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IMPROVING DYNAMICS OF OBJECTS INTERACTION IN LTE BASED WIRELESS NETWORK

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ПОКРАЩЕННЯ ДИНАМІКИ ВЗАЄМОДІЇ ОБ`ЄКТІВ У БЕЗПРОВІДНІЙ МЕРЕЖІ НА БАЗІ LTE

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Abstract. This work analyses resource scheduling in LTE technology radio channel consider dynamics of terminal network objects interaction in real-time mode for multimedia data transmission over a packet-based network. It is concluded that dynamic properties of the LTE technological platform can be enhanced to meet requirements of modern machine-to-machine wireless interaction. A method of extended resource reallocation in LTE physical downlink channel introduced which reduces real-time data latency.

Key words: LTE, real time data, object interaction.

Анотація. Проаналізовано розподіл ресурсу радіоканалу технології LTE з точки зору динаміки взаємодії термінальних об`єктів мережі у реальному часі за умови передачі даних по мультимедійних пакетних мережах. Зроблено висновок, що динамічні властивості технологічної платформи LTE можуть бути покращені для забезпечення вимог сучасних систем міжмашинної взаємодії. Запропоновано розширений метод перерозподілу ресурсів у низхідному фізичному каналі LTE, який зменшує затримки даних реального часу.

Ключові слова: LTE, дані реального часу, взаємодія об`єктів.

Аннотация. Проанализировано распределение ресурса радиоканала технологии LTE с точки зрения динамики взаимодействия терминальных объектов сети в реальном времени при условии передачи данных по мультимедийных пакетных сетях. Сделан вывод, что динамические свойства технологической платформы LTE могут быть улучшены для обеспечения требований современных систем межмашинного взаимодействия. Предложен расширенный метод перераспределения ресурсов в нисходящем канале LTE, который уменьшает задержки данных реального времени.

Ключевые слова: LTE, данные реального времени, взаимодействие объектов.

Introduction. The LTE concept of parallel subcarriers transmission also known as orthogonal frequency division multiplexing (OFDM) was firstly published in 60's of the last century [1].The parallel data streams provision aims to avoid handling short time intervals, to combat impulsive noise and multipath fading as well as to exploit all available bandwidth [2]. The first applications in this direction took place in the armed forces telecommunications; meanwhile, the term of multi-carrier modulation (MCM) got widespread use and sometimes it became synonymous with OFDM.

In contrast to OFDM with all subcarriers being orthogonal to each other, the orthogonality property is not inherent to MCM; instead, the OFDM method is rather an optimizations version of the MCM scheme. The OFDM benefits those technologies where increased data rate needed due to high spectral efficiency and being able to overcome severe channel impairments encountered in mobile environment. The OFDM technique was implemented in such technologies as air interface with digital audio broadcasting (DAB) and digital video broadcasting terrestrial (DVB-T). It is also chosen for physical layer modulation scheme in the wireless LANs (IEEE 802.11 standard).

One of the main distinctive features of LTE comparatively to the code division multiplexing (CDMA) of third generation (3G) and GSM-based 2G mobile systems is an enhanced access method based on the OFDM. 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 entire 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 (up to the values of about 1 Bps/Hz and more) [3]. The LTE technology provides data reception rate up to 326,4 Mbps, and transmission rate up to 172,8 Mbps at 20 MHz bandwidth. 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.

Dynamic properties of the OFDM-based LTE network are largely predetermined by the key features of LTE physical and data link layers: 10 millisecond time-framing and standardised time-frequency resources scheduling [4 – 6]. Therefore, the minimal one way time delay (OWD) of packet massage transmitted over the small range local network is of about 30 milliseconds. In fact, the critical parameter of mutual end network device interaction is two way delay (TWD) which minimum is estimated of about 60 milliseconds [3]. Within the region network scope the OWD is estimated of about 50 milliseconds [7]. Extrapolating these figures on the world global scope we obtain OWD of about 150 milliseconds. According to the digital telephony quality of service (QoS) standards, it is clear that LTE inherent two way time delay within the range of TWD = 60…300 ms is quite acceptable for normal human individuals' audio conversation in real time mode.

However, new challenges of high speed machine-to-machine (M2M) mobile interaction in distributed automated system control require new approaches to the time-frequency scheduling and considerable reduction of the minimal two way time delay in either mobile or wireless communication infrastructure. The key factor of automated system control is mitigating the feedback delay as much as possible.

The objective of this work is enhancement of LTE based wireless access intended to improve dynamic properties of object's interaction in machine-to-machine mobile network architecture.

Analysis of the resources scheduling in LTE physical channel. The LTE technology is not compatible on the physical layer with radio channels previously used in 2G-3G. Therefore, a special mode of circuit switch fall back (CSFB) is used in most mobile networks deployed under the brand "4G" [8]. This requires supporting two radios in user equipment (UE) device: one GSM or CDMA pulse modulation for telephone speech and one more for data transfer in OFDM mode. The "rolling back from 4G to 3G" due to the CSFB technique does not tune the general idea of 4G standard concept (All over IP) [9]. The parallel operation of two radio network devices in one UE entity reduces battery life, which is a serious challenge for users and UE manufacturers.

Another key issue of the OFDM technique is large peak-to-average power ratio (PARP) which requires high fidelity of UE amplifiers. The LTE physical layer utilizes frequency bandwidth of 1,4 MHz; 3 MHz; 5 MHz; 10 MHz; 15 MHz; 20 MHz along with three options of modulation: QPSK (2 bit/symbol), 16QAM (4 bit/symbol), 64QAM (6 bit/symbol) and frequency spacing of 15 KHz [4, 5]. The time units of LTE frame are given in the minimal time slot of 0,5 ms; it may contain either 7 or 6 OFDM-symbols (OFS) depending on the cyclic prefix (CP) length. The minimal information unit that can be addressed to mobile access entity within an LTE-frame is a logical information block (LIB) formed by physical resource blocks (PRBs) of 12 subcarriers multiplied by the number of OFDM-symbols (12 or 14 ones) within a sub-frame. The related volume of data block depends on the modulation type. If QPSK and extended CP applied then LIB data block is 12 × 12 × 2 bits = 288 bits (or 36 bytes). One of the typical vocoder G729 handling 10 ms voice samples has data compression factor 8 and technological latency of 15 ms: 10 ms sampling + 5 ms data coding and look-ahead buffering (LAB). Thus, any 10 ms the G729 vocoder generates compressed voice data block of 8 Kbps × 10 ms = 80 bits (or 10 bytes). So, the minimal LTE data unite block addressed to the UE entity (36 bytes) exceeds the conventional compressed voice sample (10 bytes) in 26 bytes. Each LIB contains control data and payload. The control data overhead varies for diverse LIB in the LTE resource grid [6].

According to one way flowchart diagram of end-to-end object voice interaction in Fig. 1 the one way delay (OWD) for voice interaction in OFDMA-base LTE network is more than 50 ms. This limitation of OWD value is primarily determined by the time-frequency resources scheduling method adopted in the LTE physical layer standard.

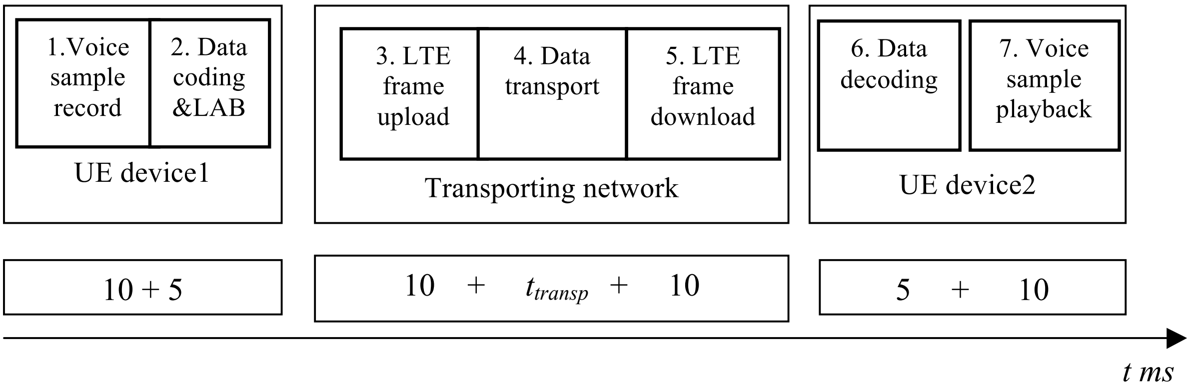
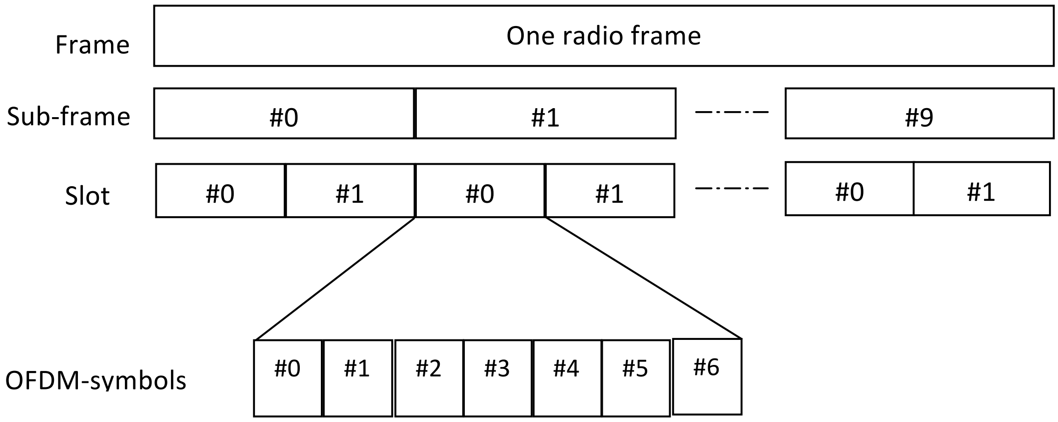


Figure 1 – One way voice interaction flowchart in LTE

The core principle of time-frequency resources scheduling in LTE radio access is factual broadcast addressing the UE devices operating in the vicinity of an evolved node-B station (eNB); that means the common down link frame is transmitted any 10 ms by eNB and received by any active UE device, but only predefined part of this frame is accepted by UE entity. Again, all the UE devices partly constitute entire upstream frame to eNB within the same 10 ms time span.

Consider the simplified diagram of LTE downlink framework in frequency division duplex mode (FDD), Fig. 2. The FDD mode provides simultaneous downstream LTE half-frame transmission by eNB and upstream half-frame composition performed by all the active UE devices; these two data streams are flowing in separated frequency bands. Eventually, the potentially minimal OFDM data unit which can be formed by eNB is one OFDM-symbol encoded in analog wave sample (AWS) due to the inverse Fourier transform (IFT). Each AWS within the eNB downlink frame potentially can be detected by any UE device as a whole one or due selective data retrieving. The OFDM-symbol is formed by the set of N_{SC} orthogonal subcarriers, where N_{SC} depends on the frequency bandwidth utilized by the LTE operator. The total number of OFDM-symbols within the FDD LTE half-frame is 7 samples × 2 slots × 10 sub-frames = 140 (if normal cyclic prefix is used due to 7 samples) or 6 samples × 2 slots × 10 sub-frames = 120 (if extended cyclic prefix is used due to 6 samples).

Any OFDM-symbol is formed by fixed number of resource blocks each comprising 12 subcarrier symbols; the number of resource blocks depends on transmission frequency bandwidth and antenna MIMO configuration, Tabl.1 [5].



LTE frame = 10 ms; FDD half-frame = 10 ms; TDD half-frame = 5 ms;
FDD half-frame comprises 10 sub-frames;
Sub-frame = 1 ms and comprises 2 slots;
Slot = 0,5 ms and comprises 6 or 7 OFDM symbols;
OFDM-Symbol = 0,5/6 (or 0.5/7) ms = 0,0833 (or 0,0714) ms

Figure 2 – Diagram of LTE downlink half-frame in FDD mode

The number of subcarriers (N_{SC}) used in any symbol sample in the LTE half-frame depends on the transmission bandwidth (ΔB_{TR}) within the dedicated channel bandwidth and the standardized frequency quantization step ($\Delta f = 15\text{KHz}$): $N_{SC} = \frac{\Delta B_{TR}}{\Delta f}$; it takes values 72, 180, 300, 600, 900 and 1200 for conventional antenna configuration (1+1).

Table 1 – LTE physical channel characteristics

Channel bandwidth (MHz)		1,40	3,00	5,00	10,00	15,00	20,00
Transmission bandwidth (MHz)		1,08	2,70	4,50	9,00	13,50	18,00
Resource blocks number (RB) each of 12 subcarriers	MIMO (1×1)	6	15	25	50	75	100
	MIMO (2×2)	12	30	50	100	150	200
	MIMO (4×4)	24	60	100	200	300	400
	MIMO (8×8)	48	12	200	400	600	800

The time duration Δt_S of one analog wave sample (AWS) is defined by the frequency quantization step Δf as the first subcarrier frequency in the OFDM set is $f_1 = \Delta f = 15\text{KHz}$; so $\Delta t_S = (f_1)^{-1} = (15\text{KHz})^{-1} = 0{,}0667\,ms$. Now, the normal cyclic prefix (CP) length is $\Delta t_{CPN} = \frac{0{,}5\,ms}{7} - \frac{1}{f_1} = (0{,}0714 - 0{,}0667)\,ms = 0{,}0047\,ms$; the extended cyclic prefix is $\Delta t_{CPE} = \frac{0{,}5\,ms}{6} - \frac{1}{f_1} = (0{,}0833 - 0{,}0667)\,ms = 0{,}0166\,ms$. It is quite obvious, that despite formally defined transmission unit in LTE downlink channel is LTE half-frame with 10 ms cycling, the actual transmission unit can be potentially reduced at least to the distinct sub-frame of 1 ms cycling.

The one OFDM-symbol information capacity is $C_S = m_{SC} \times N_{SC}$ where m_{SC} is information capacity of one subcarrier symbol depending on the instantly used modulation type (2 bits for

QPSK, 4 bits for 16 QAM and 6 bits for 64 QAM); $N_{SC} = 12 \times RB$ is the number of subcarriers within one OFDM sample depending on the operator channel bandwidth and the MIMO configuration; RB is the number of resource blocks each of 12 subcarriers, Tabl.1. For instance, if QPSK modulation used in 5 MHz channel bandwidth with MIMO (1×1) antenna profile than $C_S = (2 \times 12 \times 25)\,bits = 600\,bits = 75\,bytes$. According to Tabl.1, the information capacity C_S of one OFDM-symbol in LTE FDD mode may take discrete values calculated through the following expression obtained empirically in this work, Tabl.2:

$$C_S = (18\,byte) \cdot \frac{n_{MIMO} \cdot m_{MOD}}{6} \cdot r_B \,, \tag{1}$$

where $n_{MIMO} \in (1,2,4,8)$ for MIMO configurations (1, 1), (2, 2), (4, 4) and (8, 8) respectively; $m_{MOD} \in (1,2,3)$ for modulation types QPSK, 16QAM and 64QAM respectively; $r_B \in (6,15,25,25,50,75,100)$ for frequency bandwidths (1,4; 3,0; 5,0; 10,0; 15,0; 20,0) MHz respectively.

The Tabl. 2 indicates that minimal information capacity of one OFDM-symbol (18 bytes) equals one half of the minimal information unit that can be potentially addressed to mobile access entity within an LTE-frame (calculated above in section 2 as 36 bytes). The maximal number of 18 byte blocks for MIMO (8 × 8) in 20 MHz frequency channel is 7200/18 = 400.

Table 2 – The LTE OFDM-symbol information capacity

MIMO	Channel (MHz)	1,4	3,0	5,0	10,0	15,0	20,0
	Modulation	Information capacity (C_S), bytes					
(1×1)	QPSK	18	45	75	150	225	300
	16QAM	36	90	150	300	550	600
	64QAM	54	135	225	450	675	900
(2×2)	QPSK	36	90	150	300	450	600
	16QAM	72	180	300	600	1100	1200
	64QAM	108	270	450	900	1350	1800
(4×4)	QPSK	72	180	300	600	900	1200
	16QAM	144	360	600	1200	2200	2400
	64QAM	216	540	900	1800	2700	3600
(8×8)	QPSK	144	360	600	1200	1800	2400
	16QAM	288	720	1200	2400	4400	4800
	64QAM	432	1080	1800	3600	5400	7200

Analyzing the time-frequency resource scheduling in LTE downlink half-frame we may conclude the following:

a) The minimal physical unit of the LTE downlink half-frame is one OFDM-symbol (with information capacity $C_S = m_{SC} \times N_{SC}$ bit) which is encoded into one sample of time domain formed as the Fourier series sum of N_{SC} subcarriers where $m_{SC} \in (2,4,6)$ depends on the QAM modulation type;

b) The minimal logical information block (LIB) of the LTE downlink half-frame that can be addressed to a distinct user equipment device is formed by 12 subcarriers multiplied by either 12 or 14 OFDM-symbols (depending on the cyclic prefix duration) within a distinct LTE 1 millisecond sub-frame with minimal information capacity $C_{LIB} = 12 \times 12 \times 2 = 288$ bit;

c) In regular LTE operation mode all the logical information blocks (LIBs) of downlink channel are grouped in 10 milliseconds half-frames; however, the individual handling of 1 millisecond LIBs is potentially possible in ad hoc mode.

Ad hoc mode of LTE channel operation. Increasing the object interaction dynamics in an LTE based wireless network needs the solid restriction of one way delay (OWD) for end-to-end network connection. As noted in [3], this is a serious challenge for mobile access providers as it requires substantial rethink of the conventional IP multimedia subsystem (IMS) approach towards creation of particularly evolved IMS (eIMS) as highly scalable transporting infrastructure organized on the OSI data link layer. However, this reorganization perspective can be primarily foreseen with respect to the top range telecommunication carriers which embrace both wireless access and transporting components of regional and global telecom infrastructure; a good example of such a carrier is Verizon Wireless USA company (legally named Cellco Partnership) which is a wholly owned subsidiary of Verizon Communications [7].

As it was mentioned above, the key constraint factor of machine-to-machine (M2M) interaction dynamics in LTE based network is conventional LTE frame format with 10 ms cycling. However, the aforementioned logical information block (LIB) potentially allows handling distinct LIBs in an LTE ad hoc mode with ten times reduced 1 ms cycling. This property of the LTE physical layer we drive in our approach to enhance the object interaction dynamics in M2M wireless network architecture.

Consider particular case of the LTE downlink half-frame in 3 MHz band FDD mode and “1+1 MIMO” configuration depicted in Fig. 3 in terms of distinct LIB units. The structure of half-frame in Fig. 3 looks symmetrical towards the so called “Direct current” (DC) subcarrier (in our case this the subcarrier number 7). Analyzing the LTE resource grid for given case [6] we may see that sub-frames number 0 and 5 have particular structure in contrast to the other LIB units with regular format; this property is defined by the control information allocation. All the regular LIB units have 12 × 12 = 144 elements of 2 bit (for given case). Among those 144 elements of regular LIB units, there are $12 + 4 \times 3 = 24$ control elements and $144 - 24 = 120$ payload elements of $120 \times 2/8 = 30$ byte.

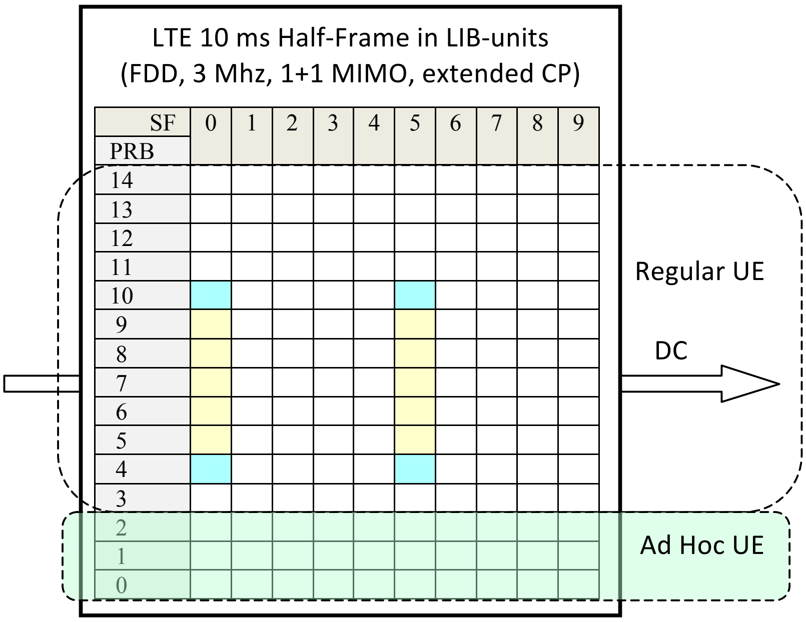


Figure 3 – The LTE downlink half-frame in LIB units:
LIB is logical information unit; DC is direct current;
FDD is frequency division duplex;
PRB colon presents physical resource block number;
SF row presents sub-frame number;
MIMO is multi input multi output antenna configuration;
CP is cyclic prefix; UE is user equipment.

In this work we propose the following principle of enforcing dynamics for dedicated subset of user equipment in LTE access network. According to the LTE downlink half-frame shown in Fig. 3, some part of logical information blocks (LIB) with regular structure (e.g. LIBs with physical resource blocks PRB = 0, 1, 2 in Fig. 3) are to be utilized in ad hoc mode as shown in Fig. 4,b; namely, any three LIBs related to a distinct sub-frame are concatenated to one module which is handled as a whole sub-frame block (SFB) of 3 × 30 = 90 bytes (for given case of LTE physical channel configuration). The regular sequence of SFBs circulates with 1 ms cycling (e.g. with 1 KHz frequency) in downlink channel, and therefore, these SFBs can be used as synchronous transporting modules (STM) which are transmitted 10 times faster than regular LTE frames are being handled.

Thus, the LTE downlink half-frame implies herewith to be split in two parts: a) cut LTE half-frame with regular 10 ms circulating period, Fig. 4,a; b) ad hoc consequence of sub-frame blocks with 1 ms cycling period, Fig. 4-b. The synchronous circulation of SFB in ad hoc LTE downlink physical channel forms a background to provide enhanced quality of service (QoS) provision towards dedicated subset of ad hoc user equipment devices such as M2M terminal devices, sensor controllers etc. According to diagram on the Fig. 1, the one way delay of data transfer over the sub-frame blocks can be estimated by the formula

$$OWD_{SFB} = [(1 + 0{,}5) + (1 + t_{transp} + 1) + (0{,}5+1)] = (5 + t_{transp})\ \text{ms}. \qquad (2)$$

Comparing the OWD_{SFB} estimation in (2) with OWD for regular LTE framing of $(50 + t_{transp})$ ms in Fig. 1 we can see that proposed method enables sufficient enhancement of the object interaction dynamics in case when $t_{transp} << 50$ ms. This is quite applicable in distributed automation systems like unmanned vehicles control systems, mobile tracking systems etc. The next stage of our researches in this direction is investigating advanced algorithms and related protocols of dynamic time-frequency resource reallocation in ad hoc mode of LTE based radio channel for dedicated subset of automated equipments devices.

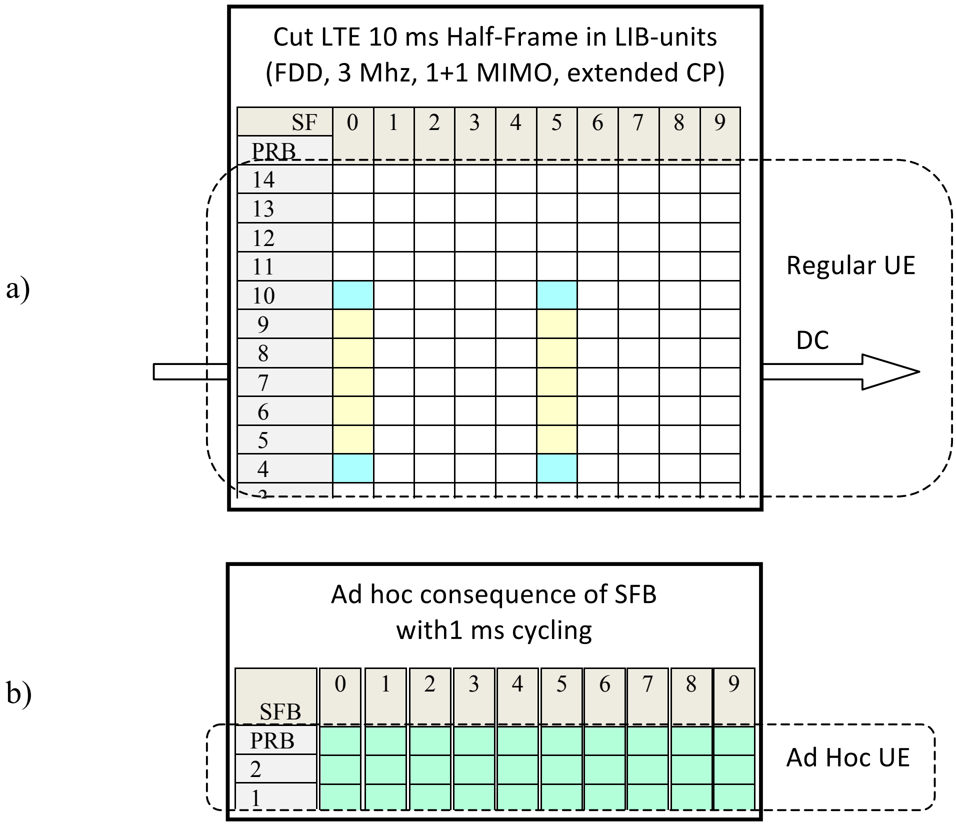


Figure 4 – The LTE frame resource grid decomposition:
a) Cut LTE half-frame for regular user with 10 ms cycling;
b) Ad hoc consequence of sub-frame blocks (SFB) with 1 ms cycling

Conclusions. The LTE physical layer with OFDM access provides an advanced multiservice technological platform for further integration of traditional packet based Internet applications and voice data transmission in real time mode which is typical to commonly used time division multiplexing (TDM) techniques with circuit switched channels. However, one of the key issues is harnessing the round trip time delay for real time data delivery in distributed automatic control systems.

This work presents an enhanced method of data flow control in LTE ad hoc mode based on the analysis of the LTE physical resource scheduling. This method reduces the real time data latency for dedicated subset of terminal devices to improve dynamic properties of object's interaction in machine-to-machine mobile network architecture. The further investigation in this direction presumes design of specific algorithms and related protocols for scheduling user equipment devices in ad hoc mode. This will need adoption of some supplements towards existing LTE specification to expand the scope of its application.

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