ОБМІН ПРАКТИЧНИМ ДОСВІДОМ ТА ТЕХНОЛОГІЯМИ

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ENHANCEMENT OF THE LTE-BASED WIRELESS OBJECT INTERACTION

This paper studies the issues of adaptation the LTE technology to increasing dynamics of wireless interaction for technical devices in distributed automated control systems. An enhanced method proposed for radio channel resource scheduling due to provision a distinct logical sub-channel with ten-times reduced data exchange cycle. An algorithm of real time data flow structuring is formalized. Proposed method implies modification of the LTE standard to expand the scope of its utilization.

Keywords: LTE, channel resource scheduling, automated distributed system.

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УСОВЕРШЕНСТВОВАНИЕ БЕСПРОВОДНОГО ВЗАИМОДЕЙСТВИЯ ОБЪЕКТОВ НА БАЗЕ LTE

В статье рассматриваются вопросы адаптации технологии LTE для повышения динамики беспроводного взаимодействия технических устройств в распределенных автоматизированных системах управления. Предложен усовершенствованный метод распределения ресурсов радиоканала путем выделения отдельного логического подканала с десятикратным уменьшенным временного цикла обмена данными. Сформулирован алгоритм структуризации потока данных реального времени на канальном уровне. Предложенный метод предусматривает модификацию стандарта LTE для расширения сферы его применения.

Ключевые слова: LTE, управление ресурсами канала, автоматизированная распределенная система.

1. Introduction

The concept of long term evolution (LTE) also referred to as fourth generation (4G) of mobile communication systems is based on the standard developed by the 3rd Generation Partnership Project (3GPP) in Release 8 with minor enhancements in Release 9 [1]. The LTE unifies and upgrades both GSM/UMTS and CDMA2000 wireless communication technologies. Different countries utilize diverse frequency bands and therefore, multi-band phones assumed to ubiquitously support LTE. The LTE services were launched by North American carriers along with the Samsung first LTE Mobile phone in 2010 [2]. Initially, CDMA operators planned to enhance existing rival standards, but finally migration to the LTE was announced. In 2011 the LTE-Advanced (LTE-A) standard was approved as one of the two 4G standards [3]. The three key traits of LTE-concept distinguish it among the other predecessors: 1) orthogonal frequency division multiplexing (OFDM) instead of GSM/CDMA coding in 2G–3G; 2) fully packet based data transmission for all multimedia data in contrast to time division multiplexing (TDM) for voice data in 2G–3G; 3) dual type of the data link layer frame in the radio channel which logically integrates down link (DL) and up link (UL) sub-frames, as well as contains distinct partitions addressed to diverse user equipment entities (UE) in DL sub-frame, or performed by diverse UE in UL sub-frame [4]; the latter property stands out of all the known before in packet data delivery systems. The LTE frame working mechanism seems to be the first real step to NGN-declared network divergence with respect to computer system data transmission based on the TCP/IP suite (existing Internet) and conventional TDM based public switched telephone network (PSTN). In recent years many operators announced deployment of mobile communication networks under the brand «4G». However, the LTE technology is not compatible on the physical layer with radio channels previously used in 2G-3G; thereby most LTE networks function in so called circuit switch fall back (CSFB) mode which requires two radios in UE (one for telephone speech and the second for data transfer in OFDM mode). The "rolling back from 4G to 3G" in CSFB mode does not meet the main 4G principle of "All over IP" multiple service delivery. Dynamic properties of the LTE network are largely predetermined by LTE physical and data link layer: 10 millisecond time-framing and standardized time-frequency resources scheduling [5]. Therefore, the minimal one way time delay (OWD) of packet massage transmitted over the small range local network is of about 30 milliseconds.

However, new challenges of dynamic wireless interaction in distributed automated control systems require further advancement of radio channel resource management. This work aims to enhance the LTE based object interaction due to provision an accelerated sub-channel for real time data delivery.

2. Analysis of the LTE data link layer

According to the finalized 4G standard [1] the LTE is one of two mainstreams in wireless/mobile communication systems. Table 1 presents in brief terms the LTE evolution steps. In contrast to 1G and 2G frequency division multiplexing, the 3G or 4G uses the shared frequency band for all the user equipment devices without guard intervals; this improves the channel bandwidth utilization. Instead, the OFDM technique provides higher spectrum efficiency vs. CDMA. Whereas in CDMA multiplexing each bit is coded by multiple bit word predetermined to distinct UE entity and recognized as Unicast dedicated bit, the evolved Node Base station (eNB) of the LTE access network generates regular down link (DL) half-frames each of either 5 or 10 ms length with the frequency of 100Hz addressed to all the UEs similar to local broadcasting technique, Fig.1; however, any UE will solely accept the specific part of this half-frame in accordance with resource scheduling control information included into the DL half-frame. The half-frame duration is 5 ms if time division duplex (TDD) is used, or 10 ms in frequency division duplex (FDD) mode.

Table 1

The LTE evolution steps

Generation	1G	2G	3G	4G
Modulation	Analog	Digital (manipulation)		
Multiplexing	FDM	FDM	CDMA	OFDM
Mobile system	NTT	GSM	UMTS	LTE

The DL half-frame is formed by eNB with the use of all the subcarriers of dedicated band (e.g. 300 subcarriers in 5 MHz band with $\Delta f = 15$ KHz increment). In turn, the UL half-frame is formed by multiple UE devices with the use of limited number of subcarriers (e.g. 12 subcarriers) due to the uplink half-frame format and current schedule which is dynamically provided by eNB. The DL LTE half-frame in the FDD mode is divided in 10 sub-frames of 1 ms each formed by two time-slots of 0.5ms. Again, each time-slot is formed by six or seven logical units (upon the length of so called "cyclic prefix") created by the set of digitally manipulated subcarriers due to the quadrature amplitude manipulation (QAM) [6]. Each QAM manipulated subcarrier bears one digital symbol of 2, 4 or 6 bits with respect to three optional types of QAM manipulation applied in LTE (QPSK, 16QAM and 64QAM). The set of subcarrier symbols forms the multiple complex symbol (denote it "word"). Thus, each word in 5NHz band contains 300 symbols. Eventually, the LTE word is the minimal information block which can be either transmitted or received on the LTE physical layer (denote it PHY). However, on the data link layer LTE words form the so called time-frequency resource grid [7] which is shown in Fig.2. The single ϖ -subcarrier symbol is defined by the number n , $n \in \{1 \div 4, 1 \div 16, 1 \div 64\}$ of the point on the constellation diagram which depends on the currently applied modulation type (QPSK, 16QAM and 64QAM respectively), Fig.3. On the PHY layer one ϖ -subcarrier symbol is presented by the complex function defined by the scalar n :

$$f(n,t) = \mu^n \cdot exp\left(i \cdot \varpi \cdot t + \varphi^n\right) = \mu^n \cdot \left[cos\left(\varpi \cdot t + \varphi^n\right) + i \cdot \left(\varpi \cdot t + \varphi^n\right)\right]. \qquad (1)$$

The Table 2 presents values of and for the case of 16QAM manipulation referred to Fig.3-b. For instance, if $n = 0$ then I/Q-code is $00-00$, $\varphi^0 = \frac{\pi}{4} rad$; $\mu^0 = \sqrt{\left(0.25^2 + 0.25^2\right)} \approx 0.35$. If $n = 1$ then I/Q-code is $00-01$, $\varphi^1 = arctg \frac{0.25}{0.75} \approx 0.3 rad$; $\mu^1 = \sqrt{\left(0.25^2 + 0.75^2\right)} \approx 0.79$. If $n = 2$ then $\mu^2 \approx 0.35$, $\varphi^2 = arctg \frac{0.75}{0.25} \approx 1.3 rad$. If $n = 3$ then $\mu^3 \approx 1.06$, $\varphi^3 = \frac{\pi}{4} rad$.

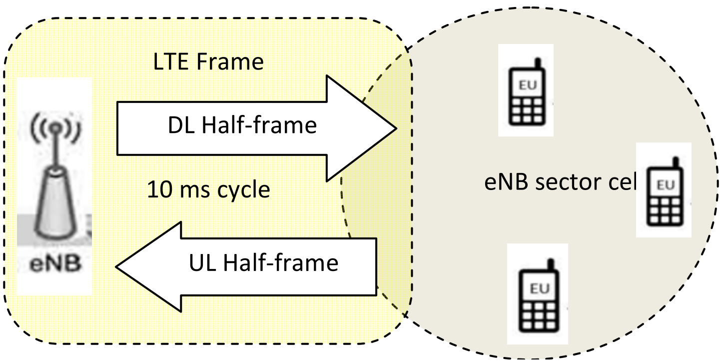

Figure 1 – The general framework of the LTE access network

One LTE word on the PHY layer is predetermined by the vector $n(k)$ and is formed by the Fourier series sum:

$$f\left[n(k),t\right] = \frac{1}{\sqrt{2 \cdot \pi}} \cdot \sum_{k=1}^{K} \mu_k^n \cdot exp\left(i \cdot \omega_k \cdot t + \varphi_k^n\right). \qquad (2)$$

The complex function

$$f\left[n(k),t\right] = Re\left\{f\left[n(k),t\right]\right\} + i \cdot Im\left\{f\left[n(k),t\right]\right\} = I\left[n(k),t\right] + i \cdot Q \cdot \left[n(k),t\right] \qquad (3)$$

is used for I/Q-modulation of main carrier harmonic signal [8].

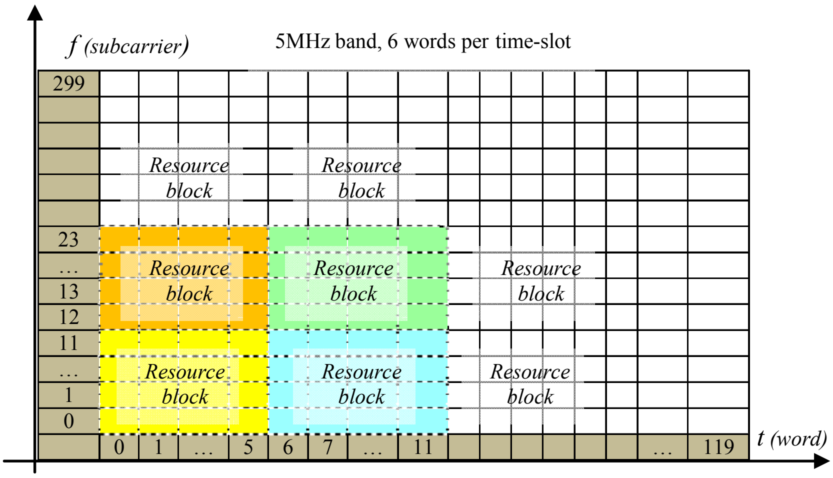

Figure 2 – The LTE frame time-frequency resource grid

Along with the LTE specification [7], the minimal logical unit which can be addressed to the UE device is resource block (RB) created by the set of 12 subcarriers taken from 6 or 7 words as shown in Fig.2. The resource elements come from six types of data source: user data, CSR (cell specific reference, or pilots), DCI (downlink control information), PSS (primary synchronization signals), SSS (secondary synchronization signals), and BCH (broadcast channel). Figure4 illustrates the allocation of different LTE-frame elements around the sub-frames, time-slots and distinct words; in this figure the variant of 7 words per time-slot is shown where two last words of each sub-frame are not scheduled for control elements. One of the seven words in the sub-frame second time-slot is optional (the seventh); thus, the word number six of the second time-slot within any sub-frame principally can be used in ad hoc mode. The DCI is placed within the first N OFDM symbols in each sub-frame, where N is 1, 2 or 3.

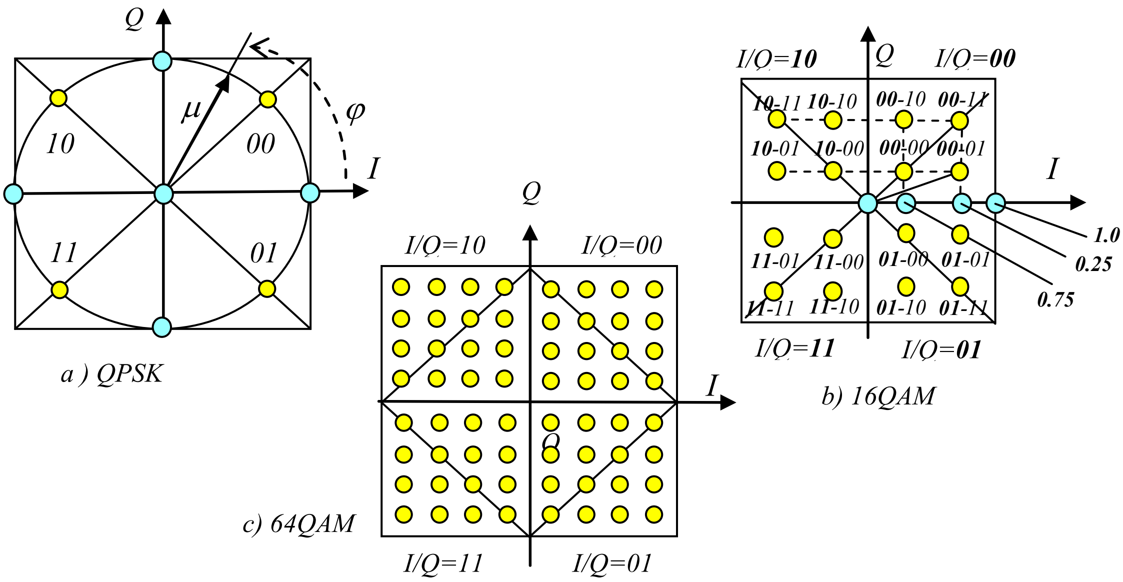

Figure 3 – The LTE QAM-manipulation modes

The DCI carries the content of the PDCCH (Physical Downlink Control Channel), PCFICH (Physical Control Format Indicator Channel), and PHICH (Physical Hybrid ARQ Indicator Channel); together these occupy all the resource elements of the first and possibly the second and third words in each sub-frame, with the exception of the CSR data, which are distributed along the first word of each sub-frame.

Table 2

The 16QAM amplitude/phase manipulation parameters

n	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Code	00-00	00-01	00-10	00 -11	01-00	01-01	01-10	01-11	10-00	10-01	10-10	10-11	11-00	11-01	11-10	11-11
μ^n	0.35	0.79	0.79	1.06	0.35	0.79	0.79	1.06	0.35	0.79	0.79	1.06	0.35	0.79	0.79	1.06
φ^n rad	$\frac{\pi}{4}$	0.3	1.3	$\frac{\pi}{4}$	$-\frac{\pi}{4}$	-0.3	-1.3	$-\frac{\pi}{4}$	$\frac{3\cdot\pi}{4}$	$0.3+\frac{\pi}{2}$	$1.3+\frac{\pi}{2}$	$\frac{3\cdot\pi}{4}$	$-\frac{3\cdot\pi}{4}$	$-0.3-\frac{\pi}{2}$	$-1.3-\frac{\pi}{2}$	$-\frac{3\cdot\pi}{4}$

The size of the DCI per sub-frame is: DCI = $N_{RB} \times \left(10 + 12\left(N - 1\right)\right)$ where N_{RB} is the number of resource blocks. Some of these sources are available in all sub-frames of a frame (user data, CSR, DCI), some are only available in sub-frames 0 and 5 (PSS and SSS), and some are only available in sub-frame 0 (BCH) [7]. Since the total number of symbols in a resource grid is constant, the total amount of user data in each frame is calculated in three different ways: 1) sub-frame 0: all the sources of data are present; 2) sub-frame 5: along with user data the CSR, DCI, PSS, and SSS are present; 3) any other sub-frame (1, 2, 3, 4, 6, 7, 8, 9): besides user data, only CSR and DCI symbols are present.

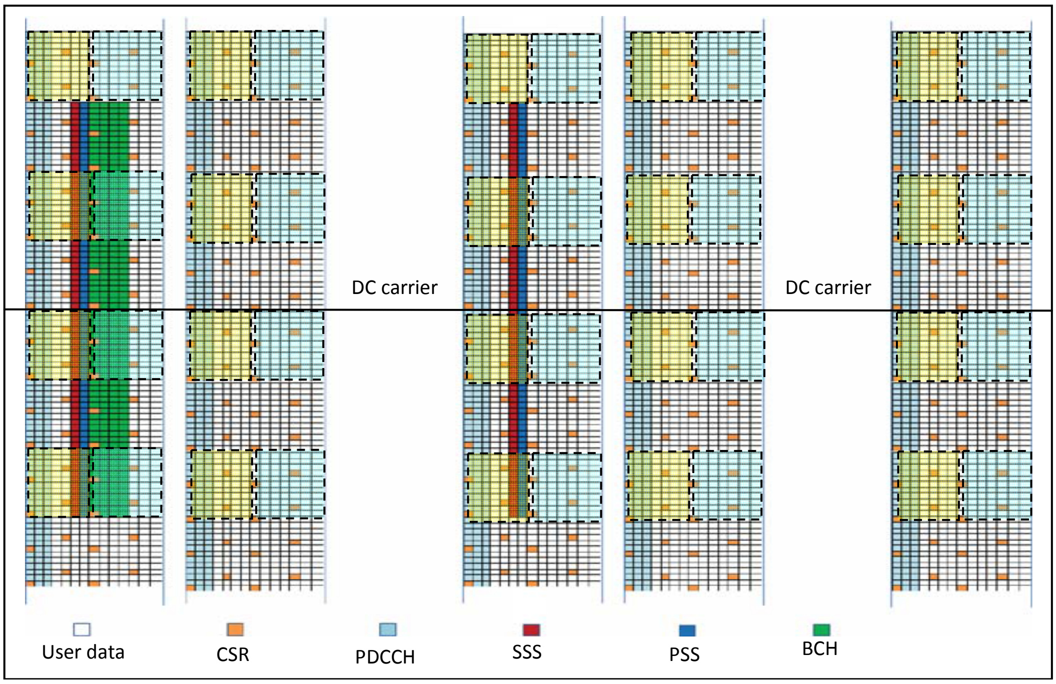

Figure 4 – The LTE resource grid allocation diagram

The analysis of the LTE framework shows the following:

1) The minimal transmission data unit on the LTE physical layer is one word (one OFDM symbol composed by the set of N subcarrier symbols of 2, 4 or 6 bit). 2) The minimal logical unit on LTE data link layer is one resource block (RB) composed by 12 subcarrier symbols within a word multiplied by 6 or 7 consequent words; the total information capacity of RB in case of first three words of a sub-frame occupied by the control data (CD) is $12 \times 6 \times \left(2,4,6\right)/8 = \left(18,36,54\right)$ bytes if 6 words aggregated into the time-slot, or it is $12 \times 7 \times \left(2,4,6\right)/8 = \left(21,42,63\right)$ bytes if 7 words aggregated into the time-slot.

3) The most of control data in DL half-frame are allocated around the central (DC) carrier within the ± 3 RB or $\pm\left(3 \times 12\right)$ subcarriers; these parts of the LTE DL half-frame have irregular structure within different time-slots and sub-frames. All the other RBs have regular structure along distinct sub-frames with three control elements CSR (in colons 1, 5, 8 and 12) in any RB and three first colons of control data in the first time-slot of any sub-frame.

4) Colons 13 and 14 of any sub-frame are not occupied by any control data.

3. Extension of LTE downlink resource scheduling

The dynamic properties of the standard LTE access network are predetermined by the 10 ms cycling while half-frame delivery from eNB to UE in downlink simplex radio channel and from the set of UE to eNB in uplink simplex radio channel. This work introduces an ad hoc mode of the LTE framework usage. The essence of this method consists in the following. Take a couple of adjacent resource blocks (RB) with regular structure shown in Fig.5 (these blocks are beyond the DC carrier zone of ±3RB used in Fig.4). Denote this couple of RB as virtual *ad hoc segment* (or ADS). The ADS regularly appears within any LTE sub-frame (each 1 ms with the frequency of 1KHz); that is 10 times faster than regular LTE frame cycling. The first three colons of ADS (36 grid elements) are assigned for control data (among those three elements of CSR); six more elements of the ADS are occupied by CSR; the user data area of ADS takes (3+6)×12–6=102 elements if 6 words per RB, or (3+7)×12–6=114 elements in 7 words per RB mode. If 16QAM modulation used (4 bits per grid element) then guaranteed volume of the user data (for the 6 per RB mode) in the ADS is 408 bits or 51 bytes. This block of 51 bytes is convenient to encapsulate into the ATM cell which conventionally has 53 bytes total lengths and 48 bytes of payload. Denote the payload of 51 byte as virtual ad hoc LTE packet (VAP). If QPSK will be used then two ADS of one sub-frame will form the VAP; instead, if 64QAM applied then one ADS will carry two VAP-packets.

Now, we assume that one or more VAPs are excluded from any LTE sub-frame to be handled in ad hoc mode creating the regular sequence of virtual packets as shown in Fig. 6. This sequence forms an *ad hoc virtual channel* (ACH) with enhanced dynamic properties which can be used either in circuit switching mode or in packet switching mode within the radio access network. Also combined circuit/packet switching mode can be applied. The manner of usage this virtual channel depends on the algorithms and protocols of its utilization. We propose the following method of VAP structuring.

The first of the 51 bytes is used as protocol identifier (i.e. 256 different protocols can be designed). The rest 50 bytes are handled as 100 hexadecimal symbols (HDS) each of 4 bits. The first ten values on any HDS (from 0 to 9) are taken as letters of an abstract formal grammar (AFG); the last 6 symbols (A, B,C, D, E, F) are reserved as control symbols whereas four symbols are syntax signs: “A” means “space”, “B” is “slash” “/”,“E” and “F” are left and right margins “(“ and “)”; two symbols “C” and “D” are meta-command prefixes respectively for “command” and “data” words. Based on this formal grammar syntax diverse APIs can be designed to benefit increased dynamics of the LTE ad hoc virtual channel (ACH).

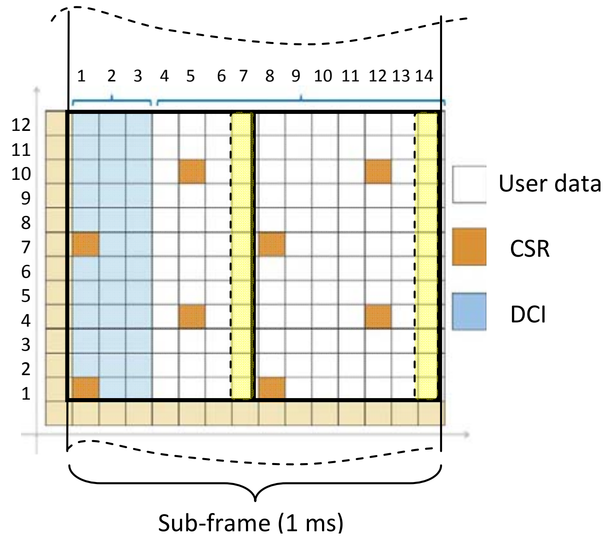

Figure 5 – The structure of virtual ad hoc segment (ADS)

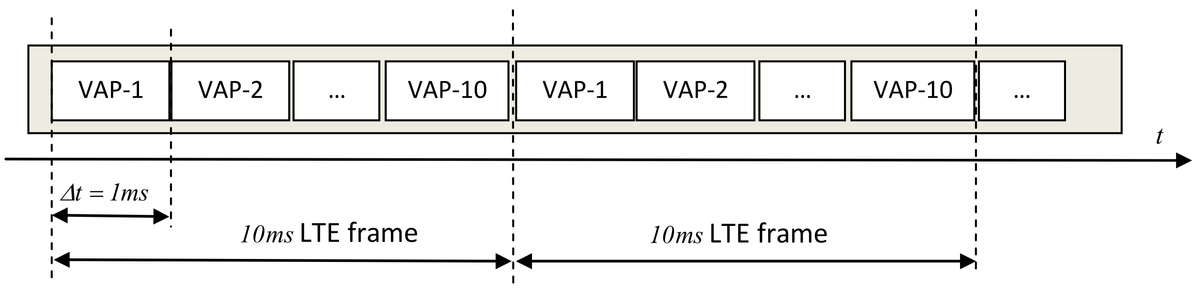

Figure 6 – The LTE ad hoc virtual channel (ACH)

Conclusion

One of the new trends in network technologies development is creating of man-machine (M2M) distributed control systems with wireless access in real-time mode. For this reason, an actual issue is adaptation of advanced mobile communication platforms like LTE to the increased demands for dynamic object interaction in machine-to-machine architecture. This paper introduces an extended mode for resource scheduling in the LTE radio channel which enables ten times accelerated cycling via the LTE ad hoc virtual channel. This virtual channel operates with 51 byte virtual packets regularly transmitted with 1 KHz frequency like synchronous transporting cells. The sequence of virtual packets is mapped onto the continuity of four-bit hexadecimal symbols divided it three subsets (10 letters, 4 syntax signs and 2 meta-commands). These symbols substantiate an abstract formal grammar to construct diverse application program interfaces for high dynamic object interaction in M2M systems.

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