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5G Wireless Technology: Spectrum Sharing and Heterogeneous Networks

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Abstract: This paper addresses the critical challenge of 5G network cell planning, emphasizing the essential role of estimating the number of cells or base stations required for a given area and user bandwidth. The proposed model explores four scenarios with varying network parameters to determine the optimal base station deployment. The increasing demand for 5G networks necessitates a focus on small cells or femtocells, offering advantages such as consistent coverage, power adjustment, energy efficiency, and higher data rates. However, deploying excessive femtocells may lead to unnecessary handovers, requiring optimization strategies. The study introduces an analytical model for heterogeneous cellular networks, integrating fourth and fifth-generation systems. The model, represented by a two dimensional Markov Chain, employs a novel decomposition approach for analyzing system performance measures. Validation is conducted through simulation and simultaneous equation systems. The proliferation of mobile devices and data traffic necessitates dense 5G network deployments, with small cells gaining traction due to their versatile coverage, power adaptability, energy efficiency, and higher data rates. However, an excessive deployment of small cells can lead to frequent handovers, prompting the need for enhanced handover strategies and coexistence with other technologies in the 5G landscape. The paper concludes by highlighting the impending need for practical implementation testing of 5G systems, emphasizing the significant role of small cell deployments. It discusses an initiative focusing on testing small cell-enabled operator business models in real-world scenarios, anticipating the pivotal role of small cells in future 5G systems.

I. INTRODUCTION

The advent of 5th generation (5G) mobile communication systems heralds a transformative era in wireless technology, poised to reshape the landscape of connectivity as we know it. With diverse applications ranging from low-sensor data transmission to high-quality video content delivery, 5G introduces a spectrum of requirements encompassing stringent low latency, minimal energy consumption, and heightened reliability. These technological aspirations are envisioned to be achieved at costs either equivalent to or lower than current technologies. The imminent World Radio communication Conference (WRC'15) stands as a pivotal juncture, steering the course toward the establishment of the next communication standard[1]. A pivotal facet of 5G's innovation lies in its proposed novel spectrum sharing mechanisms, exemplified by the concept of co-primary spectrum sharing. In this paradigm, any operator gains the privilege to leverage shared spectrum allocated specifically for 5G cellular systems. This novel approach becomes feasible within the domain of small cells, where base station coverage mirrors today's WiFi access points, and the frequency band is exclusively designated for small cell utilization. Meanwhile, the discourse surrounding the segregation of access network operation and content provision persists, despite operator reservations. Nevertheless, the rise of streaming services like Netflix and YouTube, coupled with distinct pricing models, has effectively precipitated a de facto separation.

Within the intricate realm of Radio Network Planning (RNP), an indispensable role unfolds in shaping cell design for optimal wireless cellular network development. Operators grapple with the multifaceted task of devising a network that proves both economically viable and capable of accommodating dynamic variables such as environmental factors, fluctuating user numbers, base station configurations, path loss, and frequency schemes[2]. A strategic solution to the challenges of 5G cell planning involves adopting a multi-layer architecture featuring macrocells, various small cells, relays, and D2D networks. This approach aims to meet the demands for spectral and energy efficiency, catering to users with diverse throughput requirements and Quality of Service (QoS). Contrary to a wholesale replacement, 5G networks operate synergistically with their 3G and 4G predecessors, integrating them as components within macrocells. The access part of 5G, employing micro, pico, and femtocells, operates across GHz bands, extending up to 60 GHz, with channel widths reaching 1 GHz and theoretical access rates soaring up to 10 Gbps under ideal conditions.

These short-range cells, akin to public Wi-Fi nodes, epitomize the foundational characteristic of 5G systems—heterogeneous networks characterized by distributed base stations with varying densities, strategically designed to augment capacity and coverage.

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$$\text{data rate }(Mbps) = 10^{-6} * \sum_{j=1}^{J} \left(v_{\text{Layers}}^{(j)} * Q_m^{(j)} * f^{(j)} * R_{\max} * \frac{N_{PRB}^{BW(j),\mu} * 12}{T_s^{\mu}} * \left(1 - OH^{(j)}\right) \right)$$

The used elements in the above equation are:

- 10^{-6} – constant (because of Mbps),
- $\sum$ – sum of subcarrier,
- $v^{(j)}_{\text{layers}}$ – number of layers, i.e., transmitters,
- (j)– bandwidth (MHz), should be selected with frequency band and μ(i) configuration.

II. ADVANCING 5G INNOVATION: STRATEGIC GOALS AND TEST NETWORK OVERVIEW

In the pursuit of advancing 5G technologies, a comprehensive test network has been established with strategic goals aimed at fostering research and development (R&D) in a realistic 5G environment. Beyond serving as a testing ground for cutting-edge technologies, the network endeavors to incubate new ideas, innovations, algorithms, and applications. Positioned as a living lab, it facilitates robust testing of applications, services, algorithms, and system functionalities, offering a dynamic platform for continuous improvement. The overarching goals include the evolution of the test network into a full-scale 5G network, integrating 5G devices, higher frequency bands, cognitive management functionalities, and system testing tools for innovative solutions[3-4]. Open for collaboration, the network extends invitations to third parties to develop and test cloud-based services, fostering a collaborative ecosystem. Moreover, the initiative contributes to regional competence building in 5G development and standardization, while concurrently assessing new operator business models.

The test network, orchestrated by VTT Technical Research Centre of Finland and the University of Oulu in collaboration with partners, is strategically located. Comprising a restricted network on VTT's premises and a public network at the University of Oulu, it provides a dual environment for technology functionality testing and large-scale deployment verification. The open network, featuring a macro base station and 50-100 small cell base stations, aims to evolve into an open test environment for collaborative innovation[10]. Expanding its reach across different city segments, the test network emerges as a versatile platform for the development and testing of groundbreaking applications, solidifying its role in daily business scenarios within the city of Oulu and beyond.

III. UNRAVELING THE DYNAMICS: RADIO CHANNEL MODELING IN 5G NETWORK PLANNING

In the intricate realm of cellular network planning, the concept of radio channel modeling stands as a paramount task, pivotal in ensuring the efficacy of communication systems. Diverse geographical topologies globally necessitate the development and exploration of various models, steering away from a one-size-fits-all approach[5-6]. An illustrative strategy involves employing highly accurate 3D environmental data maps with ray-tracing principles, specifically tailored for dense urban areas, while steering clear of complex estimations in rural and suburban landscapes.

Fundamentally, the radio link budget, akin to previous mobile systems, hinges on estimating path loss, factoring in a myriad of gains and losses. The coverage area estimation, a critical facet, is intricately linked to the capacity offered in terms of data transfer rate. Higher data transfer rates correspond to reduced coverage, with peak bit rates near the base station and diminished rates at the periphery of the cell's coverage area. The 5G network, characterized by its ability to manipulate power through NOMA (Non-Orthogonal Multiple Access), aims to achieve significantly higher throughput compared to 4G, boasting maximum data rates of up to 20 Gbps and an average transfer rate exceeding 100 Mbps[7-8]. This paper delves into the initial planning phase of 5G radio networks, striving to provide a preliminary assessment of coverage and capacity within the planning area, underpinning the nuanced dynamics of 5G network planning.

The approximate data transfer rate in 5G NR can be calculated :

After calculating the throughput of one cell, which contains a certain number of users, the throughput for one user in that cell is calculated according to Eq.

$$\text{Throughput for one user} = \frac{Throughput}{number\ of\ user} * C$$

After calculating the path loss, if we know the center frequency, the radius of the cell can be deduced. Path Loss is calculated according to Eq.

$$\text{Distance(d)} = 10\ Power\ \left(\frac{PL-28-20*\log10(fc)}{22}\right)$$

The radio link budget serves as a comprehensive assessment of the overall gain and loss within a system to determine the Received Signal Level (RSL) [9]. This involves evaluating the received signal level against the receiver's sensitivity to ascertain the suitability of the channel status. If the received signal level surpasses the reception sensitivity of the receiver, the channel status is deemed "Pass"; otherwise, it is categorized as "Fail."[11]

The determination of subcarrier size (parameter μ) is based on carrier configuration values within the ranges of 0-15 kHz, 1-30 kHz, and 2-60 kHz, as stipulated by 3GPP 38.211. In this specific scenario, subcarrier sizes of 30 kHz and 60 kHz have been adopted. The allocation of resource blocks is sourced from Table 1, following the guidelines outlined in [12], which recommends specific numbers of resource blocks corresponding to bandwidth and the designated number of subcarriers.

Table 1: Maximum transmission bandwidth configuration

SCS (kHZ)	5MHz	10MHz	15MHz	20MHz	25MHz	30MHz	40MHz	50MHz	60MHz	70MHz
15	25	52	79	106	133	160	216	270	N/A	N/A
30	11	24	38	51	65	78	106	133	162	185
60	N/A	11	18	24	31	38	51	65	79	88

Utilizing the link budget facilitates the computation of the cell radius based on either the receiver sensitivity or the received signal level for a given cell radius. A subsequent comparison with reception sensitivity enables the assessment of channel status, indicating success or failure. The reception sensitivity predominantly hinges on capacity requirements, specifically bandwidth, as the Signal to Interference and Noise Ratio (SINR) directly correlates with the desired bandwidth at the cell edge.

Formula or equation for 5G NR throughput where Average OFDM symbol duration in a subframe for μ value is calculated :

$$T_s^{\mu} = 10^{-3}/(14*2^{\mu})$$

The control channels overhead (OH) header values for downlink differ between the F1 and F2 bands, standing at 0.14 and 0.18, respectively. Meanwhile, for the uplink, these OH values are 0.08 in the F1 band and 0.10 in the F2 band. The frequency spectrum is partitioned into F1, ranging from 450 to 6000 MHz, and F2, spanning from 6000 to 52600 MHz. TDD (Time Division Duplex) was opted for as the spectrum utilization technique due to its distinctive feature of using the same frequency for both uplink and downlink, albeit at different time intervals. This choice proves advantageous, especially when compared to the use of paired spectrum (FDD – Frequency Division Duplex), particularly in scenarios where paired spectrum is unavailable [13]. Essentially, the augmentation of data rates per user is achieved by assigning multiple frequency blocks to a single user [14].

In DL Scenario 1, the throughput for a single user is recorded at 98.1 Mbps, while in UL, it stands at 27 Mbps. Notably, Scenario 4 emerges as the most favourable, boasting impressive results with a DL total throughput of 3698 Mbps. In this scenario, the data transfer rate for a single user reaches 370.2 Mbps. Similarly, in UL, the total throughput is 1014 Mbps, with the individual user throughput reaching 101.8 Mbps. The comparative outcomes of all scenarios for DL and UL are visually represented in Figure 1 and Figure 2.

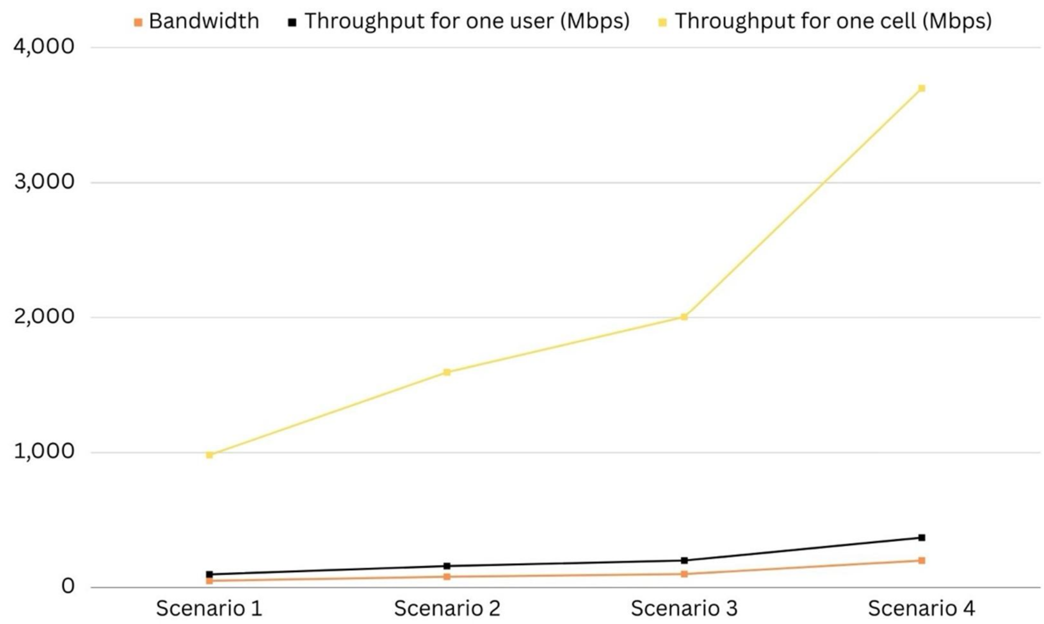

Fig. 1

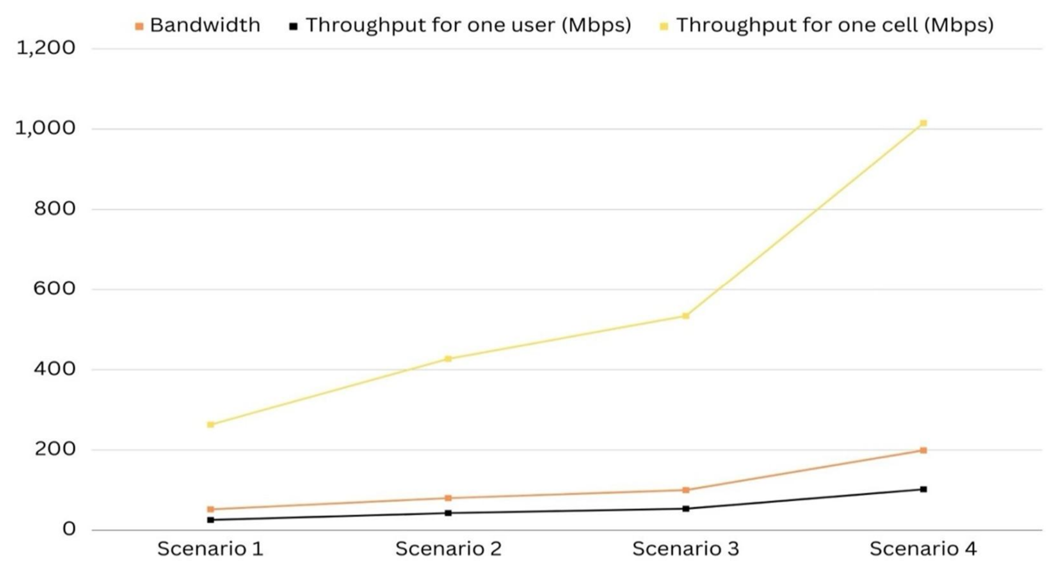

Fig. 2

IV. CONCLUSION

In summary, this paper extensively explores the intricate challenges associated with planning 5G network cells, underscoring the crucial importance of estimating optimal base station deployment for a specified area and user bandwidth. The research introduces a sophisticated analytical model tailored for heterogeneous cellular networks, seamlessly integrating both fourth and fifth-generation systems, with a specific emphasis on the potential of small cells or femtocells. The model's versatility is demonstrated through an examination of various scenarios, considering factors such as consistent coverage, power adjustment, energy efficiency, and enhanced data rates. The paper strongly advocates for the practical implementation testing of 5G systems, particularly highlighting the pivotal role of small cell deployments in addressing the surging demands of mobile devices and data traffic.

Moreover, the introduction sheds light on the transformative phase ushered in by 5G technology and its diverse applications, necessitating a paradigm shift in wireless connectivity. The overarching objectives of the test network encompass evolving into a full-scale 5G network and contributing to regional competence building in 5G development and standardization. In our future for research work, our focus will be exploring diverse models that incorporate distinct path loss calculations tailored to urban, suburban, or rural settings. Furthermore, we aim to refine the existing cell number calculation methodology to better accommodate variations in geographical terrain configurations.

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