Simulation-Based Performance Analysis of HSDPA for UMTS Networks

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***Abstract*— This paper investigates the performance of TCP over High Speed Downlink Packet Access (HSDPA) link in the third generation Universal Mobile Telecommunication System (UMTS). The throughput performance of TCP has been considered with both round robin and maximum carrier-to-interference scheduling schemes. A simulation based approach is adopted to determine the total cell throughput, both under ideal and Rayleigh fading conditions. Simulation results show that, HSDPA can effectively provide high throughputs, but with fairness depending upon the scheduling mechanism.**

I. INTRODUCTION

The revolution of wireless networking continues to unfold with the gradual emergence of WCDMA-based third generation (3G) cellular technologies, such as Universal Mobile Telecommunications System (UMTS) [1]. The range of offered services in such systems has already extended from basic speech telephony to multimedia and interactive data transfers. In such an environment one can expect that a major portion of the overall traffic will be carried by TCP/IP. Thus, particular attention must be paid to the performance of TCP/IP over 3G wireless networks.

TCP/IP performance over wireless networks has been extensively studied in the last decade. It has been found that wireless link losses have an adverse impact on performance as TCP/IP cannot distinguish them from congestion losses. These findings have been one of the main motivations for the use of extensive local retransmissions in 3G networks. In this paper we will restrict ourselves to UMTS based 3G networks only.

The rest of the paper is organised as follows. An overview of UMTS including architecture, protocol stack, channel capacities and scheduling mechanisms has been given in section II. Related work is presented in section III. Details of network model and simulation results are presented in section IV. Finally, conclusions are drawn in section V.

II. AN OVERVIEW OF UMTS

A. Network Architecture

A reference architecture for UMTS in packet switched mode is given in Fig. 1, [2]. It builds on the well known architecture of second generation networks. The major functions of the system can be grouped into the UMTS Radio Access Network (UTRAN) which handles all radio related functionalities, the core network which is responsible for switching/routing of calls and the User Equipment (UE). UTRAN consists of a Radio Network Controller (RNC)

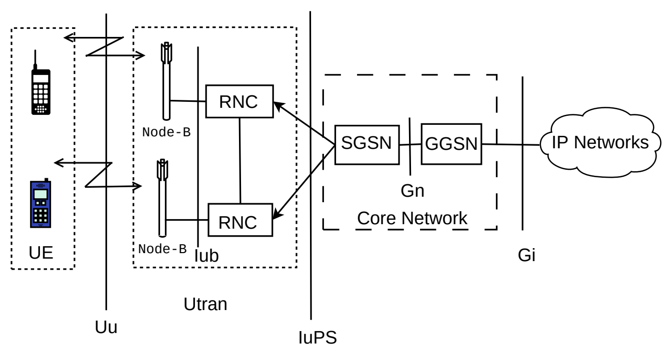

Fig. 1. An overview of UMTS Network Topology

and Node-B which acts as a base station. Node-B contains functionalities for fast link adaptation, fast hybrid ARQ (HARQ) and fast scheduling. The core network consists of two basic nodes: Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN), where the former node is connected to the RNC via the IuPS interface and the latter node provides interworking with external packet switched networks over the Gi interface. Both SGSN and GGSN have already been defined for the General Packet Radio Switch (2.5G) extension to GSM networks. The UE is connected to UTRAN over the UMTS radio interface Uu.

B. Protocol Stack

The protocol stack for UMTS in the transmission of user plane data generated by TCP/IP and UDP based applications is shown in Fig. 2, [2]. TCP/IP protocol suite and applications are located both at the UE and the end host. UDP and IP are used as a means to transport traffic and signalling information among GGSN, SGSN and RNC. The network layer, radio resource and radio link control are divided into Control (C-) and User (U-) planes. Information sent and received by the UE, such as voice calls or internet packets, is transported over the U-plane, whereas the C-plane is used for signalling.

Packet Data Convergence Protocol (PDCP) exists only in the U-plane and its main function is header compression which improves the spectral efficiency for transmitting IP packets. The Radio Link Control (RLC) layer can operate in three different modes, viz: Transparent Mode (TM), Unacknowledged Mode (UM) and Acknowledged Mode (AM).

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In AM, Automatic Repeat Request (ARQ) is used for error correction until data is received correctly. In both TM and UM, no retransmission protocol is used and data delievery is not guaranteed. Erroneous protocol data units may be discarded or marked. The RLC protocol runs in both RNC and UE, where it implements regular data link functionality over the WCDMA interface and provides segmentation and retransmission services, [2].

The Medium Access Protocol (MAC) is active at both the UE and RNC entities and it maps the logical channels to transport channels. The Physical Layer (PHY) maps the transport channels into physical channels and also provides functions for modulation, demodulation, spreading, synchronization, interleaving, forward-error correction and soft handover.

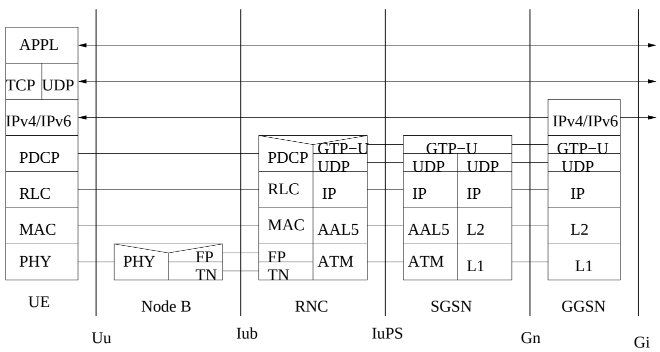

Fig. 2. UMTS Protocol Stack

C. UMTS Channel Capacities

For the UMTS release 99 downlink, data can be transferred through the shared Forward/Random Access Channel (FACH/RACH) as well as on the Dedicated Channel (DCH). The DCH can have a high throughput but it also requires a setup time of the order of 250 ms, which may be too long for short data transfers. On the other hand, the shared channel has low setup time but also low throughput. Table I presents the capacities of the different channels in UMTS. Release 5 of the UMTS-standard incorporates High Speed Downlink Packet Access (HSDPA), which is a significant advance that can offer Mobile Broadband services and is also refered to as 3.5G. HSDPA has been based on four fundamental principles: Adaptive Modulation and Coding, Hybrid Automatic Repeat Request (HARQ), Higher peak rates (up to 14.4 Mbps in downlink) and moving the scheduling functions from Radio Network Controller to Node B (thus splitting the MAC layer). HSDPA defines a new WCDMA channel, called high-speed downlink shared channel (HS-DSCH), for downlink communication to mobile cellular devices.

TABLE I
UMTS CHANNEL CAPACITIES

Transport Channel Types							
Common Channel				Dedicated Channel			
RACH		FACH		DCH			
Bit rate (Kb/s)	TTI (ms)	Bit rate (Kb/s)	TTI (ms)	Uplink		Downlink	
				Bit rate (Kb/s)	TTI (ms)	Bit rate (Kb/s)	TTI (ms)
32	10	32	10	64	20	64	20
				64	20	128	20
				64	20	384	10
				384	10	2000	10

D. Packet Scheduling

In the HSDPA context, the process of scheduling refers to the process of allocation of transmitter time and power (i.e. at base station, Node-B) to the randomly time-varying mobile data connections (i.e. cellular mobile users, UE). In such a case, the simplest type of scheduling (channel non-adaptive), is to allocate the access time fairly to all users, and this is also known as Round Robin (RR) Scheduler. Although RR is fair in time allocation, its performance is not very satisfactory in fading environments, [3].

Another scheduling approach can be based on transmitted power by the mobile users, as it is representative of channel conditions. In this case Node-B can compare the power transmitted by each mobile users and match it to the respective packet waiting in the queue for transmission. Thus, Node-B will transmit a packet to the user which has the best channel conditions and so on (channel adaptive). This approach is known as Best Channel First (BCF) or Maximum Carrier-to-Interference ratio (C/I). Maximum C/I is unfair as it favours the users who are closer than users who are further away from Node-B. In order to have a compromise between RR and Maximum C/I, Fair-Channel Dependent Scheduling (FCDS) has been proposed in [4].

In our simulation experiments, the performance of TCP is determined under two extreme conditions of fairness by employing the RR and Maximum C/I scheduling schemes. It can be noted that FCDS can be made to behave as RR or Maximum C/I, by an appropriate choice of a parameter α, [4].

The thoroughput at UE depends upon the scheduling scheme employed at Node-B. In [5] it has been stated that the total cell throughput of a HSDPA system having a total of N_u users with a mean bit rate of R_i is given by

$$T = E\left(\sum_{i=1}^{N_u} R_i\right), \tag{1}$$

where for RR, R_i is given by

$$R_i = \frac{1}{N_u}\sum_m k_m \frac{W}{SF}\frac{(N\log 2(M)\tau)_{m,i}}{N_{s,i}}. \tag{2}$$

In (2) W is a chip rate, SF is spreading factor, $N_{s,i}$ is the number of transmissions for user i due to HARQ, M is the modulation order and τ is code rate, [6] and [5]. It has been mentioned that k_m varies with the position of UE. For maximum C/I scheduling, the expression for R_i is the same as in (2) but multiplied to the probability that a Transmission Time Interval (TTI) is allocated to user i, for which no simple or closed form formula has been derived.

In [7] anlytical expressions for the RLC part of total round trip time and throughput have also been derived. The expression for throughput involves the round-trip time for the wired part, for which no expression is given. Thus, to determine the throughput at UEs, a simulation based approach IS adopted in this paper.

III. Related Work

A comparison between WCDMA Release 99 and HSDPA has been provided in [8]. The performance of WiBro, a new Korean standard, and HSDPA has been provided in [9]. It has been found that WiBro performs better in multipath fading due to the use of Orthogonal Frequency Division Mutiple Access and a Cyclic prefix, whereas HSDPA was more robust in Doppler shift fading due to its shorter Transmission Time Interval. Also it has been anticipated that both WiBro and HSDPA will compete fiercely with each other in the broadband mobile market.

In [10] it has been reported that TCP throughput is close to theoretical values and round trip time is stable. Also it has been mentioned that no performance benefit has been obtained with modifications in the TCP retransmission timer, such as Eifel. The results presented need to studied further both in real environments and simulations.

Using a quasi-static simulator the overall throughput and delay performance of 1XTREME and HSDPA has been provided in [11]. The performance has been bounded by Maximum C/I and Round Robin schedulers. The link and network layer performance aspects of WCDMA with HSDPA have also been studied in [12]. Six prototype packet schedulers have been considered and inherent tradeoff among cell capacity and user fairness has been illustrated. Under different environments and traffic aspects, flow level performance of HSDPA, has also been investigated in [13].

In [6] and [5] the authors have developed an analytical model to evaluate the impact of TCP on UMTS-HSDPA capacity and have presented a method (maximize $N_c \log 2(M)\tau$, where N_c is number of codes available, M is the modulation order and τ is code rate) to maximize the number of users in a cell i.e. cell capacity. The analytical model has been validated by using both Monte Carlo and NS based simulations.

IV. Network Model

We consider a single cell in which one base station, i.e. Node-B, is serving n mobile users on a HSDPA channel using Hybrid CDMA/TDMA transmission scheme. Further, assume that at a given timeslot t, there are $m, m \leq n$ active mobile users who are competing with each other for resources at Node-B. The packets to be transmitted have been enqueued at Node-B. For simulation purpose we employ Enhanced UMTS Radio Access Network Extensions (EURANE) to ns-2 simulator, in which handover functionality has not been implemented, [2].

We simulate a scenario in which 20 mobile users are downloading data on a HSDPA link from Node-B using TCP with selective acknowledgements and UDP. In this scenario, the number of TCP connections running FTP, exponential and Pareto (ON/OFF) distributed traffic is 5 each. As background traffic, there are 5 UDP connections, each running CBR traffic. Each of the 20 UEs are connected to Node-B through an acknowledged mode HSDPA channel as in [2]. The Node-B is connected to Wired Node 1 through RNC, SGSN, GGSN and wired node 2. Thus each UE has an end-to-end TCP connection with wired node 1 as shown in Fig. 3.

The simulations have been run both under ideal and Rayleigh fading environments. To simulate the ideal conditions we use a trace, in which there are no Channel errors and have a fixed Channel Quality Indicator (CQI) of 14, [2]. For Rayleigh fading we use UEs that are 700 m away from Node-B and moving with velocity 3Km/h. The trace files under different environments and fading conditions can be generated using Matlab code available at [2].

The simulated network with link capacities, is shown in Fig. 3. The link between Base station (Node-B) and Radio Network Controller (RNC) is using a Droptail queue with arbitrarily large size of queue buffer, so that there is no packet loss due to overflow. The parameters of the exponential

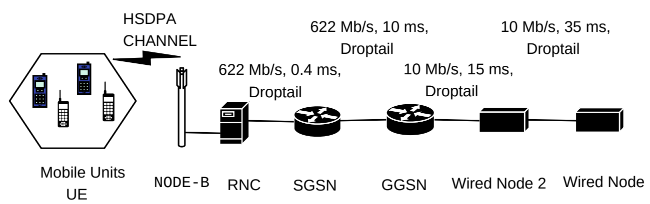

Fig. 3. Simulated UMTS Network

ON/OFF and CBR traffic are the same as the default values in the ns-2 simulator (i.e. burst and idle times of 0.5 s each with a rate of 64 Kb/s for exponential traffic; data rate of 448 Kb/s for CBR traffic). Data transfer on the Internet has been modelled as the heavy tailed Pareto distribution with CDF given by:

$$F(x) = P[X \leq x] = 1 - \left(\frac{k}{x}\right)^{\alpha}, \tag{3}$$

where k is the minimum value X and α is a shape factor. In [14], it has been found that the shape factor, α, ranges from 1.04-1.14. In our simulations we have used Pareto distribution based ON/OFF traffic carried on TCP with burst time and idle time each having a mean of 500ms, data rate of 64 Kb/s and shape factor of 1.09.

The throughput obtained at each of the 15 UEs, under ideal conditions, has been plotted in Fig. 4. Also, for both RR and Max C/I scheduling, throughputs has been plotted in Figs. 5 and 6, respectively. For ideal conditions, the throughput of each UE achieves a steady value between 60 and 65 Kb/s after 10 s of simulations. In the case of Rayleigh fading with RR scheduling, there is an intial transient in throughput during the period between 0 to 40 s, which after 80 s decreases smoothly as UEs move away from Node-B. For maximum C/I scheduling the transient state in throughput lasts for a period of 80s. In Fig 6 it can be seen that UE 15 gets much less throughput, thereby depicting the unfairness caused by the maximum C/I scheduling policy.

The total cell throughput obtained by all UEs, both for RR and maximum C/I, has been plotted in Fig. 7. It shows that maximum C/I will generate a higher value of total cell throughput as compared to RR. Queue size variations in the link between Node-B and RNC have also been plotted in Figs. 8 and 9, respectively. These show that RR has slightly higher queue size than maximum C/I. The variations in end-to-end delay for TCP packets have been plotted in Figs. 10 and 11.

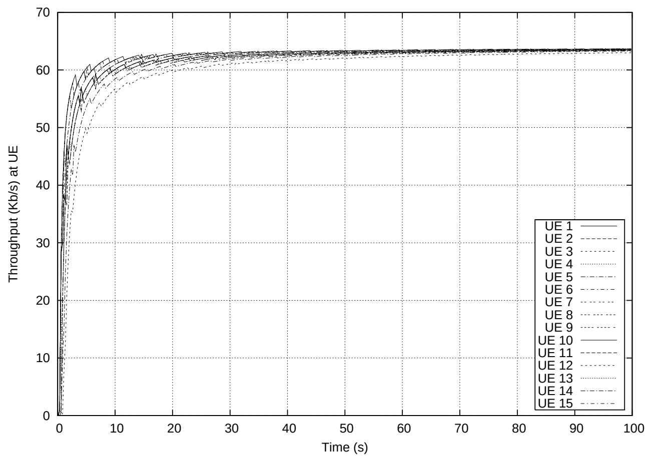

Fig. 4. Throughput for 15 UE's under ideal conditions.

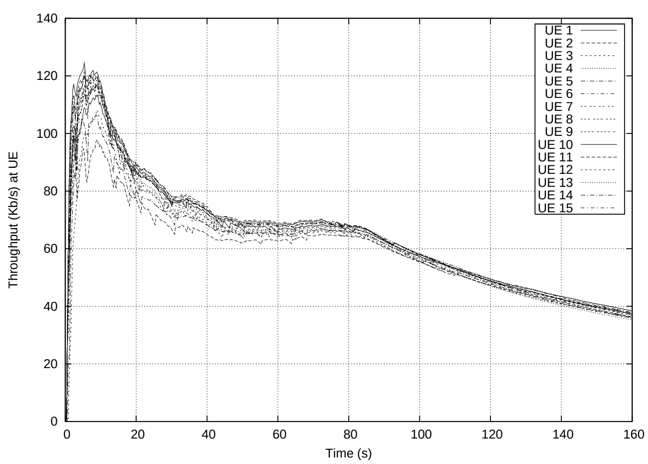

Fig. 5. Throughput for 15 UE's under Rayleigh fading with RR scheduling.

V. Conclusions

In this paper, a simulation based approach has been adopted to evaluate the performance of HSDPA in 3G UMTS networks. It has been found that, under ideal conditions, throughputs of all 15 UEs converge quickly (within around 20 s) to a steady-state value of 60 Kb/s, whereas in the case of Rayleigh fading conditions the throughput convergence depends upon the scheduling policy. Round robin scheduling is shown to distribute channel resources fairly, but also to

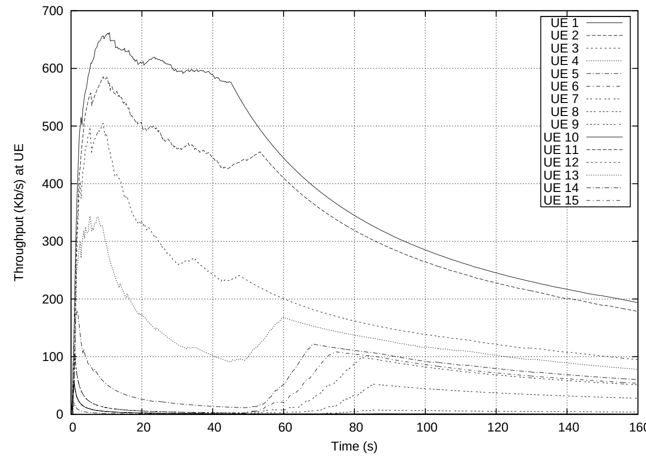

Fig. 6. Throughput for 15 UE's under Rayleigh fading with max C/I scheduling.

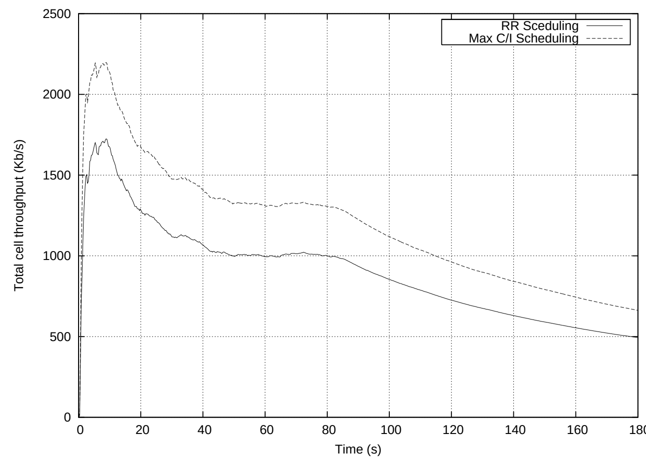

Fig. 7. Total cell throughput with RR and Max C/I Scheduling

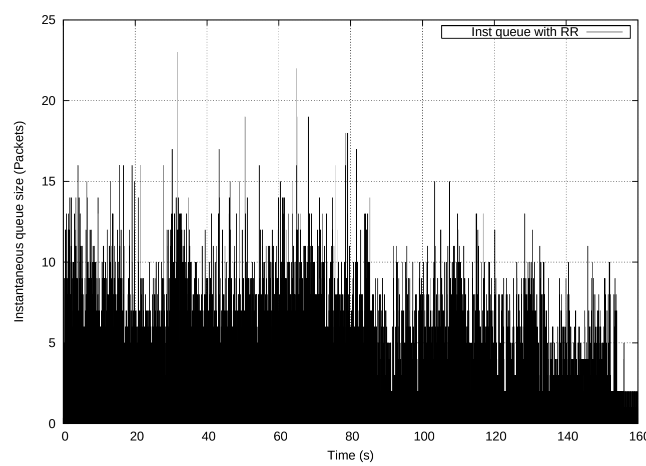

Fig. 8. Instantaneous queue variations (between Node-B and RNC) with RR scheduling.

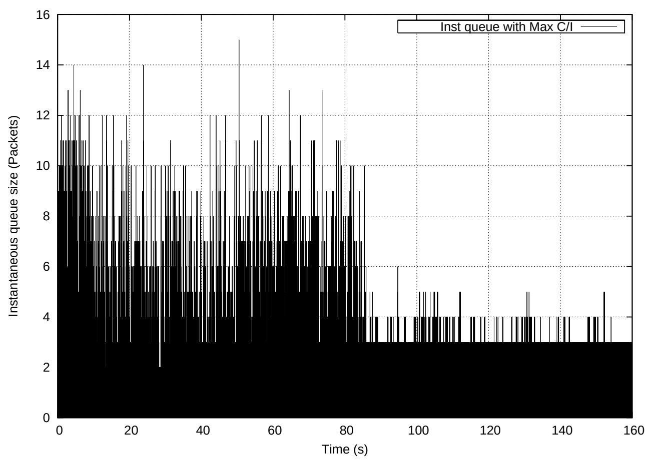

Fig. 9. Instantaneous queue variations (between Node-B and RNC) with Max C/I Scheduling.

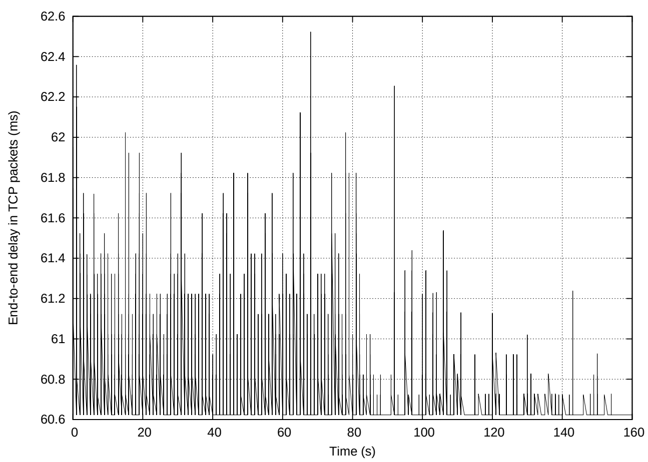

Fig. 10. End-to-end delay in TCP packtes, with RR scheduling.

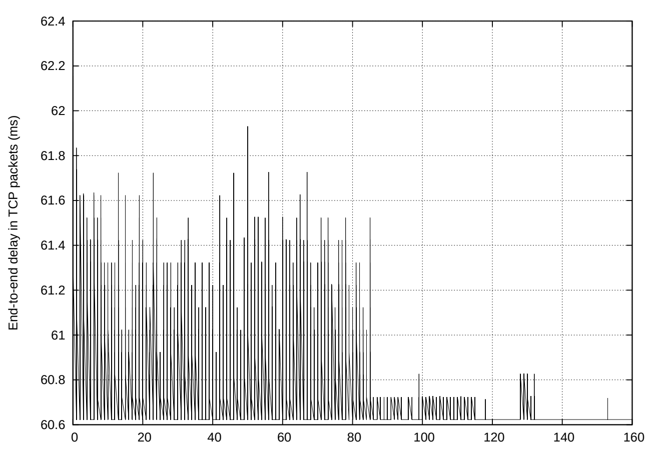

Fig. 11. End-to-end delay in TCP packtes, with max C/I scheduling.

yield a larger queue size, i.e. buffer occupancy, in the link between Node-B and RNC. For higher total cell thorugh-put, maximum C/I scheduling is preferred, though it will cause severe unfairness by providing only a small channel bandwidth to some of the UEs. The variation in end-to-end packet delay is shown to be lower for maximum C/I then RR, as some UE throughputs are very low, due to unfair distribution of channel bandwidth, in the former case. Performance evlaulation of HSDPA with other scheduling mechanisms, such as proportional fair throughput, is left for a future work. Another direction of future work may be to employ AQM controllers (RED, PI and PID) between Node-B and RNC.

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