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THE LTE TECHNOLOGY PERSPECTIVES IN MULTIMEDIA APPLICATIONS

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ПЕРСПЕКТИВИ МУЛЬТИМЕДІЙНОГО ЗАСТОСУВАННЯ ТЕХНОЛОГІЇ LTE

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ПЕРСПЕКТИВЫ МУЛЬТИМЕДИЙНОГО ПРИЛОЖЕНИЯ ТЕХНОЛОГИИ LTE

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Abstract. The LTE technology perspectives analyzed in respect to real time data transmission over multimedia packet based future generation networks. It is concluded that LTE doesn’t meet requirements of modern machine-to-machine architecture and sensor networks. Advancement surmised for radio channel scheduling and internetwork communication based on the dynamic flow control method.

Keywords: LTE, real time data, multimedia application.

Анотація. Проаналізовано перспективи застосування технології LTE для передачі даних реального часу по мультимедійних пакетних мережах майбутніх поколінь. Зроблено висновок, що LTE не задовольняє вимоги до сучасних систем між-машинної взаємодії та сенсорних мереж. Запропоновано застосування динамічного управління потоками для управління радіоканалом та міжмережевої взаємодії.

Ключові слова: LTE, дані реального часу, мультимедійні додатки.

Аннотация. Проанализированы перспективы применения технологии LTE для передачи данных реального времени по мультисервисным пакетным сетям будущих поколений. Сделан вывод, что внедрение LTE не удовлетворяет требованиям к современным системам межмашинного взаимодействия и сенсорным сетям. Предложено использование динамического управления потоками для управления радиоканалом и межсетевым взаимодействием.

Ключевые слова: LTE, данные реального времени, мультимедийные приложения.

1. INTRODUCTION

The development of standards and technologies of wireless access networks and mobile telephony began with the launch of an analog mobile communication system of the first generation NMT-450 (1981, Saudi Arabia). One of the best nowadays (2015) decisions in that direction is the implementation of a joint network system for mobile communication of the fourth generation (4G) by two leading US telecommunications operators through the Voice over LTE (VoLTE) technology (2014, Verizon

Wireless and AT & T Inc.), [1, 2]. However, some experts have recognized the "4G" term not to be finally determined de facto for today [3].

There are at least three following implications of "4G" term to be distinguished:

1) The official standard of 4G, which includes two items: LTE Advanced and WiMax2 (IEEE802.16m); this packet of standards was finalized in 2010 ([4]) and adopted in 2011, Among two 4G standards the LTE shows to be more prospective.

2) The commercial brand «4G» that implies combined usage of conventional 3G circuit switched channel for telephone conversation and packet switched LTE based channel for broadband mobile/wireless access to the Internet (so called Circuit Switch Fall Back technique, or CSFB). The CSFB requires two radio systems, as 3G and LTE differ in physical layer. The first commercial LTE deployment took place in Stockholm and Oslo (December 2009) by the Swedish-Finnish network operator TeliaSonera and its Norwegian brand name NetCom (Norway), [5].

3) The pure packet switched one radio access in 4G network based on VoLTE.

2. THE CONCEPT OF THE FOURTH GENERATION FOR MOBILE COMMUNICATION TECHNOLOGY

The 4G Standard key points

Historically, the concept of fourth generation of mobile networks has been associated with the development and adoption of 4G standard package (LTE-A and WiMax2). The first release of 4G standard, known as the "IMT Advanced" specification (International Mobile Telecommunications Advanced), was published in 2008 by the ITU-R sector of ITU, [6]. The main idea of the 4G standard is ultra wideband access of wireless and mobile devices to the info-communication infrastructure. The peak access speed of the mobile device, according to the 4G standard, is 100-300 Mbps, and the maximum access speed for stationary wireless devices is up to 1 Gbps. The second basic principle of 4G standard is the integration of all types of telecommunication and information services (including telephony services) based on IP (the IP Multimedia Subsystem concept, or IMS) [7]. The third 4G standards key point is implementation of "universal mobility" as one of the basic feature in NGN concept which allows a smooth transition of any mobile subscriber from one network to another without loss of connectivity [8]. Finally, the principal background of the 4G standard is expected widespread introduction of the IPv6 protocol instead of IPv4 to expand the address space and increase the possible number of terminals of the global network. The 4G standards were finalized at the meeting of ITU-R Sector in China (Oct., 2010, [4]) and ratified by the ITU in the spring of 2011.

The «4G/3G» commercial brand

In recent years, a number of operators have announced the creation of mobile communication networks under the brand «4G»: 2009 – Lithuania declared the first in the Baltic region «4G» mobile network on WiMax; 2009 –TeliaSonera and NetCom launched the first commercial mobile phone network; December 2010 – ITU-R workshop recognized that LTE, WiMax and other technologies aimed to improve the «3G» can be seen as «4G»; in fact, that means the abandonment of the original ITU strategy towards 4G [9]. In 2011, Lithuania (Omnitel) opened a network of LTE «4G» in the five major cities of the country; Argentina (Claro) and Thailand (Truemove-H) have launched their countries on the scale of the so-called «Pre-4G» HSPA+. In 2012, a number of countries, including India (Bharti Airtel), Azerbaijan (Azercell), South Africa (Vodacom), Mexico (Telcel), Kazakhstan and others deployed commercial «4G» branded systems based on wireless access technology LTE. Currently (2015) the number of networks based on LTE access technology has been increased to dozens.

The main distinctive feature of LTE is an improved access method (called orthogonal frequency division multiplexing – OFDM) which is used on physical layer instead of the 2G inherent frequency division multiplexing in GSM standard or 3G specific code division multiple access (CDMA). Both GSM and CDMA methods provide pulse code modulation resulting in continuous spectrum presentation of the signal; therefore the Gaussian quasi-white noise smoothly affects the signal everywhere within the utilized bandwidth. Instead, the OFDM provides pure discrete harmonic presentation of the coded symbols; this reduces the Gaussian noise impact, improves the signal-to-noise ratio (SNR) and therefore, increases the spectral efficiency of the communication channel (to values of about 1 Bps/Hz and more).

The LTE technology theoretically allows the peak reception rate up to 326.4 Mbps, and transmission rate up to 172.8 Mbps at 20 MHz bandwidth. For that, the data transmission delay in a radio channel segment may be limited within 5 milliseconds. The experienced exchange rate in the deployed LTE networks is considerably less compare to LTE peak rate figures mentioned above. The LTE supports both frequency division duplex (FDD) and time division duplex (TDD) modes in the bandwidth of (1.4, 3.0, 5.0, 10.0 15.0 20.0) MHz while the FDD is primary designed for LTE. Each LTE cell of 5 MHz bandwidth could maintain for about several hundreds of active clients.

However, the LTE technology is not compatible on the physical layer with radio channels previously used in 2G-3G; thereby most LTE networks functioning in CSFB mode require support of two radios in user equipment (UE) – one for telephone speech (e.g., GSM or CDMA pulse modulation) and one more for data transfer in OFDM mode. The first is used for synchronous time division multiplexing (TDM), and the second one provides asynchronous packet delivery. The "rolling back from 4G to 3G" (Circuit Switch Fall Back, or CSFB) in telephone connection contradicts to the principal 4G standard concept (All over IP). Parallel operation of the mobile device on two radio networks (voice channel and data channel) causes the accelerated discharge of the battery, which is a serious challenge for users and UE manufacturers. One more severe problem of the OFDM technique is jumbo peak-factor of Fourier series synthetic signal which requires high fidelity of UE amplifiers.

The VoLTE based 4G networking

In 2011, Bell Canada has deployed one of the world's first commercial fully packet based «4G» network technology VoLTE, [10]. In 2012, three companies of South Korea (including LG Uplus), as well as the MetroPCS company (USA) announced the creation of wireless access networks VoLTE. And in 2014, for about 10 operators, including Verizon Wireless of USA (a subsidiary of one of the world's leading telecom Verizon Communications), AT&T, T-Mobile, started to provide VoLTE based services. At the end of 2014, Verizon and AT&T firstly announced their intention to integrate in 2015 their wireless networks into the joint national mobile communication infrastructure.

The essence of VoLTE technology (vs. LTE) is that the transfer of all types of traffic (including voice telephony) occurs over the single OFDM radio channel due to the extended VoLTE protocol stack based on the TCP/IP suit. To overcome the known issues of packet based real time data delivery (e.g. packet loss possibility and time delay variation) a number of technological enhancement on data link layer have been introduced in VoLTE in the access and transporting network segments. In particular, an updated evolved packet core (EPC) for mobile VoLTE access network had been developed along with evolved IMS transport platform (eIMS), [2]. The eIMS transporting network is also referred to as Multimedia over Telephony (MMTel) concept. This means that the telephone packet flow over the end-to-end virtual connections is maintained as a primary QoS guaranteed telecommunication service, in contrast to the best effort service for the rest of packet data. The maximum time delay of voice packet data in VoLTE is also limited in radio access channel (due to the cyclic frame circulation) and within the EPC (due to the accurate channels capacity scheduling).

These measures result in that a new type of switching technique emerged in telecommunication which takes intermediate position between conventional circuit and packet switching approaches: the VoLTE last mile radio channel looks very similar to circuit switching, whereas the eIMS network remains being packet switched (at least formally). Thus, behind the VoLTE approach, the widely used IMS platform with background IP-packet service apparently shifted the focus towards the primarily QoS guaranteed voice packet delivery on the evolved eIMS platform; hereby a new packet based service class appeared – GBR (Guaranteed Bit Rate) in contrast to the conventional constant bit rate (CBR) in TDM channels. On the one hand, the VoLTE technology together with the EPC/eIMS/MMTel integrated service platform is yet another important step towards the next generation networks (NGN) convergence. On the other hand, however, this approach introduces significant transformation of initial "naive" idea to provide all types of network services immediately on the top of IP protocol.

We assume that substantial prerequisites to redefine traditional IMS concept towards eIMS transporting infrastructure are, first of all, pure scalability of IP-based resource reservation protocols (such as RSVP, NSIS, etc.), rigorous problems in IP-packet delay harnessing, potential packet loss due to network congestions etc. Another key point of the eIMS platform, in our opinion, is understanding that commonly dispersed Internet architecture hinders the process of actual voice/data network convergence; instead, the opposite trend of smooth transition to regional network centralized management and administration turns to be on demand in respect to future generation network engineering. This insight correlates with currently intensive researches on so called Software Defined Network (SDN) of centralized architecture. The latest fact of Verizon/AT&T wireless network integration in USA domain declared for 2015 year, along with appearance of new giants on the global mobile telecom market (e.g. British Vodafone Group plc) is further evidence of the spoken trend.

3. LTE PROTOCOL STACK

The LTE protocol stack is embedded into the TCP/IP suite (Fig.1.). The LTE specific functions are allocated in physical layer (PHY), Data Link Layer (DL), and in control plane of Network and Transport layers. The DL layer of LTE is divided in three sub-layers: MAC (Media Access Control), RLC (Radio Link Control) and PDCP (Packet Data Convergence Protocol). On the IP control plane acts the Radio Resource Control (RRC) protocol; the control plane of the transport layer is presented by EMM (Mobility Management Entity) and ESM is (EPS Session Management), where EPS is Evolved Packet System.

LTE Physical layer

The LTE PHY layer provides digital symbols transmission with OFDM technique for downlink radio channel in the discrete set of frequency bandwidth: 1.4MHz, 3MHz, 5MHz, 10MHz, 15 MHz, 20 MHz wherein the following types of modulation envisaged: QPSK (2 bit/symbol), 16QAM (4 bit/symbol), 64QAM (6 bit/symbol), Fig.2, [11]. LTE enables spectrum flexibility where the transmission bandwidth can be selected between 1.4 MHz and 20 MHz depending on the available spectrum. Therefore, the maximum number of users that can be served at every 0.5 ms is 800 considering a 20 MHz channel with 8 simultaneous transmitter branches. Tab.1, [11]. The OFDM frequency spacing is 15 KHz. For uplink radio channel the Single Carrier Frequency Division Multiple Access (SCFDMA) technique is used in LTE [12]. The SCFDMA is a modified form of OFDM with similar throughput performance and complexity.

This is often viewed as by the Discrete Fourier transform (DFT) pre-coded OFDM where time-domain data symbols are transformed to frequency-domain by DFT before going through the standard OFDM modulation. Thus, SCFDMA inherits all the advantages of OFDM over such techniques such as TDMA and CDMA. The major problem in extending GSM TDMA and wideband CDMA to broadband systems is the increase in complexity with the multipath signal reception. The main advantage of OFDM, as is for SCFDMA, is its robustness against multipath signal propagation, which makes it suitable for broadband systems. SCFDMA brings additional benefit of low peak-to-average power ratio (PAPR) compared to OFDM making it suitable for uplink transmission by user-terminals. The time units of LTE frame are given in Tab.2. The minimal time slot of LTE frame is 0.5 ms; it may contain either 7 symbols (for normal cyclic prefix (CP) or 6 symbols for extended cyclic prefix (CP). If 7 symbols per slot, then the total time interval of 1 symbol presentation is $0.5s/7 = 0.0714ms$.

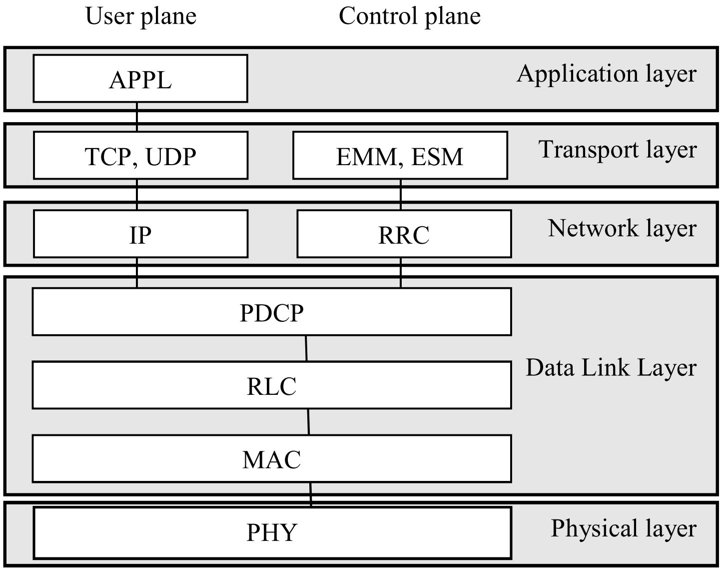

Figure 1 – LTE protocol stack

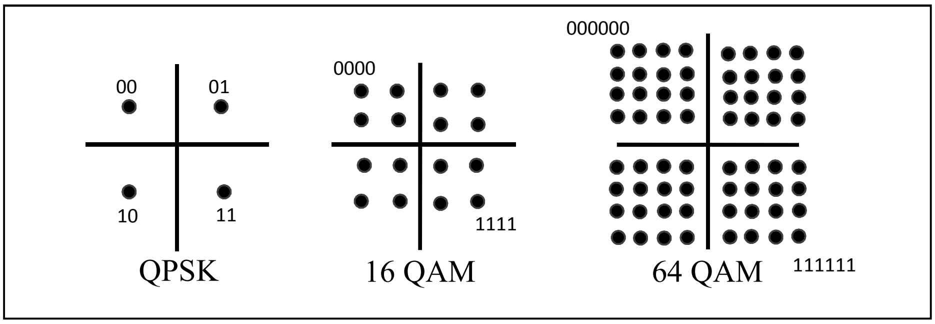

Figure 2 – LTE modulation types

Table 1 – LTE physical channel characteristics

1	Channel bandwidth (MHz)	1.40	3.00	5.00	10.00	15.00	20.00
2	Transmission bandwidth (MHz)	1.08	2.70	4.50	9.00	13.50	18.00
3	Resource blocks (0.5 ms)	6	15	25	50	75	100
4	Resource blocks (MIMO 2×2)	12	30	50	100	150	200
5	Resource blocks (MIMO 4×4)	24	60	100	200	300	400
6	Resource blocks (MIMO 8×8)	48	12	200	400	600	800

The OFDM signal duration Δts for the spectrum collection of a symbol is determined by the first harmonic which equal to the frequency spacing (i.e. $f1 = 15\ KHz$): $\Delta ts = 1/15KHz = 0.0667ms = 66.7$µs. The normal cyclic prefix is $0.0714ms - 0.0667ms = 0.0047ms = 4.7$µs. The extended cyclic prefix is $0.5s/6 - 0.0667ms = 0.0166ms = 16.6$µs. For instance, if LTE radio channel bandwidth is $\Delta F = 5MHz$, then utilized transmission bandwidth is $\Delta FT = 4.5MHz$; the total number of OFDM sub-carriers within one time interval $\Delta ts = 66.7$µs is $4.5MHz/15KHz = 300$; these sub-carriers are organized in 25 resource blocks per 12 sub-carriers (25×12=300). For this case, when QPSK is used, then each of 300 sub-carriers transmits 2 bit information; therefore, the capacity of the 5 MHz LTE radio channel with QPSK is $R = 300 \times 2bit/66.7$µs≈9 Mbps. The spectral efficiency is $\gamma = R/\Delta F = 9\text{Mbps}/5\text{MHz} = 1.8Bps/Hz$. The radio channel resource could be dynamically allocated to active UE devices. If one UE device will get 128 Kbps of LTE radio channel capacity, then approximately 9 Mbps/128 Kbps≈70 mobile devices may co-work simultaneously within a base station cell. The shortest time interval Ts = 32.6 ns in the physical channel is the sampling interval if the system uses a fast Fourier transform that contains 2048 points. The 66.7 μs symbol duration is then equal to 2048×Ts= 2048 × 32.6 ns=66.7μs, [13].

Table 2 – Time units of an LTE frame

Nr.	Time Unit	Value
1	Frame	10 ms
2	Half-frame	5 ms
3	Subframe	1 ms
4	Slot	0.5 ms
5	Symbol	(0.5 ms)/7 for normal CP; (0.5 ms)/6 for extended CP
6	Ts	1/(15000 × 2048) sec ≈ 32.6 ns

LTE Data Link Layer structure

The LTE DL layer covers MAC, RLC and PDCP as shown in Fig. 1. The LTE MAC sub-layer operates with complex frames of 10 ms duration consisting of two half-frames (5 ms in TDD or 10 ms in FDD mode) for down- and uplink respectively. Each half-frame in downlink mode is constituted by either 7 or 6 symbols multiplied by blocks of subcarriers (each 12 ones). Two consecutive slots form a sub-frame of 1 ms duration. The minimal information block $\Delta I_{\min}$ addressed to a UE entity is one 0.5ms slot of 7 or 6 symbol slots ×12 sub-carriers×1 symbol capacity. For QPSK (with normal CP) that is $\Delta I_{\min} = 7 \times 12 \times 2 = 168 bit = 21 byte$. The downlink sub-frame is used in bandwidth shared mode (each UE entity listens the whole sub-frame and accepts its own predetermined partition of it. The minimal information block $\Delta B_{\min}$ in downlink mode which could be allocated to a UE within the 0.5 ms interval (if $\Delta F = 5MHz$ and QPSK then $\Delta B_{\min} = 300 \times 2 = 600 bit = 75 byte$).

The LTE uplink bandwidth channel is divided into subcarriers with 15KHz spacing which are dynamically allocated to the active UE entities due to the downlink scheduling. The subcarriers are formed into the uplink sub-frame similar to downlink frame structure. Though, in contrast to downlink sub-frame, each UE entity creates its own partition of the common uplink sub-frame with the use of limited number of subcarriers. This results in peak-factor damping. However, because of the multipath radio channel signals generated by a set UE, an issue of UE interleaving frequency dispersion appears. To mitigate this phenomenon, the information of uplink symbols is preliminary dispersed in “abstract harmonics” spectrum due to the discrete Fourier transform (DFT) applied to a block of symbols before the followed subcarrier mapping and inverse fast Fourier transform (IFFT). While receiving the uplink signals the inverse DFT (IDFT) is applied after the regular OFDM demodulation procedure due to direct FFT.

The LTE RLC sub-layer performs segmentation and re-assembly in transparent mode (TM), acknowledged mode (AM) or unacknowledged mode (UM). The RLC provides in-sequence delivery and duplicate detection [14]. The segmentation process involves unpacking an RLC packet data unit (PDU) into RLC service data unit (SDU) or SDU partition. The RLC PDU size is not fixed being dependent on channel conditions which eNB assigns to UE in downlink. Transport block size can vary due to bandwidth requirements, distance, power levels, modulation scheme and packets size. The LTE PDCP sub-layer (Packet Data Convergence Protocol) inherits the earlier versions of GSM and 3GPP standards (used for the packet data management) and additionally accomplishes the circuit switched voice data service. The PDCP functions in downlink user plane (Fig.1) include: decryption, decompression of robust header compressed by the ROHC (Robust Header Compression) function, sequence numbering and duplicate removal [15]. PDCP functions in the control plane include decryption, integrity protection, sequence numbering and duplicate removal. Each radio bearer is completed with its own PDCP instance (radio bearers are channels offered by Layer 2 to higher layers for the transfer of either user or control data similar to logical channels).

4. THE LTE PERSPECTIVES TOWARDS INTERACTIVE REAL TIME DATA EXCHANGE

The LTE technology primarily targets the QoS guaranteed voice data delivery in mobile/wireless telephone connections. Due to the 10 ms cyclic frame timing in LTE radio channel, the one way time delay (OWD) in radio channel is limited by approximately 20 ms. The experience of Verizon VoLTE network usage shows, that end-to-end OWD within the USA geographical domain does not exceed the 50 ms [2]; this parameter tolerates the related QoS requirement of the digital telephony standard (i.e. is surely less than 100 ms). For today we do not observe reliable wide range examples of VoLTE deployment, though, the expected OWD for a future wide range intercontinental VoLTE network is of about 150 ms. This value of the OWD also consider to be a good solution for QoS packet based voice traffic transfer.

However, the solid OWD restriction in end-to-end VoLTE connection over the Internet is a serious challenge for mobile access providers. In fact, the creation of an evolved IMS (eIMS) transporting infrastructure is quite decidable task solely for a large carrier which owns both wireless access and transporting components of the global telecom infrastructure (like Verizon). If that, then a converged “Access + Core transport” autonomous system (AS) could be designed where the fast voice data transfer may be provided on the data link layer (e.g. due to the GMPLS) eliminating the crucial issues of IP-packet forwarding and inter domain routing. This argument is an obstacle in bright prospects towards VoLTE-based 4G networks deployment.

The second problem related to the VoLTE multiservice platform is caused by the fixed 10 ms frame cycling in the radio channel which is quite suitable for normal or high quality voice conversation along with delay tolerant packet data delivery; however, the 10 ms cycling can’t meet the new requirements of fast dynamic Machine-to-Machine network (M2M) interaction and sensor networks demands in future generation networks. *The third* tender spot of LTE/VoLTE network architecture is an excessive complexity of radio channel multiplexing and too much overhead in VoLTE protocol stack. This results in superfluous interlayer operational costs.

As a promising advancement of network convergence and multimedia service integration on the base of general mobility platform we consider dynamic flow control (DFC) method of the Ukraine Integrated Telecommunication Technology (ITT) to be implemented for radio channel scheduling and internetwork communication protocols [16]. The main idea of DFC is formalization a digital serial channel on the first ITT-layer as an asynchronous infinite stream of arbitrary mixed payload data symbols (DS) and overhead control symbols (CS). On the second ITT-layer the DS/CS sequence is to be reconfigured in the sequence of data words (DW) and control words (CW) and next be interpreted as an abstract automata program code. This approach enables a great diversity of data processing algorithms and protocols along with wide range of time delay sensitive data transfer scenarios.

5. CONCLUSION

The deployment of LTE based mobile access networks meets serious difficulties in end-to-end QoS voice communication provision. The possible implementation of the 4G standards is hampered by inadequate cost-to-quality ratio and unwillingness of the client to pay money for high standard of 4G-service. The major issue of an evolved IMS platform which is critical for VoLTE network is one way delay harnessing upon the conventional Internet infrastructure. The LTE protocol stack based on TCP/IP looks too complicated and overregulated. The 10 ms frame timing in LTE radio channel can’t meet the new challenges of machine-to-machine real-time dynamic interaction and sensor network demands. Therefore, new researches towards multiservice network convergence are needed. A fundamentally new approach for this respect is visible based on the Integrated Telecommunication Technology

(ITT) developed in Ukraine. This concept enables a great diversity of data processing algorithms and protocols along with wide range of time delay sensitive data transfer scenarios.

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