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M.K.H. Al-Dulaimi[1], A.M.K. Al-Dulaimi[2], O.S. Yeremenko[3], H.D. Al-Janabi[2]

[1] *Al-Rafidain University College, Bagdad, Iraq*
[2] *Odesa National Academy of Telecommunications named after O.S. Popov, Odesa*
[3] *Kharkiv National University of Radio Electronics, Kharkiv*

BANDWIDTH MANAGEMENT MODEL IN LTE DOWNLINK WITH RESOURCE ALLOCATION TYPE 1

The results of development of mathematical model for time-frequency resource allocation in the downlink of the LTE technology using the Resource Allocation Type 1 were given. The proposed model is aimed to provision of the guaranteed quality of service for wireless network users by allocating the required downlink bandwidth to user equipment. The analysis of the proposed model for time-frequency resource allocation in the LTE technology from the viewpoint of providing the required bandwidth for user equipment in the downlink was conducted.

Keywords: *LTE, time-frequency resource, resource block, scheduling block, mathematical model, bandwidth, Resource Allocation Type 1.*

Introduction

One of the most effective ways to improve performance and basic parameters of Quality of Service (QoS) in LTE technology (Long-Term Evolution) is to implement principles of optimal network resource allocation. Use of solutions for network resource allocation allows effectively react on changes of state and conditions of wireless network functioning that can be dictated, for instance, by outage or overload of its elements, oscillations of traffic coming into network, dynamics of signal-to-noise ratio changes, etc.

Functions of resource allocation in LTE technology can be entrusted to the system of Radio Resource Management (RRM), namely to the scheduler responsible for scheduling resources for user equipment (UE). Similar to HSDPA or WiMAX in the LTE technology mechanisms of resource scheduling in the downlink are not determined by a standard leaving the priority of option to manufacturers of base station equipment (evolved NodeB, eNodeB) [1].

Such resources primarily include symbols (time resource) and frequency subcarriers (frequency resource). The smallest structural unit or a radio resource which can be allocated to any user equipment is a resource block (RB) [2]. Note that the RRM decision on network resources allocation is first of all based on QoS requirements. Therefore, the task of frequency and time resource allocation in LTE technology should be formulated as a task of RB allocation between network UEs according to the required bandwidth and QoS parameters.

Since in the LTE technology a downlink uses several UEs together, there exists a need to select a method or mechanism for frequency and time resources scheduling in order to provide access to transmission medium for all user equipment. The scheduling mechanism, in its turn, is used by the scheduler for allocating bandwidth between UEs. The main idea of frequency and time resources allocation in LTE technology is to provide benefits for data transmission of the UE, which has the best radioparameters.

In solving the problem of bandwidth allocation we must take into account the fact that LTE technology offers three resource allocation types (RATs). In [3, 4] models of resource blocks allocation in the LTE downlink, which uses zero recourse allocation type (RAT 0) were proposed. When using the RAT 0 each user equipment receives one or more allocated recourse block groups (RBGs) formed in accordance with the technological features of LTE. The number of RBs, belonging to one RBG (P), depends on the width of the frequency channel and it is defined according to the Table 1 [5]. The main drawback of RAT 0 is that a number of RBs divisible by P parameter can be allocated for any user equipment in a downlink.

To make bandwidth control in the LTE downlink more flexible we propose to use the first resource allocation type (RAT 1). When using RAT 1 all the set of resource blocks is divided into several nonoverlapping subsets, the number of which is determined by P parameter (Fig. 1).

Table 1

Dependence of RBG size
on the total number of formed RBS

The total number of RBs, N_{RB}^{DL}	RBG size, P
≤ 10	1
11-26	2
27-63	3
64-110	4

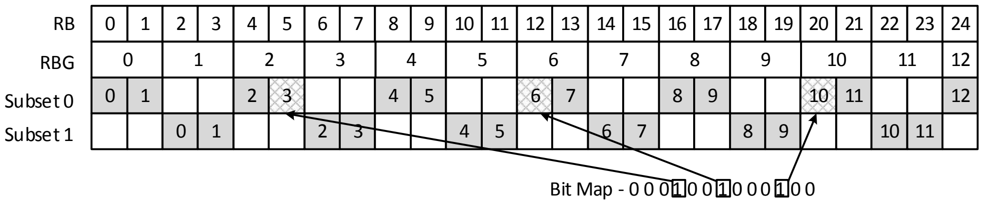


Fig. 1. Example of resource blocks allocation between subsets

As shown in Fig. 1, the number of resource blocks in the subsets may vary. To determine the power of the resource blocks in the subsets of the LTE technology the following expression proposed to use [5]:

$$N_{RB}^{RBGsubset}(p) = \\ = \begin{cases} \left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2} \right\rfloor P + P, \\ \text{at } p < \left\lfloor \dfrac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P; \\ \left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2} \right\rfloor P + \left(N_{RB}^{DL}-1\right) \bmod P + 1, \\ \text{at } p = \left\lfloor \dfrac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P; \\ \left\lfloor \dfrac{N_{RB}^{DL}-1}{P^2} \right\rfloor P, \\ \text{at } p > \left\lfloor \dfrac{N_{RB}^{DL}-1}{P} \right\rfloor \bmod P, \end{cases} \qquad (1)$$

where $N_{RB}^{RBGsubset}(p)$ is power of the p-th subset; p is a current number of resource blocks subset for which calculation of its power is made ($p = \overline{0, P-1}$); N_{RB}^{DL} is the number of RBs formed during the transmission of one time slot. In the LTE technology the number RBs depends on the width of the frequency channel and may be equal to: 6, 15, 25, 50, 75, 100.

As a result of the conducted analysis there was taken the decision on the need to develop a mathematical model for bandwidth management in the LTE downlink that uses the Resource Allocation Type 1 and it is formulated as a task of resource blocks allocation to provide the required bandwidth for each user equipment.

Model For Downlink Bandwidth Management

The proposed model assumes that the following initial data are known:

1) N is the number of UEs;

2) K_S is the number of subcarriers for data transmission in a single RB. This parameter depends on the frequency diversion between subcarriers Δf and it must satisfy the term $K_S \Delta f = 180$ KHz. K_S can be equal to 12 and 24, that already correspond to the frequency diversion between subcarriers Δf as 15 KHz and 7.5 KHz;

3) N_{symb}^{RB} is the number of symbols that form a single resource block. Parameter N_{symb}^{RB} =7 in case of using normal cyclic prefix (CP). Duration of the normal CP of the first OFDM symbol is T_{CP}^{1} =5.2 μs, from first to sixth OFDM symbol it is T_{CP}^{2-6} =4.7 μs. When using the extended CP (T_{CP} =16.7 μs) RB consists of six OFDM symbols (N_{symb}^{RB} =6);

4) T_{RB} =0.5 ms is time of one RB transmission;

5) T_{SF} =1 ms is time of one subframe transmission;

6) N_{SF}^{RB} =2 is the number of RBs that are formed on the identical subcarriers and are allocated to UE during the transmission of one subframe;

7) R_c^n is the rate of a code used in coding a signal of the *n*-th UE;

8) k_b^n is bit symbol load of the n-th UE;

9) type of channel division – FDD or TDD, and frame configuration used;

10) R_{req}^n is the required data transmission rate for *n*-th UE;

11) K is the number of subframes used to transmit information in the downlink. When using FDD the number of downlink subframes is equal to the total number of subframes per frame (K =10). When using TDD the number of downlink subframes must be in accordance with the frame configuration used (Table 2);

12) P is the number of RBs belonging to a single RBG (Table 1);

13) $M = \max(N_{RB}^{RBGsubset})$ is the largest number of resource blocks belonging to any subset.

To account for the number of subframes allocated for information transmission in the downlink [2, 6], the mathematical model uses the concept of downlink configurations matrix introduced in [3, 4]. The matrix is a rectangular with the number of lines corresponding to the number of configurations of the frame (L), and the number of columns corresponding to the number of subframes (K) in the frame, i.e.

Table 2

Configuration frame LTE in mode FDD and TDD

Mode channel separation	Configuration frame	Subframe Number									
		0	1	2	3	4	5	6	7	8	9
TDD	0	D	S	U	U	U	D	S	U	U	U
	1	D	S	U	U	D	D	S	U	U	D
	2	D	S	U	D	D	D	S	U	D	D
	3	D	S	U	U	U	D	D	D	D	D
	4	D	S	U	U	D	D	D	D	D	D
	5	D	S	U	D	D	D	D	D	D	D
	6	D	S	U	U	U	D	S	U	U	D
FDD	7	D	D	D	D	D	D	D	D	D	D

$$H = \left\| h_{l,k} \right\|, (l = \overline{0, L-1};\ k = \overline{0, K-1}), \qquad (2)$$

where

$$h_{l,k} = \begin{cases} 1, & \text{if the } k-\text{th subframe under the } l-\text{th configuration is used for information transmission in the downlink;} \\ 0, & \text{in the opposite case.} \end{cases}$$

As a result downlink configurations matrix will take the form

$$H = \begin{Vmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{Vmatrix}. \qquad (3)$$

When solving the task of downlink bandwidth management within the proposed model it is needed to provide the calculation of Boolean control variable ($x_n^{m,p}$), that determines the order of resource block allocation:

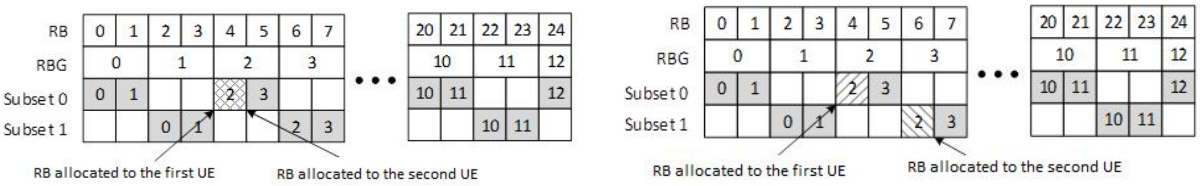
$$x_n^{m,p} = \begin{cases} 1, & \text{if the } m-\text{th resource block on the } p-\text{th subset is allocated to the } n-\text{th UE;} \\ 0, & \text{in the opposite case,} \end{cases} \qquad (4)$$

where $m = \overline{0, M-1}$; $p = \overline{0, P-1}$; $n = \overline{1, N}$.

When calculating the desired variables $x_n^{m,p}$ several important terms-limitations should be fulfilled:

1) The term of allocating each resource block to only one user equipment:

$$\sum_{n=1}^{N} x_n^{m,p} \le 1, (m = \overline{0, M-1}; p = \overline{0, P-1}). \qquad (5)$$



a – the term (5) is not fulfilled

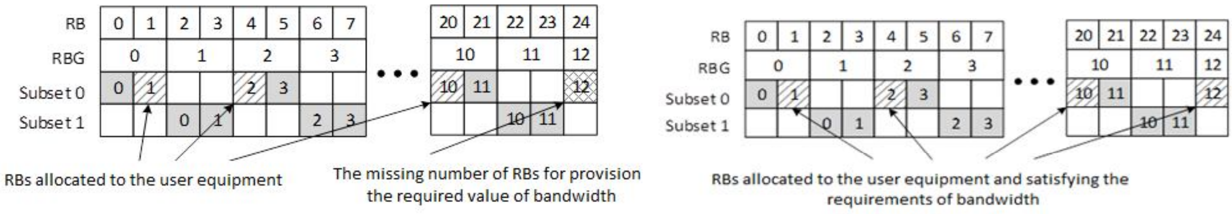
b – the term (5) is fulfilled

Fig. 2. Example of checking the term (5)

2) The term of allocating a number of resource blocks to n-th user equipment that provide the required bandwidth in the downlink using modulation and coding scheme (MCS):

$$\sum_{m=0}^{M-1} \sum_{p=0}^{P-1} x_n^{m,p} \frac{N_{symb}^{RB} N_{SF}^{RB} K_S R_c^n k_b^n K}{10 T_{SF}} \ge R_{трб}^n, \qquad (6)$$

at $n = \overline{1, N}$.



a – the term (6) is not fulfilled

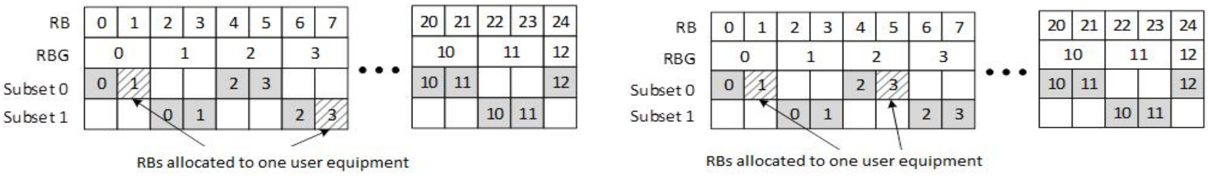
b – the term (6) is fulfilled

Fig. 3. Example of checking the term (6)

3) The term of allocating n-th user equipment a number of resource blocks of only one subset, which is introduced to satisfy the specifics of designing the LTE downlink that uses RAT 1:

$$\sum_{p=0}^{P-1}\sum_{s=0,\, s\neq p}^{P-1}\left[\sum_{m=0}^{M-1} x_n^{m,p}\sum_{m=0}^{M-1} x_n^{m,s}\right]=0\,, \qquad (7)$$

at $n=\overline{1,N}$.

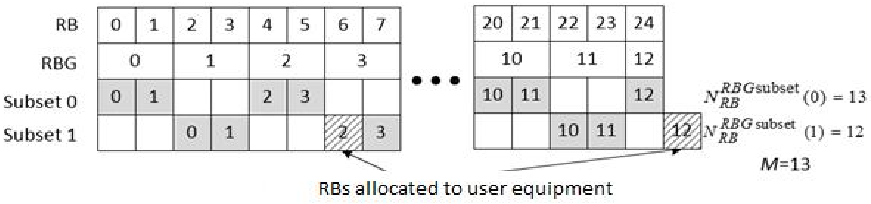


a – the term (7) is not fulfilled b – the term (7) is fulfilled

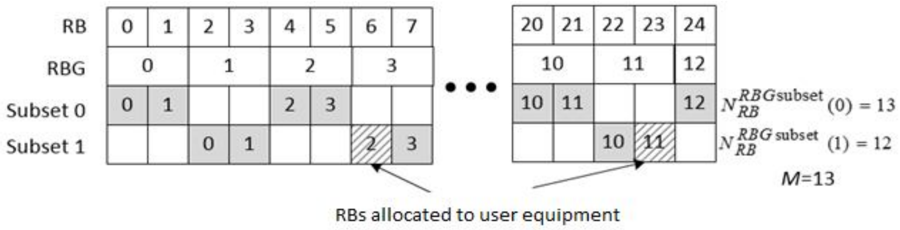
Fig. 4. Example of checking the term (7)

4) The term of allocating n-th user equipment a number of resource blocks that satisfy sizes of subsets determined using the expression (1)(at $p=\overline{0,P-1}$):

$$\sum_{n=1}^{N}\sum_{m=N_{RB}^{RBGsubset}(p)}^{M-1} x_n^{m,p}=0\,,\ N_{RB}^{RBGsubset}(p)<M\,. \qquad (8)$$



a – the term (8) is not fulfilled



b – the term (8) is fulfilled

Fig. 5. Example of checking the term (8)

Use of the term (8) is directed to allocate a number of resource blocks, corresponding to the power of the *p*-th subset and determined with the expression (1), to UEs. Introduction of this term into the mathematical model is caused by the fact that during the calculation of control variables (4) for accounting the number of resource blocks we use a variable m, that takes values from 0 to $M-1$ ($m=\overline{0,M-1}$). Thus fulfillment of the term (8) guarantees that resource blocks which do not belong to the *p*-th subset ($m=\overline{N_{RB}^{RBGsubset}(p),M-1}$), will not be allocated to UEs in conditions when the power of this subset is less than maximum value ($N_{RB}^{RBGsubset}(p)<M$).

The calculation of desired variables (4) according to the terms-limitations (5)-(8) is reasonable to make while solving the optimization task using optimality criterion directed at maximization of the overall downlink performance:

$$\max\sum_{n=1}^{N}\sum_{m=0}^{M-1}\sum_{p=0}^{P-1} x_n^{m,p}\,\frac{N_{symb}^{RB}N_{SF}^{RB}K_S R_c^n k_b^n K}{10T_{SF}}\,. \qquad (9)$$

The task formulated from the mathematical point of view is the task of integer linear programming (ILP). In the model the desired variables $x_n^{m,p}$ (4) are Boolean, and restrictions for the desired variables (5)-(8) are linear.

Analysis of Solutions for Resource Blocks Allocation Task

In order to analyze solutions on resource blocks allocation task in the downlink using the proposed model (4)-(9) let us consider an example where the initial data are the following:

1) the number of UEs is N =3;

2) the number of RBs formed during the transmission of one time slot is N_{RB}^{DL} =15;

3) the number of subcarriers for data transmission in a single RB is $K_s = 12$;

4) the number of symbols forming one RB is $N_{symb}^{RB} = 7$;

5) time for transmission of one RB is $T_{RB} = 0{,}5$ ms;

6) time for transmission of one subframe is $T_{SF} = 1$ ms;

7) the number of RB formed on the identical subcarriers and allocated to UE during the period of one subframe transmission is $N_{SF}^{RB} = 2$;

8) the rate of a code used in coding a signal of different UEs is $R_c^1 = 0{,}5$; $R_c^2 = 1$; $R_c^3 = 0{,}5$;

9) bit symbol load used by UEs is $k_b^1 = 6$; $k_b^2 = 4$; $k_b^3 = 4$;

10) type of channel division is FDD;

11) the number of subframes used for information transmission in the downlink is $K = 10$;

12) the number of RBs belonging to a single RBG (the number of formulated subsets) is $P = 2$;

13) the required data transmission rate for the first UE is $R_{req}^1 = 0{,}5$ Mbps, for the second UE is $R_{req}^2 = 0{,}5$ Mbps, and for the third one it has been changing within the range $R_{req}^3 = 0{,}1 \div 2{,}6$ Mbps.

As an example, the solution of the optimization task formed in the work was received using MatLab R2014a.

The bintprog function of the Optimization Toolbox package was activated. Fig. 6 shows the dependence of allocation of bandwidth and resource blocks (Fig. 7) in the downlink between different user equipment under changing the desired value of one of them (the third UE).

As simulation results showed at the measurement interval $R_{req}^3 = 0{,}1 \div 2$ Mbps the second UE had the highest value of bandwidth, which was 5,376 Mbps (Fig. 6).

This is explained by the fact that the second UE had the highest MCS value due to which all eight resource blocks of zero subset were allocated to it (Fig. 7). Allocation of seven resource blocks of the first subset at the interval $R_{req}^3 = 0{,}1 \div 2$ Mbps was made between the first and the third UEs (Fig. 7).

The bandwidth of the third UE was growing in accordance with increase of the required value from 0,336 to 2,016 Mbps.

On the contrary the bandwidth of the second UE decreased from 3,024 to 0,504 Mbps due to the limitation of time-frequency resource (resource blocks), most of which were allocated to the third UE with the increase of R_{req}^3.

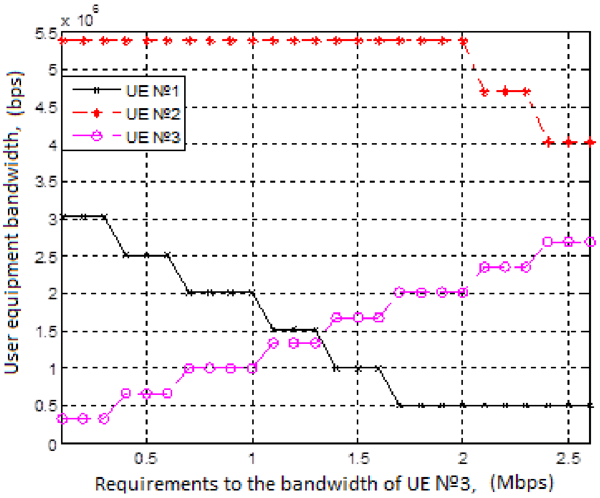


Fig. 6. Dependence of bandwidths allocated to UEs from change of the required bandwidth of the third UE

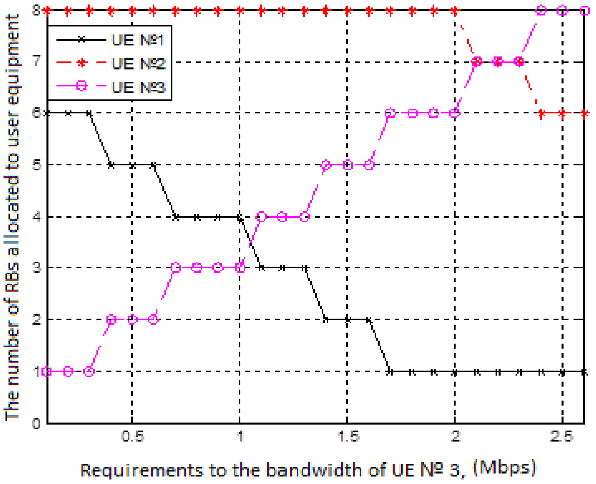


Fig. 7. Dependence of the number of resource blocks allocated to UEs from change of the required bandwidth of the third UE

At the measurement interval $R_{req}^3 = 2{,}1 \div 2{,}3$ Mbps resource blocks of zero subset were allocated between the first and second user equipment. The bandwidth of the first UE was 0,504 Mbps, as only one RB was allocated to it, and the second UE was 4,704 Mbps (seven RB). All the seven resource blocks of the first subset were allocated to the third UE and its resulting bandwidth was 2,352 Mbps.

In case when R_{req}^3 took the value of $2{,}4 \div 2{,}6$ Mbps all the eight resource blocks of zero subset were allocated to the third UE and its bandwidth was 2,688 Mbps. Resource blocks of the first subset were allocated between the first and second UEs: one RB (0,504 Mbps) was allocated to the first UE and six RBs (4,032 Mbps) were allocated to the second UE. Under $R_{req}^3 > 2{,}6$ Mbps the formulated task did not have a solution because it was impossible to provide all UEs with the required values of bandwidth.

Conclusion

It is confirmed that one of the main tasks in wireless network that functions using the LTE technology is the task of required QoS provision which includes the need to allocate the required downlink bandwidth to user equipment. Providing the required bandwidth can be achieved by solving the problem of allocation of time-frequency resource represented by resource blocks in the downlink. As the analysis has shown the known solutions for bandwidth allocation in the downlink of the LTE technology are focused on the use of zero resource allocation type, which has low flexibility due to combining resource blocks in the groups. As a result, in this paper we propose the mathematical model for LTE downlink bandwidth allocation, the novelty of which lies in using the first resource allocation type (Recourse Allocation Type 1).

Using the proposed model allows us to account the technological features of the LTE downlink (splitting the resource blocks into subsets, allocation of RB of only one subset to user equipment), as well as territorial remoteness of user equipment (type of modulation system and coding).

During the analysis it was found that use of the proposed model is aimed at providing each user equipment with quality of service according to the bandwidth in the downlink with the possibility of access to additional (unguaranteed) bandwidth.

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Рецензент: д-р техн. наук, проф. О.Ю. Евсеева, Харьковский национальный университет радиоэлектроники, Харьков.

МОДЕЛЬ УПРАВЛЕНИЯ ПРОПУСКНОЙ СПОСОБНОСТЬЮ НИСХОДЯЩЕГО КАНАЛА СВЯЗИ LTE ПО СХЕМЕ ВЫДЕЛЕНИЯ РЕСУРСА ПЕРВОГО ТИПА

М.Х.Х. Аль-Дулайми, А.М.Х. Аль-Дулайми, А.С. Еременко, Х.Д. Аль-Джанаби

Приведены результаты разработки математической модели распределения частотно-временного ресурса нисходящего канала связи технологии LTE, использующего первый вид распределения ресурсов. Предложенная модель направлена на обеспечение гарантированного качества обслуживания пользователей беспроводной сети путем выделения пользовательским станциям требуемой пропускной способности в нисходящем канале связи. Проведен анализ предложенной модели распределения частотно-временного ресурса технологии LTE с точки зрения обеспечения требуемых пропускных способностей различных пользовательских станций в нисходящем канале связи.

Ключевые слова: *LTE, частотно-временной ресурс, ресурсный блок, блок планирования, математическая модель, пропускная способность, первый вид распределения ресурсов.*

МОДЕЛЬ УПРАВЛІННЯ ПРОПУСКНОЮ ЗДАТНІСТЮ НИЗХІДНОГО КАНАЛУ ЗВ'ЯЗКУ LTE ЗА СХЕМОЮ ВИДІЛЕННЯ РЕСУРСУ ПЕРШОГО ТИПУ

М.Х.Х. Аль-Дулаймі, А.М.Х. Аль-Дулаймі, А.С. Єременко, Х.Д. Аль-Джанабі

Наведено результати розробки математичної моделі розподілу частотно-часового ресурсу низхідного каналу зв'язку технології LTE, що використовує перший вид розподілу ресурсів. Запропонована модель спрямована на забезпечення гарантованої якості обслуговування користувачів бездротової мережі шляхом виділення користувальницькою станціям необхідної пропускної спроможності в низхідному каналі зв'язку. Проведено аналіз запропонованої моделі розподілу частотно-часового ресурсу технології LTE з точки зору забезпечення необхідних пропускних спроможностей різних користувальницьких станцій в низхідному каналі зв'язку.

Ключові слова: *LTE, частотно-часовий ресурс, ресурсний блок, блок планування, математична модель, пропускна здатність, перший вид розподілу ресурсів.*