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VA YECHIMLAR**

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Annotatsiya

Mazkur to'plamda "Yangi davr ilm-fani: inson uchun innovatsion g'oya va yechimlar" mavzusidagi XIX Respublika ilmiy-amaliy konferensiyasi materiallari jamlangan. Nashrda respublikaning turli oliy ta'lim muassasalari, ilmiy markazlari va amaliyotchi mutaxassislari tomonidan tayyorlangan maqolalar o'rin olgan bo'lib, ular ijtimoiy-gumanitar, tabiiy, texnik va yuridik fanlarning dolzarb muammolari va ularning innovatsion yechimlariga bag'ishlangan.

Ushbu nashr ilmiy izlanuvchilar, oliy ta'lim o'qituvchilari, doktorantlar va soha mutaxassislari uchun foydali qo'llanma bo'lib xizmat qiladi.

Kalit so'zlar: ilmiy-amaliy konferensiya, innovatsion yondashuv, zamonaviy fan, fanlararo integratsiya, ilmiy-tadqiqot, nazariya va amaliyot, ilmiy hamkorlik.

Barcha huquqlar himoyalangan.

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5G NR TARMOQLARIDA GETEROGEN TRAFIKNI MODELLASHTIRISH VA RADIORESURLARNI TAQSIMLASH BO'YICHA ADABIYOTLAR TAHLILII

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Annotatsiya. 5G NR tarmoqlarining asosiy xususiyati — eMBB, URLLC va mMTC xizmatlarini yagona fizik infratuzilmada birlashtirishdir, bu esa radioresurslarni geterogen trafikning bir-biridan keskin farq qiluvchi QoS talablariga mos taqsimlash masalasini keltirib chiqaradi. Tezisdan ushbu masalaga bag'ishlangan 16 ta ilmiy manba tahliliy jihatdan o'rganildi. Puasson modelidan o'z-o'ziga o'xshash (fraktal) trafik modellariga o'tish asoslari, og'ir dumli taqsimotlar va Hurst parametrining roli, GI/G/m navbat nazariyasi apparati, slice'lar (network slice) o'rtasida radiokanal o'tkazish polosasini optimal taqsimlash modellari hamda URLLC va eMBB trafiginin birgalikda rejalashtirish usullari qiyosiy tahlil qilindi. Tahlil natijasida ikki asosiy cheklov va ulardan kelib chiqadigan istiqbolli tadqiqot yo'nalishi aniqlandi: mavjud modellarda qabul qilingan trafik taqsimotlari real tarmoq o'lchovlariga to'liq mos kelmaydi, optimallashtirish esa asosan oflayn rejimdagi analitik va sonli yechuvchilar yordamida bajariladi. Shu asosda real o'lchovlarga asoslangan taqsimotlar, 5G NR numerologiyasi va QoS cheklovlarini yagona matematik modelda birlashtirgan hamda neyron tarmoq approksimatori va mustahkamlovchi o'qitishga tayangan moslashuvchan taqsimlash modelini ishlab chiqish yo'nalishi asoslandi.

Kalit so'zlar: 5G NR, network slicing, trafik modeli, o'z-o'ziga o'xshashlik, G/G/1, o'tkazish polosasini, neyron tarmoq, sun'iy intellekt.

LITERATURE ANALYSIS ON HETEROGENEOUS TRAFFIC MODELING AND RADIO RESOURCE ALLOCATION IN 5G NR NETWORKS

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Annotation. 5G NR networks combine eMBB, URLLC and mMTC services on a single physical infrastructure, which raises the problem of allocating radio resources according to the sharply different QoS requirements of heterogeneous traffic. This paper presents an analytical review of 16 scientific sources devoted to this problem. It summarizes the transition from Poisson models to self-similar (fractal) traffic models, the role of heavy-tailed distributions and the Hurst parameter, the GI/G/m queueing apparatus, models for distributing radio channel bandwidth among network slices, and joint scheduling methods for URLLC and eMBB traffic. Two main limitations are identified: the traffic distributions adopted in existing models do not fully match real network measurements, and optimization is performed mainly with offline analytical and numerical solvers. On this basis, a research direction is substantiated towards an adaptive allocation model combining measurement-based traffic distributions, 5G NR numerology and QoS constraints with a neural network approximator and reinforcement learning.

Keywords: 5G NR, network slicing, traffic model, self-similarity, G/G/1, bandwidth, neural network, artificial intelligence.

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Kirish

5G NR arxitekturasini uchta xizmat toifasini — eMBB, URLLC va mMTC — yagona fizik infratuzilmada birlashtiradi. Ularning QoS talablari keskin farq qiladi: eMBB uchun 4 ms gacha foydalanuvchi tekisligi kechikishi va yuqori uzatish tezligi, URLLC uchun 32 baytli paketni 1 ms ichida $1-10^{-5}$ ishonchlilik bilan yetkazish, mMTC uchun 164 dB MCL qamrovi, 10 yildan ortiq batareya muddati va 10^6 qurilma/ km^2 gacha ulanish zichligi [1], [12], [13]. Chen va Zhao [8] ko'rsatganidek, trafikning 90 % gacha qismi bino ichi va hotspot zonalarida to'planadi, DL/UL nisbati 10:1 gacha o'sadi; bu esa resurslarni statik emas, trafik xususiyatlariga moslashuvchan taqsimlashni talab qiladi. Bunday real vaqtdagi moslashuvni ta'minlashda sun'iy intellekt usullari — neyron tarmoqlar va mustahkamlovchi o'qitish — istiqbolli vosita sifatida qaralmoqda. Ishning maqsadi — 5G NR da geterogen trafikni modellashtirish va radioresurslarni taqsimlash bo'yicha adabiyotlarni tahlil qilib, sun'iy intellekt asosidagi taqsimlash modeliga o'tish uchun ilmiy bo'shliqlarni aniqlash.

Metodlar va uslublar

Tadqiqotda 16 ta manba tahliliy sharh usulida o'rganildi: standart talablar va sharhlar [8], [12], [13], trafik modellari bo'yicha nazariy va empirik ishlar [7], [11], [14], [15], navbat nazariyasi [16], resurslarni taqsimlash modellari [2], [3], [4], [5], [6], [9], [10] hamda mMTC texnologiyalari [1]. Har bir manba uchta mezon bo'yicha qiyoslandi: (i) trafikning statistik modeli; (ii) xizmat sifatini baholash apparati (navbat modeli); (iii) taqsimlash masalasini yechish usuli.

Tadqiqot natijalari

Trafik modellari. Becchi [7] Puasson modeli telefoniya sharoitida paydo bo'lganini va ma'lumotlar tarmoqlaridagi portlashlilikni aks ettira olmasligini ko'rsatadi: Puasson trafik vaqt masshtabi oshirilganda oq shovqinga yaqinlashadi, real trafik esa turli masshtablarda portlashlilikni saqlaydi. Buning ifodasi — uzoq muddatli bog'liqlik va Hurst parametri H :

$$r(k) \sim k^{-\beta}, \quad H = 1 - \frac{\beta}{2} > 0,5, \quad 0 < \beta < 1. \quad (1)$$

Mitzenmacher [11] fayl hajmlari uchun lognormal tana va Pareto dumli «qo'sh Pareto» taqsimotini asoslaydi; bunday og'ir dumli hajmlar agregat trafikdagi o'z-o'ziga o'xshashlikka hissa qo'shadi. Navarro-Ortiz va b. [12] standart modellarni tizimlashtiradi: FTP — kesilgan lognormal, video — kesilgan Pareto ($\alpha = 1, 2$), VoIP — ikki holatli Markov modeli, MTC — beta-taqsimot yoki Puasson. Soos va b. [15] real 5G tarmog'ida eMBB trafigi katta paketli va UL/DL asimmetrik, mMTC trafigi esa kichik va deyarli nol dispersiyali ekanini o'lchagan. Ruiz-Guirola va b. [14] MTC trafigidagi hodisaviy oqim uchun Puasson (xato < 11%), davriy oqim uchun kvazi-davriy model (xato < 7%) eng mos kelishini aniqlagan. Demak, uchala slice uchun yagona Puasson/eksponensial farazi yetarli emas.

Navbat nazariyasi apparati. Whitt [16] GI/G/m tizimlari uchun o'rtacha kutish vaqtining Kingman tipidagi yaqinlashuvini beradi:

$$W_{GI/G/m} \approx \frac{C_\lambda^2 + C_\mu^2}{2} \cdot W_{M/M/m}, \quad (2)$$

bu yerda C_λ va C_μ — kelish va xizmat ko'rsatish vaqtlarining variatsiya koeffitsientlari. Approksimatsiya ikkinchi momenti chekli taqsimotlar, jumladan kesilgan og'ir dumli taqsimotlar uchun qo'llaniladi. Amirsaidov va Qodirov [3] $M/M/1/L$ navbatlar asosida kanal va bufer resurslarini kechikish va yo'qotish cheklovlari ostida fmincon yordamida taqsimlaydi.

Resurslarni taqsimlash modellari. Amirsaidov va Turumbetov [4] o'tkazish polosi ΔF ni slice'lar o'rtasida $G/G/1$ modeli asosida taqsimlaydi:

$$\Delta F_i = x_i \Delta F, \quad \Delta F_e + \Delta F_u + \Delta F_m \rightarrow \min, \quad t_i \leq t_p^i, \quad (3)$$

bu yerda x_i — i -slice ulushi, t_i va t_p^i — o'rtacha va ruxsat etilgan kechikish, $i \in \{e, u, m\}$. Model NR numerologiyasini hisobga oladi va $H = 0,8$ da eMBB ga $H = 0,5$ dagiga nisbatan 3 barobar ko'p polosa kerakligini ko'rsatadi. AlQahtani [2] C-RAN resurslarini CTMC asosidagi ustuvorlikli navbat modeli bilan taqsimlaydi. Anand va b. [5] URLLC ni eMBB ustidan «puncturing» orqali multiplekslashda onlayn gradient rejalashtirgichni taklif qiladi, [6] esa URLLC sig'imini $M/GI/\infty$ modeli bilan baholab, HARQ sxemalarini optimallashtiradi. Lee va b. [10] uplink resurslarini Nash muvozanati va water-filling algoritmi bilan taqsimlaydi. Feng va b. [9] URLLC ning uchdan-uchga kechikishini komponentlarga ajratadi:

$$D_t + D_q + D_a + D_p + D_b + D_g \leq D_{max}, \quad (4)$$

bu yerda qo'shiluvchilar — uzatish, navbat, kirish, qayta ishlash, backhaul va tarqalish kechikishlari.

Aniqlangan bo'shliqlar. 1) Ayrim modellarda trafik soddalashtirilgan farazlar bilan ifodalanadi ([10] da Puasson, [3] da $M/M/1/L$); o'z-o'ziga o'xshashlikni hisobga olgan [4] modelida ham taqsimotlar tanlovi real o'lchovlarga [12], [14], [15] to'liq mos kelmaydi — nomzod sifatida eMBB uchun Pareto, URLLC uchun Bernulli, mMTC uchun murakkab Puasson taqsimotlarini tekshirish maqsadga muvofiq. 2) Statik optimallashtirishga tayanuvchi [3], [4] yondashuvlarda trafik o'zgarganda masalani qayta yechish talab qilinadi; [5] da onlayn mexanizm mavjud, ammo kirish parametrlaridan optimal slice ulushlarini bevosita o'rganuvchi approksimator ko'rib chiqilmagan. 3) Tahlil qilingan manbalar doirasida sun'iy intellekt (neyron tarmoq, RL) asosida ulushlar (x_e, x_u, x_m) ni approksimatsiya qilish va natijani analitik optimum bilan validatsiya qilish o'rganilmagan.

Xulosa

Tahlil 5G NR tarmoqlarida resurs taqsimoti samaradorligi trafikning og'ir dumli va o'z-o'ziga o'xshash xususiyatlarini modelda to'g'ri aks ettirishga bog'liq ekanini ko'rsatdi. [4] modelini tayanch qilib, uni real o'lchovlarga asoslangan taqsimotlar bilan boyitish va fmincon yechimini etalon sifatida saqlagan holda, neyron tarmoq approksimatori hamda RL yechuvchisi yordamida minimal polosa sharoitida kechikish cheklovlari bajarishga va resurslarni real vaqt rejimida moslashuvchan boshqarishga yo'naltirilgan sun'iy intellekt asosidagi taqsimlash modelini ishlab chiqish mumkin.

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