.24	17.36	11.28	17.35	11.43	17.18	11.31
Load = 36	16.46	9.24	16.73	10.27	16.73	10.41	16.59	10.33

of samples but decreases the average user throughput and minimum throughput for 95% of the samples and increases the number of samples with low bit rates. Shorter updating periods also produce a higher number of CS changes. According to these observations, the decision on which LA updating period to use should be based on the QoS strategy targeted, that is, for example whether the aim is to decrease the number of users experiencing low bit rates while also decreasing the number of CS changes or increase the throughput to a number of users.

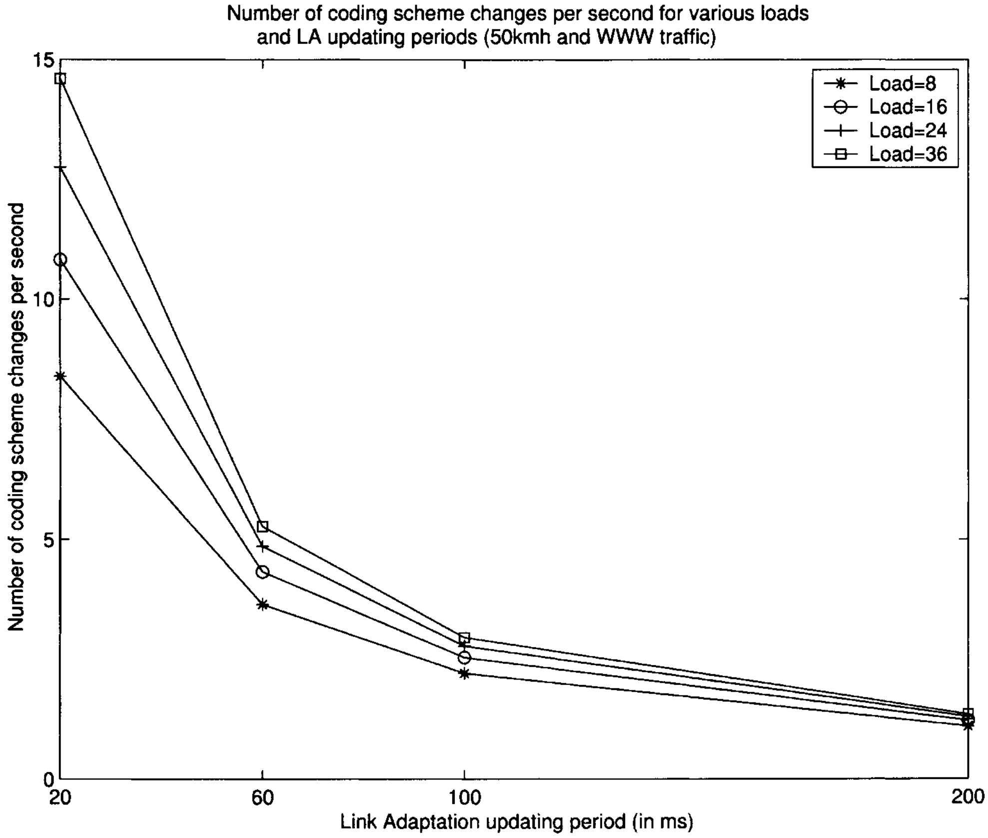

Figure 3. Number of CS changes (WWW traffic, 50 km/h).

4.2. Effect of Speed and Traffic Source

Different mobile speeds influence the dynamics of the link quality; high speeds quickly change link quality conditions while low speeds experience correlated link quality conditions over longer periods of time. Figure 4 shows the throughput performance at 5 km/h for a load of 36 users. The results show a degradation in performance for lower speeds. For example, with a load of 36 users and a speed of 50 km/h, 10% of the samples have a throughput below 12 kbits/s with an updating period different from 20 ms. This percentage is increased to over 20% at lower speeds. In terms of load variation, similar trends to the 50 km/h results previously described were observed. However, the benefits of a 20 ms updating period were reduced compared to high speeds as the performance for high throughputs under different updating periods is closer. Also the degradation in terms of average user throughput and minimum throughput for 95% of the samples for a 20 ms updating period compared to a 60 ms updating period is further increased at lower speeds. Under low speeds, the 60 ms, 100 ms and 200 ms updating periods also give better throughput for 95% of the samples than a 20 ms updating period, following the trend observed at 50 km/h. The decrease in throughput performance for longer updating periods is also reduced at lower speeds and an updating period of 200 ms even provides, at low and medium loads, the highest minimum throughput for 95% of the samples. This may be due to the fact that at low speeds the channel quality conditions are more correlated than at high speeds. In this case, longer updating periods can create more

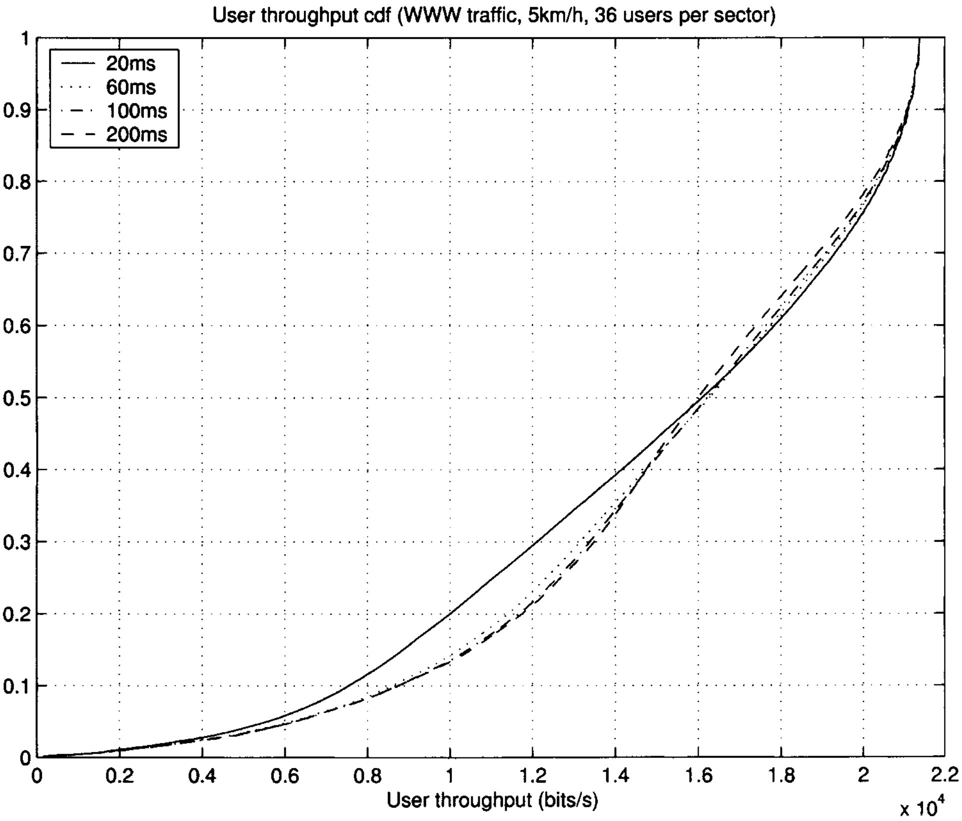

Figure 4. User throughput cdf (WWW traffic, 5 km/h, 36 users per sector).

reliable channel quality estimates which can improve the LA performance, specially under bad channel quality conditions.

All the results previously presented were extracted for users receiving WWW traffic. Results have also been obtained for users receiving email traffic, and the observations concerning the dynamics of the LA updating periods remain similar.

5. Conclusions

This paper has expanded the study of Link Adaptation for mobile packet switched systems by looking at the dynamics of the updating periods under various operating conditions. It has been shown that the load and speed have a significant impact on these dynamics. The observations presented in this paper suggest that the decision on which updating period to use should be based on the particular QoS strategy targeted. The study also shows that the selection of the updating period offers a trade-off between throughput performance and signalling load.

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