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DEVELOPMENT AND ANALYSIS OF BANDWIDTH ALLOCATION LINEAR MODEL IN LTE DOWNLINK WITH RESOURCE ALLOCATION TYPE 1

Lemeshko O. V., Al-Dulaimi A.M.K. Development and analysis of bandwidth allocation linear model in LTE downlink with Resource Allocation Type 1. The LTE (Long-Term Evolution) technology is a leader in telecommunications market and seen as an effective solution in construction of telecommunication networks of the Fourth Generation (4G). To ensure high performance and noise immunity in the LTE OFDMA (Orthogonal Frequency-Division Multiple Access) applied as a method of providing information transmission to multiple users of the radio spectrum based on an orthogonal frequency division multiplexing. The effectiveness of time-frequency resources allocation between user equipment that are represented in the LTE as resource blocks is largely determined by the mathematical models and computational techniques. In this regard, in the article proposed the mathematical model of bandwidth allocation of the downlink in the LTE network, organized as the first type of allocation (RAT 1, Resource Allocation Type 1). Using the proposed model allowed to reduce the solutions of the technological problem of bandwidth allocation downlink in the LTE network to solving the optimization problem of Boolean programming. The linear nature of the model will significantly reduce the computational complexity of obtaining the final solutions on the resource blocks allocation between the user equipment in LTE network. The research results of the proposed model confirmed its adequacy and accuracy on a number of numerical examples.

Keywords: network, channel, resource block, bandwidth, quality of service, optimization, LTE

Лемешко О. В., Аль-Дулаймі А.М.Х. Розробка та аналіз лінійної моделі розподілу пропускної здатності низхідного каналу за першим типом в мережі LTE. Запропоновано математичну модель розподілу пропускної здатності низхідного каналу в мережі LTE, організованого за першим типом розподілу (RAT 1, Resource Allocation Type 1). Використання запропонованої моделі дозволило звести вирішення технологічного завдання щодо розподілу пропускної здатності низхідного каналу в мережі LTE до розв'язання оптимізаційної задачі булевого програмування. Лінійний характер моделі дозволив значно знизити обчислювальну складність отримання кінцевих рішень щодо розподілу ресурсних блоків між станціями користувачів в мережі LTE. Результати дослідження запропонованої моделі довели її адекватність та підтвердили достовірність на ряді обчислювальних прикладів.

***Ключові слова*:** мережа, канал, ресурсний блок, пропускна здатність, якість обслуговування, оптимізація, LTE

Лемешко А. В., Аль-Дулайми А.М.Х. Разработка и анализ линейной модели распределения пропускной способности нисходящего канала по первому типу в сети LTE. Предложена математическая модель распределения пропускной способности нисходящего канала в сети LTE, организованного по первому типу распределения (RAT 1, Resource Allocation Type 1). Использование предложенной модели позволило свести решения технологической задачи по распределению пропускной способности нисходящего канала в сети LTE к решению оптимизационной задачи булевого программирования. Линейный характер модели позволил значительно снизить вычислительную сложность получения конечных решений по распределению ресурсных блоков между станциями пользователей в сети LTE. Результаты исследования предложенной модели доказали ее адекватность и подтвердили достоверность на ряде вычислительных примеров.

Ключевые слова: сеть, канал, ресурсный блок, пропускная способность, качество обслуживания, оптимизация, LTE

1. Introduction. Currently, the LTE (Long-Term Evolution) technology is one of the most effective in the field of solutions for high-speed multi-service access. This technology is a standard offered by 3GPP (3rd Generation Partnership Project) consortium, and is seen as basis for the fourth generation of mobile telecommunications (4G) [1]. Performance of any telecommunication technology is mainly determined by performance of solutions in management on available network resources (frequency, time, channel, buffer, and information) with mechanisms and protocols of all OSI (Open Systems Interconnection Basic Reference Model) layers. For LTE technology basic layers that determine its performance are physical and data link. Functions of network resource allocation in LTE technology may be performed by the Radio Resource Management system (RRM), namely, the scheduler, which is responsible for allocating resources to user stations (User

Equipment, UE). Such resources primarily include symbols (time resource) and frequency subcarriers (frequency resource). Thus as the basic access technology of UE to the frequency and time resources in LTE there is selected multiple access with orthogonal frequency division based on orthogonal frequency-division multiplexing (OFDM).

The smallest structural radio resource unit that can be managed in solving the self-organization problem is a Resource Block (RB). Each RB occupies 12 adjacent OFDM subcarriers in frequency domain and one slot (0.5 ms) in time domain, consisting of six or seven OFDM symbol (the smallest structural OFDM unit in time domain).

The smallest structural element allocated to unique UE is Scheduling Block (SB), formed by two adjacent RBs with the same subcarriers and transmitted over a Transmission Time Interval (TTI) of 1 ms. The result of solving the problem of frequency and time resources allocation must be binding SB with UE in downlink frame transmitted over 10 ms. Thus, the task of planning time and frequency resources in LTE technology should be formulated as a problem of SB allocation among the UE network, depending on required rate and QoS parameters.

The LTE technology uses three types of resource allocation (Resource Allocation Type, RAT): RAT 0, RAT 1, RAT 2, suggesting the union of RBs in so-called Resource Block Groups (RBG). To make bandwidth management in LTE downlink more flexible it is proposed to use the RAT 1. When using RAT 1 the set of resource blocks is divided into several non-overlapping subsets, the number of which (N_{RB}^{DL}) is determined by RBG size (P parameter):

$$P=1 \text{ if } N_{RB}^{DL}\le 10;\, P=2 \text{ if } N_{RB}^{DL}=11\div 26;\, P=3 \text{ if } N_{RB}^{DL}=27\div 63;\, P=4 \text{ if } N_{RB}^{DL}=64\div 110 \quad (1)$$

The number of resource blocks in subsets may vary. To determine the number of resource blocks in subsets in LTE technology the following expression is proposed [1]:

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

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

As a result of performed analysis there was made a decision to develop a mathematical model for bandwidth management in LTE downlink using RAT 1, and it is formulated as a problem of resource blocks allocation for providing required bandwidth for each UE. In [2]-[4] proposed non-linear models of bandwidth allocation in LTE downlink with RAT 1. However, the non-linear nature of model complicates the calculation of bandwidth allocation order in LTE downlink. In this regard, proposed a linear model of bandwidth allocation in LTE downlink with RAT 1.

2. Linear Model of Bandwidth Allocation in LTE Downlink with Resource Allocation Type 1. In proposed model assumed that the following initial data are known:

- N is the number of UEs;
- 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;

- 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);
- T_{RB}=0.5 ms is time of one RB transmission;
- T_{SF}=1 ms is time of one subframe transmission;
- 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;
- R_c^n is the rate of code used in coding a signal of the n-th UE;
- k_b^n is bit symbol load of the n-th UE;
- type of channel division (FDD or TDD), and frame configuration used;
- R_{req}^n is the required data transmission rate for n-th UE;
- 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 used according to the frame configuration;
- $M = \max(N_{RB}^{RBGsubset})$ is the largest number of resource blocks belonging to any subset.

For solving the problem of bandwidth allocation in LTE downlink with RAT 1 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:

$$x_n^{m,p} = \begin{cases} 1, \text{ if the } m-\text{th resource block on the } p-\text{th subset is allocated to the } n-\text{th UE;} \\ 0, \text{ otherwise,} \end{cases} \quad (3)$$

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

Additional control variables are the variables x_n^p that determine belonging of resource block to user stations (UEs):

$$x_n^p = \begin{cases} 1, \text{ if } n-\text{th UE uses resourse only of } p-\text{th subset;} \\ 0, \text{ otherwise.} \end{cases} \quad (4)$$

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

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

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

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

2) 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:

$$\sum_{p=0}^{P-1} x_n^p = 1, \quad \text{where } n = \overline{1, N}. \quad (6)$$

3) 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):

$$\sum_{m=0}^{M-1} x_n^{m,0} r_{n,m} \ge R_{трб}^n x_n^0; \ldots\ldots \sum_{m=0}^{M-1} x_n^{m,p} r_{n,m} \ge R_{трб}^n x_n^p; \ldots\ldots \sum_{m=0}^{M-1} x_n^{m,P-1} r_{n,m} \ge R_{трб}^n x_n^{P-1}, \quad (n = \overline{1, N}), \quad (7)$$

where $r_{n,m} = \dfrac{N_{symb}^{RB} N_{SF}^{RB} K_S R_c^n k_b^n K}{10 T_{SF}}$ is a bandwidth allocated by m-th RB to n-th UE.

Calculation of desired variables (3), (4) according to the terms-limitations (5)-(7) is reasonable to make in solving the optimization problem using optimality criterions:

$$\min_{x} \sum_{n=1}^{N} \sum_{m=0}^{M-1} \sum_{p=0}^{P-1} x_n^{m,p} r_{n,m} , \tag{8}$$

while saving channel bandwidth;

$$\min_{x} \sum_{n=1}^{N} \sum_{m=0}^{M-1} \sum_{p=0}^{P-1} x_n^{m,p} , \tag{9}$$

while minimizing the number of used RBs;

$$\min_{x} \sum_{n=1}^{N} \sum_{m=0}^{M-1} \sum_{p=0}^{P-1} \left[x_n^{m,p} r_{n,m} + x_n^{m,p} \right], \tag{10}$$

in combined minimization of criterions (8) and (9).

The task formulated from the mathematical point of view is a problem of integer linear programming (ILP). In the model desired variables (3) and (4) are Boolean, and restrictions for desired variables (5)-(7), object functions (8)-(10) are linear.

3. Research of Bandwidth Allocation Process in LTE Downlink with RAT 1

3.1. Problem Solving Bandwidth Allocation in LTE Downlink with RAT 1 (channel bandwidth 3 MHz)

Within the investigation were considered the following input data:

- number of UEs is 3 ($N = 3$);
- number of RBs is 11 ($N_{RB}^{DL} = 11$);
- access rates required for each of the UEs are $R_{req}^{1} = 1.2$ Mbps, $R_{req}^{2} = 1.3$ Mbps, $R_{req}^{3} = 0.8$ Mbps;
- number of RBs in subsets $M = \max(N_{RB}^{RBGsubset}) = 6$ (0÷5);
- matrices of RBs bandwidths for subsets 0÷1 and UEs 1÷3:

$$\left\| r_{n,k}^{0} \right\| = \begin{Vmatrix} 0.1 & 0.3 & 0.2 & 0.5 & 0.4 & 0.7 \\ 0.6 & 0.7 & 0.7 & 0.1 & 0.2 & 0.3 \\ 0.8 & 0.9 & 0.7 & 0.1 & 0.6 & 0.7 \end{Vmatrix}, \quad \left\| r_{n,k}^{1} \right\| = \begin{Vmatrix} 0.1 & 0.3 & 0.2 & 0.5 & 0.4 & 0 \\ 0.6 & 0.7 & 0.7 & 0.1 & 0.2 & 0 \\ 0.8 & 0.9 & 0.7 & 0.1 & 0.6 & 0 \end{Vmatrix}.$$

Results of using model (1)-(10) for solving problem of bandwidth allocation in LTE downlink with Resource Allocation Type 1 based (channel bandwidth 3 MHz) on the use of different optimality criteria (8)-(10) shown in Tables I-III.

During minimization the number of used resource blocks (8) obtained the following results (Table I):

- first and second UEs use zero subset, while third UE uses the first subset;
- totally used 5 resource blocks out of 11;
- procedure of bandwidth allocation for each UE is following: 1.2 Mbps; 1.3 Mbps, 0.9 Mbps, i.e. to third UE allocated 0.1 Mbps more than the required level.

There are numbers of UEs using one or other RB shown in rows “Subset 0” and “Subset 1” of Tables I.

Procedure of bandwidth allocation to UEs using criterion (8) Table I

RB	0	1	2	3	4	5	6	7	8	9	10
RBG	0		1		2		3		4		5
Subset 0	2	-			2	1			-	1	
Subset 1			-	3			-	-			-

With saving allocated channel bandwidth to UEs (9) obtained results presented in Table II:

- first and third UEs use zero subset, while second UE uses the first subset;
- totally used 6 resource blocks out of 11;
- procedure of bandwidth allocation for each UE is following: 1.2 Mbps; 1.3 Mbps, 0.8 Mbps.

Procedure of bandwidth allocation to UEs using criterion (9) Table II

RB	0	1	2	3	4	5	6	7	8	9	10
RBG	0		1		2		3		4		5
Subset 0	3	1			1	-			-	1	
Subset 1			2	2			-	-			-

While using combined optimality criterion (10) obtained the next results (Table III):

- first and second UEs use zero subset, while third UE uses the first subset;
- totally used 5 resource blocks out of 11;
- procedure of bandwidth allocation for each UE as in second case corresponds to required values: 1.2 Mbps; 1.3 Mbps, 0.8 Mbps.

Procedure of bandwidth allocation to UEs using criterion (10) Table III

RB	0	1	2	3	4	5	6	7	8	9	10
RBG	0		1		2		3		4		5
Subset 0	2	-			2	1			-	1	
Subset 1			3	-			-	-			-

3.2. Problem Solving Bandwidth Allocation Process in LTE Downlink with RAT 1 (channel bandwidth 10 MHz)

Within the investigation were considered the following input data:

- number of UEs is 3 ($N = 3$);
- number of RBs is 27 ($N_{RB}^{DL} = 27$);
- access rates required for each of the UEs are $R_{req}^{1} = 4.3$ Mbps, $R_{req}^{2} = 3.4$ Mbps, $R_{req}^{3} = 2.7$ Mbps;
- number of RBs in subsets $M = \max(N_{RB}^{RBGsubset}) = 9 \;\; (0 \div 8)$;
- matrices of RBs bandwidths for subsets 0÷2 and UEs 1÷3:

$$\left\| r_{n,k}^{0} \right\| = \left\| \begin{matrix} 0.3 & 0.5 & 0.6 & 0.9 & 0.3 & 0.4 & 0.6 & 0.3 & 0.3 \\ 0.4 & 0.4 & 0.5 & 0.8 & 0.2 & 0.3 & 0.5 & 0.2 & 0.4 \\ 0.2 & 0.6 & 0.4 & 0.7 & 0.3 & 0.5 & 0.7 & 0.1 & 0.2 \end{matrix} \right\|;$$

$$\left\| r_{n,k}^{1} \right\| = \left\| \begin{matrix} 0.5 & 0.4 & 0.6 & 0.8 & 0.4 & 0.5 & 0.7 & 0.1 & 0.4 \\ 0.5 & 0.3 & 0.4 & 0.9 & 0.2 & 0.3 & 0.6 & 0.2 & 0.4 \\ 0.6 & 0.5 & 0.5 & 0.7 & 0.3 & 0.4 & 0.5 & 0.3 & 0.3 \end{matrix} \right\|;$$

$$\left\| r_{n,k}^{2} \right\| = \left\| \begin{matrix} 0.8 & 0.9 & 0.6 & 0.7 & 0.6 & 0.7 & 0.6 & 0.7 & 0.8 \\ 0.7 & 0.7 & 0.7 & 0.8 & 0.5 & 0.7 & 0.5 & 0.5 & 0.6 \\ 0.6 & 0.8 & 0.8 & 0.8 & 0.4 & 0.7 & 0.7 & 0.6 & 0.7 \end{matrix} \right\|.$$

Results of using model (1)-(10) for solving problem of bandwidth allocation in LTE downlink with Resource Allocation Type 1 based (channel bandwidth 10MHz) on the use of different optimality criteria (8)-(10) shown in Tables IV-VI.

During minimization the number of used resource blocks (8) obtained the following results (Table IV):

- first UE use first subset, second UE use second subset, third UE uses the second subset;
- totally used 17 resource blocks out of 27;
- procedure of bandwidth allocation for each UE is following: 4.3 Mbps; 3.4 Mbps, 2.8 Mbps, i.e. to third UE allocated 0.1 Mbps more than the required level.

Procedure of bandwidth allocation to UEs using criterion (8) Table IV

RB	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RBG	0			1			2			3			4		
Subset 0	-	-	-							-	-	-			
Subset 1				1	1	1							1	1	1
Subset 2							2	3	2						
RB	15	16	17	18	19	20	21	22	23	24	25	26	Not used		
RBG	5			6			7			8					
Subset 0				-	-	-									
Subset 1							1	-	1						
Subset 2	2	2	2							3	3	3			

With saving allocated channel bandwidth to UEs (9) obtained results presented in Table V:

- second UE use zero subset, first UE use first subset, while third UE use second subset;
- totally used 20 resource blocks out of 27;
- procedure of bandwidth allocation for each UE is following: 4.3 Mbps; 3.4 Mbps, 2.7 Mbps.

Procedure of bandwidth allocation to UEs using criterion (9) Table V

RB	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RBG	0			1			2			3			4		
Subset 0	2	2	2							2	2	-			
Subset 1				1	1	1							1	1	1
Subset 2							3	3	-						
RB	15	16	17	18	19	20	21	22	23	24	25	26	Not used		
RBG	5			6			7			8					
Subset 0				2	2	2									
Subset 1							1	-	1						
Subset 2	-	-	-							3	3	-			

While using combined optimality criterion (10) obtained the next results (Table VI):

- first UE use first subset, second UE uses the second subset, while third UE use second subset;
- totally used 17 resource blocks out of 27;
- procedure of bandwidth allocation for each UE as in second case corresponds to required values: 4.3 Mbps; 3.4 Mbps, 2.7 Mbps.

Procedure of bandwidth allocation to UEs using criterion (10) Table VI

RB	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RBG	0			1			2			3			4		
Subset 0	-	-	-							-	-	-			
Subset 1				1	1	1							1	1	1
Subset 2							2	2	2						
RB	15	16	17	18	19	20	21	22	23	24	25	26	Not used		
RBG	5			6			7			8					
Subset 0				-	-	-									
Subset 1							1	-	1						
Subset 2	2	2	3							3	3	3			

4. Conclusion

The linear model of bandwidth allocation in LTE downlink with Resource Allocation Type 1 was presented. The use of model (1)-(10) allowed to convert the solution of basic problem of bandwidth allocation in LTE downlink with RAT 1 to solving the optimization problem of Boolean programming with varying object functions (8)-(10) and the constraints (1)-(7). The linear character of model significantly reduces the computational complexity of final solutions on allocation channel (frequency) resource in LTE technology. Results of research the proposed model proved its adequacy in a number of computational examples. Within the analysis it is recommended to use the combined objective function (10) to be minimized. Its use allowed to minimize the number of resource blocks used and bandwidth LTE downlink as a whole, while ensuring compliance with the requirements to access rate to set of user equipment.

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