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Small Cell Technology in Heterogeneous Wireless Mobile Networks of Future Smart Cities

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Abstract

In this paper, the use of intelligent heterogeneous mobile networks in congested smart cities, where macro, micro, pico, and femto cells are smartly monitored, is examined. The study demonstrates, from a physical-layer standpoint, the key benefits of deploying smart-driven small cells, including coverage area, transmission throughput, and resource consumption. The proposed design employs progressive intelligent software solutions to enable smart coordination among the installed base stations via the used waveform. By adopting both advanced cell technologies and smart applications, a developed communication system for future smart cities can be realized. Accordingly, the smart control of the presented scheme achieves lower battery usage, higher throughput, and wider transmission. Specifically, the offered solution is applied to crowded cities around the world, particularly the capitals and tourist cities, where millions of people visit each year. To verify the system performance of our advanced, smart, and effective solution, the transceiver systems at the explored locations were investigated before and after peak times using MATLAB.

Keywords: heterogeneous mobile networks, smart cities, small cells, intelligent software.

1. Introduction

As the world moves into a new era of telecommunications technologies that rely mainly on intelligent systems [1], the need to develop smart transmission is highly warranted. One of the significant fields that has a great impact on humanity's day-to-day life is cellular mobile networks [2]. The rapid progress of mobile generations, from the first generation (1G) to the fifth generation (5G), has had a positive impact on aspects of our daily work [3]. The main challenges beyond these revolutionary upgrades are the continuous scientific research for developing the infrastructure of the applied mobile networks [4]. It is quite important to improve the physical layer of the employed wireless networks of mobile devices to be more compatible with the new applications of the modern lifestyle [5].

Although the future mobile generation requires extra efforts to develop the hardware side of the telecommunication layers, the need to upgrade the used software is highly necessary [6]. Hence, the improvement must include both the devices and the application systems involved in the transmission process. That means, the future communication systems have to advance two plans of signal processing, one for data and the second for control.

It's worth mentioning that the traditional control plan is not able to support the new requirements of the market unless developing its supporting software [7]. Besides, the data arrangement of the next mobile network is supposed to be efficient to synchronize with the sophisticated requirements of the future smart cities [8]. In this context, with respect to the modern smart city essentials, traditional macro cells offer a wider coverage area for mobile transmission, but with very poor transmission rates [9]. Hence, the usage of such old-fashioned cells no longer fits with today's market requests. On the other hand, using only advanced small cell technology, throughput efficiency increases significantly; however, the coverage distance becomes much shorter [10].

For these reasons, looking for advanced communication networks that combine smartly different cell types is extremely required for the next generation of modern cities. Although the mobile cells combination process is a vital solution for improving the way that base stations need to communicate, the clever handover procedure of a mobile subscriber between non-similar base stations still represents a challenge. As a result, utilizing smart software tools, a new layer of processing is introduced for the applied heterogeneous mobile networks, resulting in autonomous intelligent handling for signal distribution among the base stations.

Despite the heterogeneous networks having varied types of access points, the intelligence control solution is logically able to remove borders among them, improving management operations for the involved cells. Nevertheless, adding an extra level of processing for smart management causes an increase in the processing complexity. Therefore, additional transmission latency can be registered for the processed digital signal.

The rest of this paper is organized as follows: In Section 2, the system model of the proposed approach is theoretically presented, clarifying the main principles behind it. In Section 3, the part where the experiments are done is demonstrated, where MATLAB is used to simulate the tested cases. At the end, in Section 4, a suitable summary of the existing research is introduced, highlighting the key findings of the applied technique.

2. System Model

In this part, the transmission operation of heterogeneous mobile networks based on smart manipulation is explored. The presented system adds a new layer of intelligent processing to control signal distribution among the registered cells. In addition, based on the smart control plane, transmitted data is delivered automatically, ensuring a minimum level of signal conflicts. As such, by following a clever plan for arranging the transmission structure, especially in crowded user zones, an effective, robust, and high-throughput system can be obtained.

As seen in Fig. 1, the proposed transceiver system for heterogeneous wireless communications comprises five functional layers, including a dedicated layer for smart centralization rather than the conventional non-smart one. The entire management of the presented topology is applied by intelligent software control, where the transmitted signal of both big and small cells needs to pass first through the smart controller, finding the best available cell for reception. Hence, as the network cells used can span a wide range of bandwidths, from low to very high, a smart solution that unifies and organizes them is urgently required. Thus, despite the different types of cells like macro, micro, pico, and femto cooperating in heterogeneous networks, the need for smart monitoring, handling, and running is still necessary.

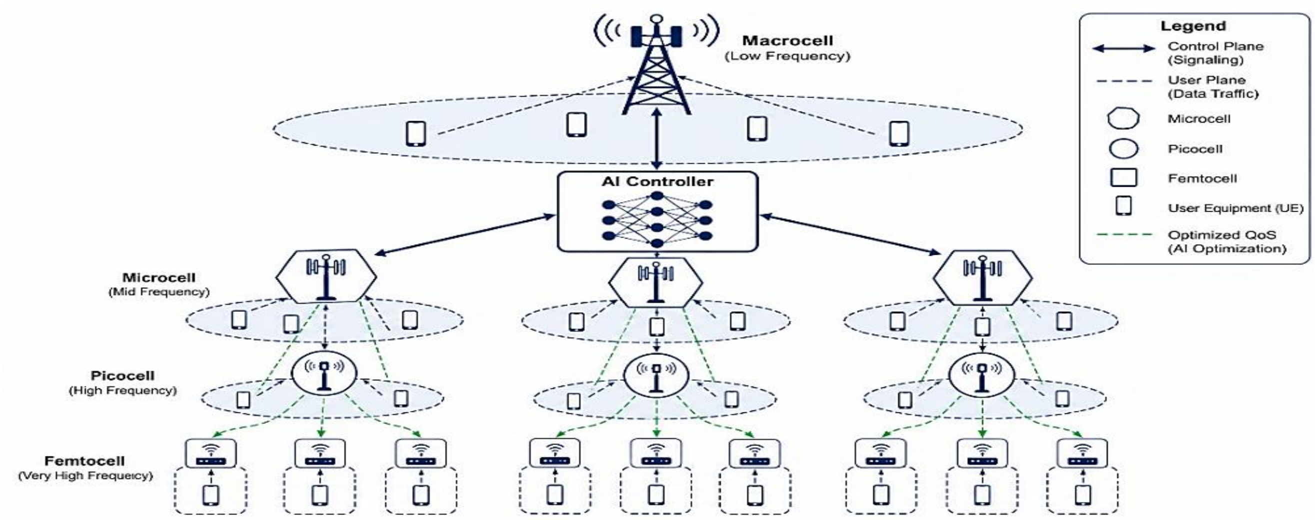

Fig.1: Functionality layers of the heterogeneous mobile network including the smart controller.

As shown in Fig.2, the smart software controller employs intelligent codes for supervising the up-to-date reports of the network's status, such as the free and busy cells, the capacity of each cell, and the coverage distance for them. Hence, at every base station, the received signal cannot directly move to the next hop unless given smart permission by the intelligent controller. In this context, the transmission and reception decision is fully controlled by the artificial intelligence applications, ensuring a balanced performance level for transferred signals. Accordingly, mobile subscribers can have a higher quality of service within the clever heterogeneous network in comparison with a traditional network. Nevertheless, the presented layer for smart management resulted in adding extra computational complexity for the digital signal processing. Therefore, the transmitter part needs additional checking and calculations for launching signals among multiple hops. Similarly, the receiver side has a reversed manipulation before completing the response. Hence, additional delay time is accompanied by smart handling of future wireless networks. However, the fast growth of the upcoming processing technology can mitigate the latency issue, bringing the network back to normal.

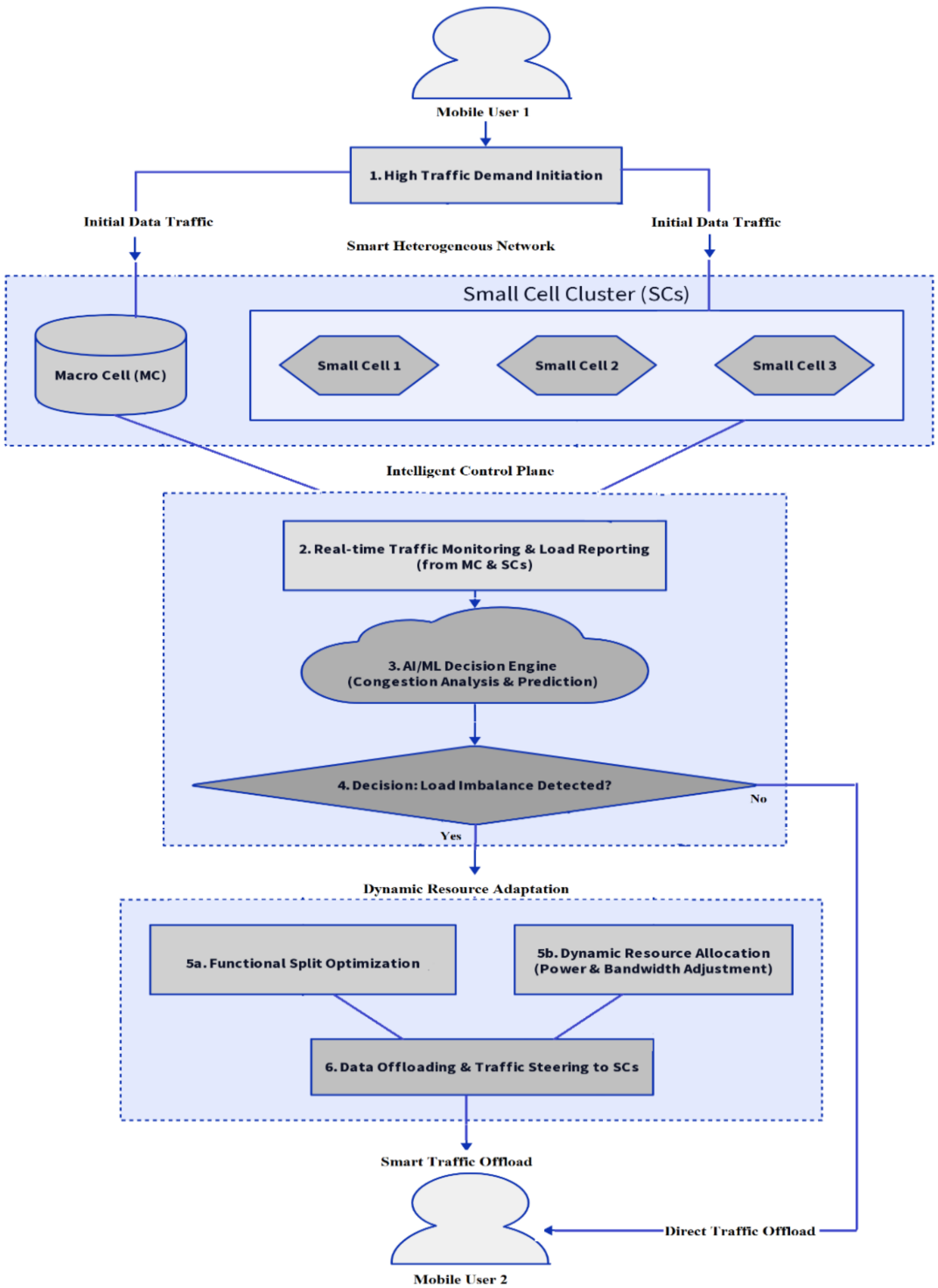

Fig. 2: Smart management diagram of the on-peak heterogeneous network using the intelligent control plane.

3. Experimental Part

In this part, three key scenarios are considered to investigate the transmission coverage area before and after using the smart controller, both off-peak and in-peak. Thus, the scenarios aim to show the differences between the traditional and intelligent methods for handling heterogeneous networks, particularly in a crowded coverage area. Worth mentioning that orthogonal generalized frequency division multiplexing is the waveform used for testing the heterogeneous network before and after the smart manipulation.

In scenario 1 (not a crowded area), as shown in Fig. 3, the heterogeneous network comprises 10 small cells and one large central cell. For this initial simulation of the off-peak case, the experiment assumes that each small cell can serve about 5 subscribers within its coverage area. Accordingly, users in this case can share resources smoothly, resulting in high throughput. As a result, the tested network can offer a good quality of service for covered mobile subscribers. Notably, the signal-to-noise ratio (SNR) is determined based on the mobile position relative to the coverage area limit of each cell in the heterogeneous network. Accordingly, the colored circle representing the signal power of a mobile user varies in color from blue for low SNR to red for high SNR. Despite this scenario being useful for small cities or rural areas, the need for heterogeneous mobile networks with an outstanding ability to serve huge numbers of users is extremely high.

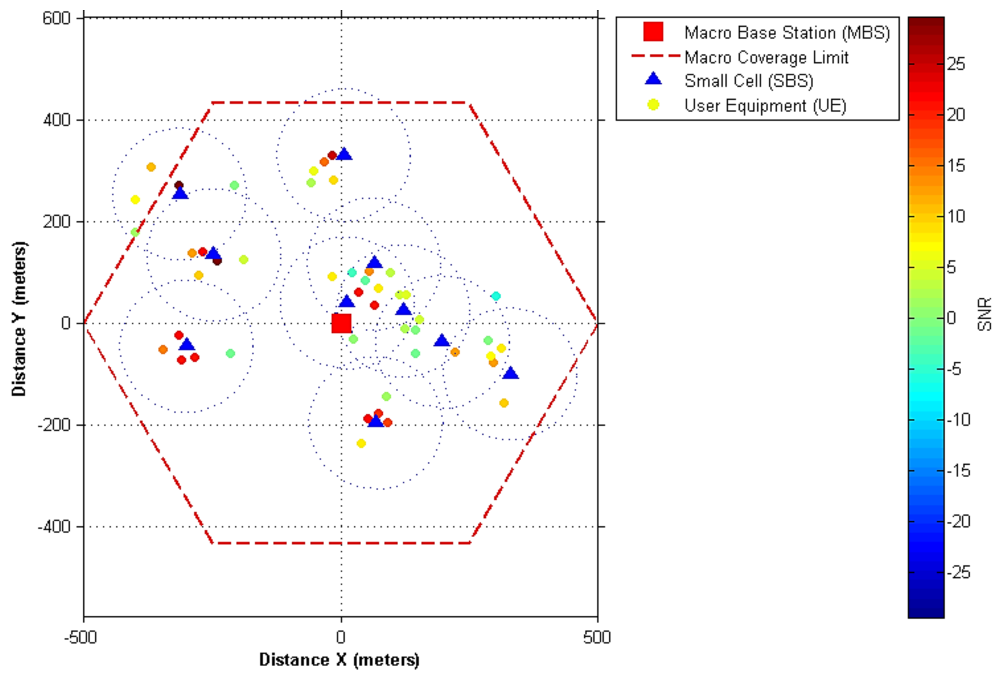

Fig. 3: Distribution map of a not congested heterogeneous network (scenario 1).

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For this reason, in scenario 2, as seen in Fig. 4, a mobile network for crowded areas is experienced. Compared to the first scenario, the applied simulation raised the number of small cells to 40, distributed around the central macro cell. Besides, as this scenario is specified for the in-peak case, the number of covered subscribers by each small cell is expanded by about 5 times, where 25 mobile users can be served. Moreover, the key issue in this scenario is the high potential increase in the number of users engaged with each small cell. This, as such, makes sharing offered resources by mobile phone a challenge due to the limited spectrum among an extreme number of subscribers. As a result, the heterogeneous network faces a poor quality of service.

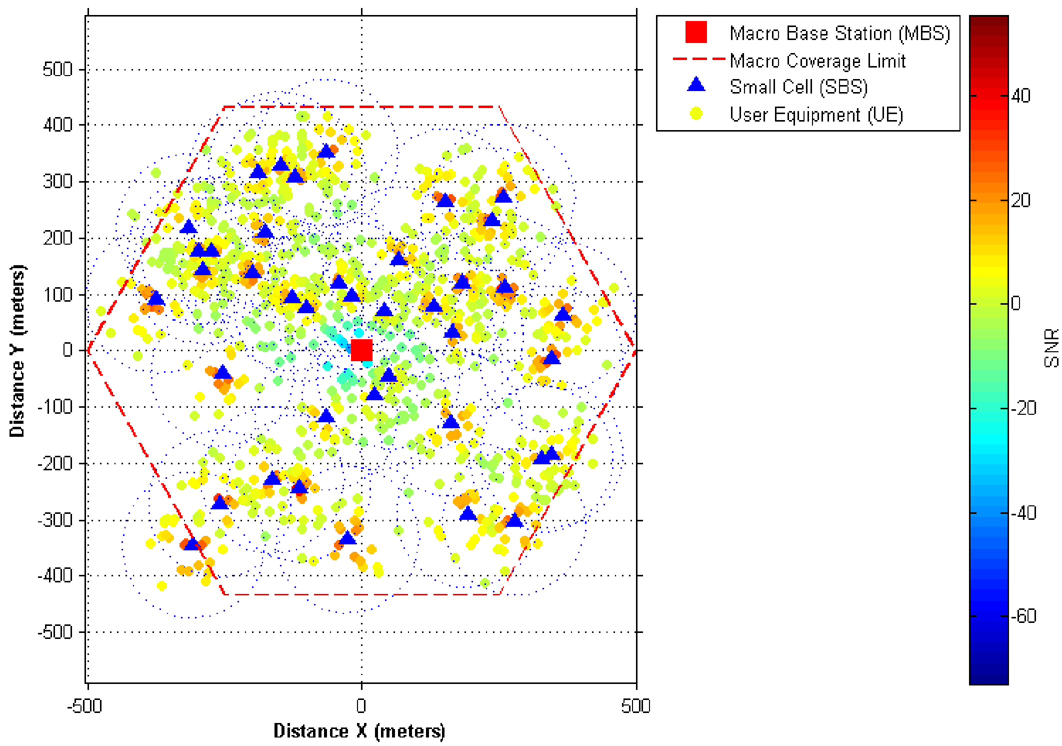

Fig. 4: Distribution map of a conventional congested heterogeneous network (scenario 2).

To address this problem, the third scenario, as shown in Fig. 5, is simulated, where the smart controller is utilized to automatically rearrange subscribers among cells based on an intelligent application. The introduced scenario offers a dynamic range of 10 fixed small cells and 30 supporting ones to supply a helpful solution for the expected increment of phone subscribers. Therefore, a flexible number of small cells is employed based on smart control processing. The main concept of the proposed solution is the clever distribution of phone-user signals among the available small cells, ensuring balanced tolerance, deployment, and engagement for all network resources (cells).

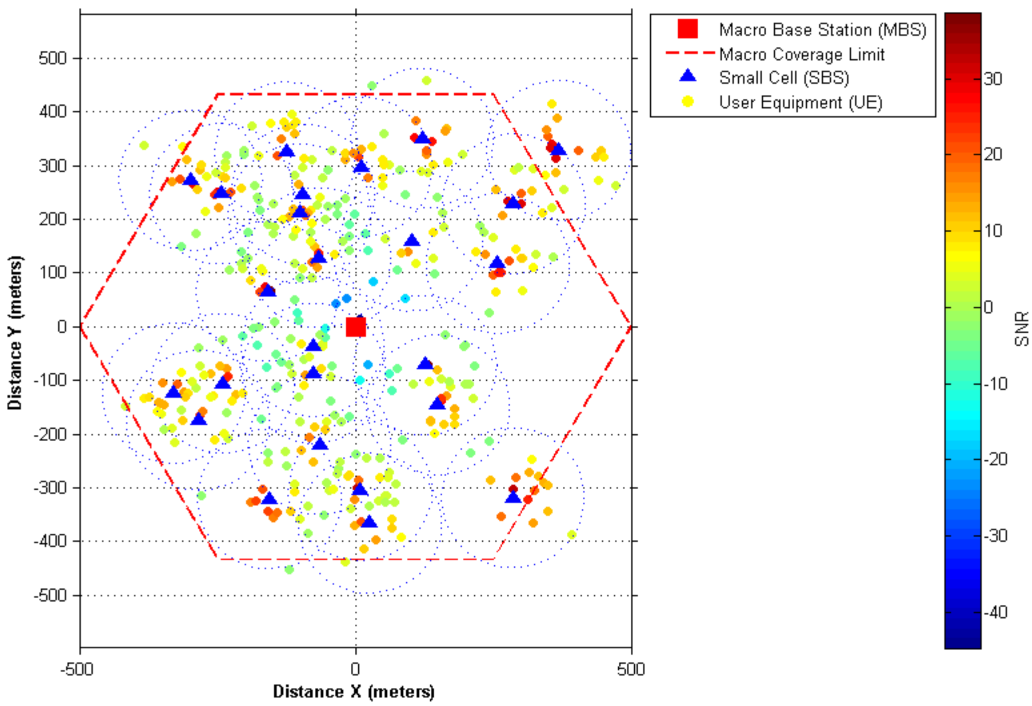

Fig. 5: Distribution map of a congested heterogeneous network with the smart control (scenario 3).

In terms of the reliability of transmission for the in-peak case, it is clear in Fig. 6 that the SNR efficiency for the networks that are based on the smart handling is improved relative to the non-smart networks. This mainly happens because the smart solution tends to avoid interference between the signals by picking the best available path according to an intelligent application. Worth noting that the best routing does not necessarily mean the closest available small cell; it depends on the level of occupation for the chosen cell. The small cell with fewer subscribers is given a higher priority than the one with crowded mobile users. As such, the presented solution aims to secure a clever and reliable path between the transmitter and receiver.

To compare the throughput efficiency for the in-peak case between the traditional and smart heterogeneous networks, it is seen in Fig. 7 that the throughput rate is increased by around 1.7 dB, where, for instance, at an SNR limit of 20 dB, the average throughput for a non-smart heterogeneous network equals 1.5 Gbps, and 2.55 Gbps is recorded for the smart one. The main reason behind this enhancement is smart control, which routes overloaded signals to the best nearby small cell based on intelligent application. Accordingly, the mobile user is served by the best small cell based on smart cell deployment, not on the distance between the user and the base station. Thus, a mobile subscriber is served by lower-loaded and high-injected-power small cells regardless of the distance between them.

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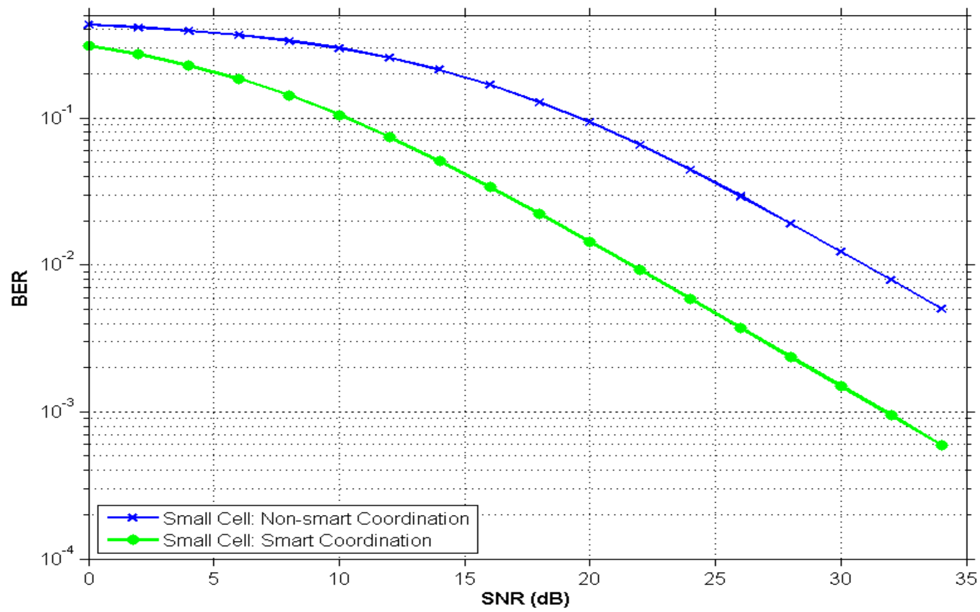

Fig. 6: Solve the interference problem using the smart solution.

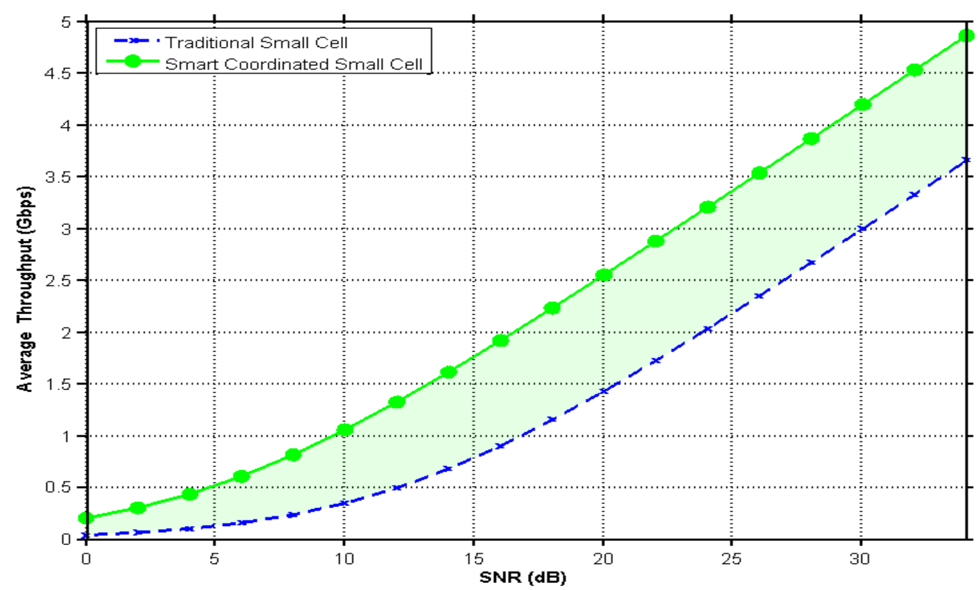

Fig. 7: Improved throughput efficiency after using the smart solution.

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The system parameters for the studied scenarios are listed in Table 1.

Table 1: Main parameters of scenarios 1, 2, and 3.

Parameters	Values
Number of Small Cells	10 - 40
Density in each Small Cell	5 – 25 Subscribers
Simulation Area Size	1000 m (1km x 1km)
Macro Power (Tx)	46 dBm
Small Cell Power (Tx)	30 dBm
Sampling Frequency	20 GHz

4. Conclusion

In this study, the impact of using a new processing layer based on an advanced intelligent application in heterogeneous mobile networks (on-peak time) is presented. The clever solution aims to achieve smart processing in each engaged small cell, side by side with the main big cell, utilizing the intelligent central controller. Accordingly, the smart manipulation level includes both the data and control planes of the transmission process, where the best throughput, SNR, and BER are obtained. The applied experiment, through testing three key scenarios (off-peak, conventional in-peak, and in-peak-based smart solution), demonstrates the main advantages of applying clever handling in the crowded heterogeneous mobile network. The smart system's performance, in terms of transmission throughput, is improved by around 1.7 dB compared to the traditional one. In addition, an improved SNR is recorded for the smart network, about 10 dB higher than that of the old-style network. Therefore, sophisticated cooperation among the cells of the smart heterogeneous network results in higher average throughput, lower power consumption, and more reliable transmission compared to the traditional network.

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