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ESTIMATION OF POTENTIAL PARAMETERS FOR 5G MOBILE NETWORKS RADIOCHANNELS

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Background. Deploying of 5G mobile networks opens up wide opportunities for the development of IoT, high-speed access to Internet services, industrial automation, telemedicine and other modern services. Peak transmission rate, latency, and spectral efficiency are important indicators for network performance. These indicators are primarily determined by the 5G-NR radio subsystem, which is built using modern technologies such as OFDM, interference-resistant LDPC coding and massive MIMO antenna systems. In addition, frames and time-frequency resource distribution in 5G-NR are improved for both Downlink and Uplink. All of these are described in various 3GPPP documents, but to evaluate these indicators, it is necessary to create an appropriate methodology and perform calculations.

Objective. The purpose of the research is to create a methodology and estimate the potential values of peak transmission rate, latency and spectral efficiency of 5G-NR radio channels.

Method. Analytical calculation methods based on recommendations and source data of 3GPP documents are used.

Results. Analytical studies show that 5G-NR radio channels can potentially provide a peak transmission up to 37 Gbps, latency less than 0.5ms, and spectral efficiency up to 46 bps/Hz rate in the Downlink direction using 50 MHz FR1 frequency band, QAM256 modulation and MIMO 8 x 8-antenna system.

Conclusions. The researched 5G-NR radio channels efficiency indicators meet current and future services requirements.

Keywords: *5G-NR; peak rate; latency; spectral efficiency; subcarrier; OFDM; QAM; resource block; MIMO.*

The creation of radio channels in the 5G mobile communication network takes place due to use the modern technologies such as OFDM and massive MIMO. Also optimized frames and improved distribution of time-frequency resources on both Downlink and Uplink. All of these technologies are used in the 5G-NR (5G - New Radio) and described in 3GPP documents as radio interface specification. Peak transmission rate, latency and spectral efficiency are very significant among the key indicators (KPI) which define the quality of radio channels. Therefore, research was performed specifically for these indicators.

According to the recommendation of the 3GPP document [1], the estimated common peak transmission rate in the Downlink direction can be calculated using the formula:

$$R_{p,Mbps} = 10^{-6} \sum_{j=1}^{j} \left(\vartheta_{Layers}^{(f)} \times Q_m^{(f)} \times f^{(f)} \times R_{m.LDPC} \times \frac{N_{PRB}^{BW(f),\mu} \times 12}{T_S^{\mu}} \times \left(1 - OH^{(j)}\right)\right), \quad (1)$$

where: J – the number of aggregated component carriers in a frequency band or combination of bands (maximum 16); $R_{m.LDPC}$ = 948/1024 - the maximum relative speed of interference-resistant coding LDPC; $\vartheta_{Layers}^{(f)}$ – the maximum number of streams from the gNB (gNodeB) base station transmitter to the user terminals; $Q_m^{(f)}$ – QAM modulation order; $f^{(f)}$ = 1; 0,8; 0,75; 0,4 – scaling factor; μ = 0; 1; 2; 3; 4 – number of the one of subcarrier channel space (SCS) corresponding to 15, 30, 60, 120 and 240 kHz, respectively; $T_S^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$ - the average duration of an OFDM symbol in a subframe according to the SCS; $N_{PRB}^{BW(f),\mu}$ – the maximum number of resource blocks in the used frequency band; OH (Over Head) – the proportion of time spent on service data in the Downlink direction. OverHead is equal 0.14 for the FR1 band (410…7125 MHz) and equal 0.18 – for the FR2 band (24250…52600 MHz).

The number of resource blocks that can be used in a frequency band depends on subcarrier channel space and frequency band [2].

The maximum number of resource blocks for frequency bands 5...100 MHz and 50...400 MHz are shown in Tables 1 and 2, respectively.

Table 1. Maximum number of resource blocks for frequency bands 5...100 MHz

SCS, kHz	Bandwidth, MHz											
	5	10	15	20	25	30	40	50	60	80	90	100
15	25	52	79	106	133	160	216	270	-	-	-	-
30	11	24	38	51	65	78	106	133	162	217	245	273
50	-	11	18	24	31	38	51	65	79	107	121	135

Table 2. Maximum number of resource blocks for frequency bands 50...400 MHz

SCS, kHz	Bandwidth, MHz			
	50	100	200	400
60	25	52	79	106
120	11	24	38	51

According to formula (1), the calculations of the peak transmission rate were performed for the maximum modulation order 8 (QAM256), MIMO 8x8, aggregated component carriers and general frequency bands used in the network. The results of the calculations are shown in the form of graphs on Fig. 1.

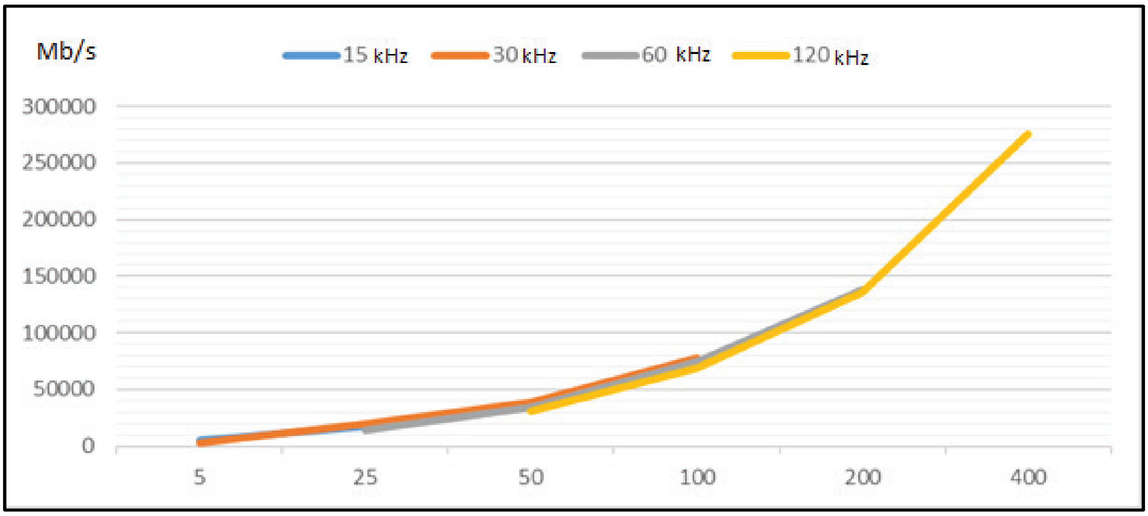

Fig. 1. Peak transmission rate (Mbps) for QAM256, MIMO 8 x 8 and the different SCS

The peak transmission rate is up to 275 Gbps and is achieved when using the SCS of 120 kHz, the number of aggregated components carriers is 16, and a total frequency band of 400 MHz

At this time continue the work to allocate part of the 700 MHz band in Ukraine, which is currently occupied for television. Also band 3400...3600 MHz unlocked now (part of the FR1 band). Thus, the frequency band for the operation of 5G networks in Ukraine is 200 MHz. If we consider that the 4 largest operators of Ukraine can potentially apply for this band, then the frequency band for each of them can be allocated in the amount of 50 MHz. According to calculations (Fig. 1), this can potentially provide a Downlink peak transmission rate up to 37 Gbit/s for each operator's network.

The transmission latency for the user plane is defined [5] as the delay in data transmission between the gNB and the UE (User Equipment), i.e. the time from the moment the IP packet is transmitted to the moment when the receiver successfully receives the IP packet and delivers the packet to the upper layer. The input data to make a latency calculation method are given [4]. The model for latency is described in [5] and shown on Fig. 2.

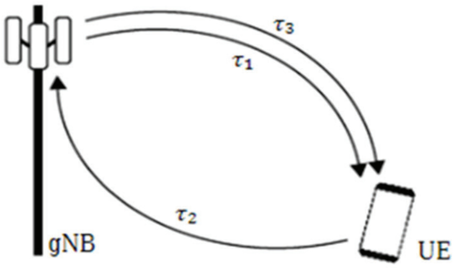

Fig. 2. Model for latency calculation

The latency (τ) consists of payload packet transmission delay (τ1), Hybrid Automatic Repeat Request (HARQ) retransmission delay (τ2) and payload packet retransmission delay (τ3). The latency according to the given model can be determined as follows:

$$\tau = \tau_1 + p(\tau_2 + \tau_3),$$

where: p – retransmission probability.

The payload packet transmission delay τ_1 can be calculated according to the following formula:

$$\tau_1 = t_{gNB,tx} + t_{FA1} + t_{TTI} + t_{UE,rx},$$

where: $t_{gNB,tx}$ – packets processing duration in gNB; t_{FA1} — time interval needed for frame alignment or it is a time to wait next DL (Down Link) slot; t_{TTI} — data transmission duration; $t_{UE,rx}$ — packet processing duration in UE (interval between packet receiving and packet full decoding).

The duration of packet processing in the base station can be calculated according to the following formula:

$$t_{gNB,tx} = \frac{\max\,(N_2(2048+144) * k * 2^{(-\mu)} * T_c)}{2}$$

where: N_2 — the duration defined in the number of OFDM symbols needed for preparing the PUSCH (Physical Uplink Shared Channel) signaling messages [4], $\kappa = 64$ — constant; $T_c = 1/(\Delta f_{max} \cdot N_f)$ – number of time units . As defined in [3] Δf_{max} always equal 480×10^3 Hz and $N_f = 4096$.

N_2 parameter depends on SCS and has the following value (Table 3):

Table 3. N_2 -parameter – PUSCH-signaling message preparation duration

SCS, kHz	N_2 (OFDM symbols)
15	5
30	5.5
60	11 (for FR1)

It should be noted that the delay in the gNB is the same during transmission and reception. This also applies to the delay in the UE (user device). Therefore, the processing time can be calculated as follows:

$$t_{UE,rx} = \frac{\max\,(N_1(2048+144) * k * 2^{(-\mu)} * T_c)}{2}$$

where: N_1 – PUSCH-message processing duration.

N_1 parameter also depends on SCS and specified in Table 4 [4]:

The minimum delay $\tau = \tau_1$ corresponds to p =0 and depends on SCS. Calculations for p =0 give the following τ results for different SCS: 15kHz – 1.8ms; 30 kHz – 1.91ms; 60kHz – 2.08ms.

In case of reception errors, a request for retransmission using a HARQ packet is formed on the UE side, which requires the following time:

$$\tau_2 = t_{UE,tx} + t_{FA2} + t_{HARQ} + t_{gNB,rx}$$

where: t_{FA2} – frame alignment time duration; t_{HARQ} – request duration, which equal one OFDM symbol duration.

After receiving and processing the HARQ request, the gNB retransmits the content of the IP packet. Duration for retransmission will be as following:

$$\tau_3 = t_{gNB,tx} + t_{FA3} + t_{TTI} + t_{UE,rx}$$

HARQ processing duration for UE and gNB is the same. For example, the UE spends 107 μs to process a request with SCS of 15 kHz:

$$t_{UE,tx} = t_{gNB,rx} = 107\,\mu s$$

Duration for frame alignment t_{FA2} is 0 μs. Duration for a HARQ request is one OFDM symbol, so t_{HARQ} at 15 kHz SCS is 71.4 μs. Then gNB processes the request within 178.4 μs. In general, a HARQ request with SCS of 15 kHz has a duration of τ_2= 356.8 μs.

In the third step, the gNB again takes a time to process the transmission with the same value of 178.4 μs. The frame alignment time in this case is 357 μs. In either case to reach the first symbol of the subframe and retransmit the packet. The TTI is retransmitted in 1 ms and the UE processes the data in 107 μs. The total retransmission time τ3= 1.64 ms for the 15 kHz SCS.

Table 4. N1 – PUSCH-message processing duration

SCS, kHz	N_1 (OFDM symbols)
15	3
30	4.5
60	9

According to mentioned above method was calculated the latency for all possible SCS and re-request probabilities of 0; 0.1 and 1. The calculation results are shown in Table 5.

Table 5. Packet transmission latency (milliseconds) is as dependence of SCS and probability of retransmission

OFDM slot configuration	Probability of HARQ	SCS, kHz		
		15	30	60
2 symbols	p=0 p=0,1 p=1	0,5 0,58 1,35	0,28 0,34 0,86	0,23 0,28 0,77
4 symbols	p=0 p=0,1 p=1	0,71 0,81 1,71	0,39 0,46 1,04	0,29 0,35 0,86
7 symbols	p=0 p=0,1 p=1	1,04 1,17 2,35	0,55 0,64 1,38	0,37 0,44 1,07
14 symbols	p=0 p=0,1 p=1	1,8 1,99 3,79	0,93 1,06 2,22	0,55 0,65 1,59

Based on [5] the peak spectral efficiency can be calculated by the following formula:

$$\eta_p = \frac{R\,p}{\alpha * BW},$$

where: $R\,p$ – peak transmission rate (1); α – coefficient of frequency resources utilization; BW – frequency band used in the network.

Calculation results of η_p in bps/Hz for QAM256 modulation are shown in Table 6.

Table 6. Peak spectral efficiency for 5G NR with QAM256 modulation

Band	SCS, kHz	Bandwidth, MHz			
		25		50	
		η_p SISO	η_p MIMO 8 x8	η_p SISO	η_p MIMO 8x 8
FR1	15	5,7	45,5	5,8	46,2
	30	5,6	44,5	5,7	45,5
	60	5,3	42,5	5,6	44,5
FR2	60	5,6	45,2	5,7	45,6
	120	5,2	41,8	5,4	43,1

Note: SISO – Single Input Single Output

In addition, peak spectral efficiency was calculated for different modulation order and MIMO variants. The results are shown in Fig. 3.

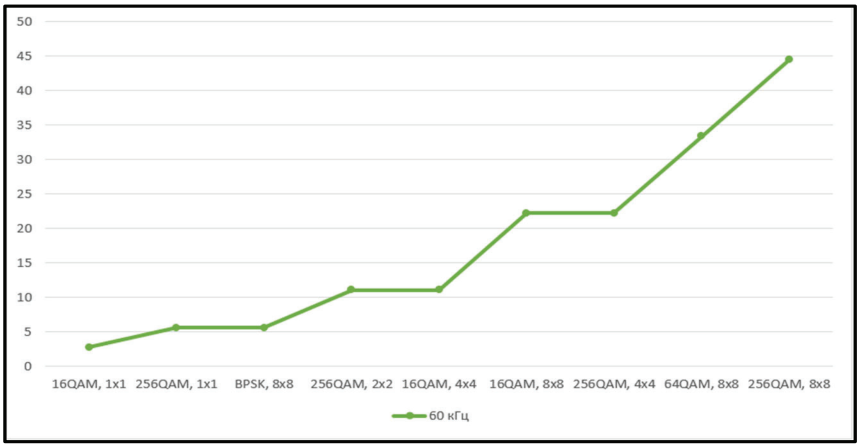

Fig. 3. Peak spectral efficiency for different modulation order and MIMO variants

Conclusions:

1. The overall maximum peak speed of 5G-NR in the Downlink direction practically does not depend on the subcarrier frequency band, but depends on the frequency band allowed for mobile operator in a specific range. Given that the 3400...3600 MHz band (part of the FR1 band) is currently allocated in Ukraine and potentially claimed by 4 mobile operators, the Downlink peak transmission rate can be expected at the level of up to 37 Gbps for the 50 MHz band for each operators networks. Potentially, according to calculations, for a frequency band of 400 MHz, the peak speed can reach the value of 275.8 Gbps.
2. The packets hardware latency decreases when using a larger subcarrier spectrum width and increases with a larger number of symbols in the OFDM slot and the probability of retransmission. URLLC (Ultra-Reliable Low Latency Communications) services are the most demanding in terms of delay, where the delay according to the requirements of IMT-2020 should not exceed 0.5 ms. These requirements are satisfied with OFDM slot configuration, which includes no more than 7 symbols. For other services, it is optimal to use the standard OFDM slot configuration of 14 symbols and SCS of 60 kHz.
3. High level of spectral efficiency is provided due to using MIMO 8x8 antenna systems, high order of QAM modulation and can be in range of 44.5...46.2 5 bps/Hz for the FR1 band depending on the subcarrier channel space.

References:

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Оцінка потенційних можливостей радіоканалів мобільних мереж 5G

Проблематика. Впровадження мобільних мереж 5G відкриває широкі можливості для розвитку IoT, високошвидкісного доступу до сервісів мережі Інтернет, промислової автоматизації, телемедицини та інших сучасних сервісів. Серед показників, за якими визначається ефективність мережі, важливими є пікова швидкість передачі, затримка та спектральна ефективність. Ці показники в першу чергу визначаються радіопідсистемою 5G-NR, яка побудована з використанням сучасних технологій таких як OFDM, завадостійке кодування LDPC та масивні MIMO антенні системи. Також в 5G-NR оптимізовані фрейми та вдосконалений розподіл частотно-часових ресурсів як на Downlink, так і на Uplink. Все це відображено у різних документах 3GPPP, але для оцінки зазначених показників потрібно створити відповідну методику та провести розрахунки.

Мета досліджень. Метою досліджень є створення методики та оцінка потенційних значень пікової швидкості, затримки та спектральної ефективності радіоканалів в 5G-NR.

Методика реалізації. Використовуються аналітичні методи розрахунку на основі рекомендацій та вихідних даних документів 3GPP.

Результати досліджень. Аналітичні дослідження показали, що радіоканали 5G-NR при використанні смуги частот 50 МГц діапазона FR1, модуляції QAM256, антенної системи MIMO 8 x 8 потенційно можуть забезпечити пікову швидкість у напрямку Downlink до 37 Гбіт/с, затримку менше ніж 0,5 мс та спектральну ефективність до 46 біт/с/Гц.

Висновки. Досліджені показники ефективності радіоканалів 5G-NR відповідають сучасним та майбутнім вимогам сервісів.

Ключові слова: *5G-NR; пікова швидкість; затримка; спектральна ефективність; піднесуча; OFDM; QAM; ресурсний блок; MIMO.*