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SOFT FREQUENCY REUSE FOR MILIGATION OF INTERCELLULER INTEREFERENCE

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Background. The appearance of femtocells in LTE networks has provided indoor coverage and overcome large data flows for operators. However, strong interference occurs in neighbouring femtocell users due to the limited available spectrum in cellular networks that transmit data in the same radio range. In densely deployed environments, interference issues in single-channel femtocells cause significant performance degradation. In this study, we mitigate inter-cell interference in femtocell networks by combining femtocells as a result of common interference and soft frequency reuse in downlink and uplink by moving and exchanging interfering physical blocks.

Objective. The purpose of the paper is to improve the efficiency of ensuring the quality of services in wireless networks by reducing any interference due to the distribution of traffic, which is able to provide uninterrupted connection to the user.

Methods. Enabling conditions for inter-cell interference mitigation in LTE-based femtocell networks with soft frequency reuse.

Results. Interference is a key issue in the deployment of LTE femtocells. Closely located femtocells interfere with each other if they transmit on the same frequency. Therefore, crossing femtocells and enabling them to allocate resources and reuse soft frequencies effectively reduces interference and prevents the loss of network resources. The scheme is triggered whenever the user's femto equipment experiences strong interference from neighbouring femtocells. By assigning a separate set of physical resource blocks to users at the edge of the cell, our scheme significantly reduces interference, which automatically increases cell throughput. The simulation results show the advantages of applying our scheme, in particular, the interference of the user's femto-equipment is reduced by 14% and the throughput is improved by 25%. That is, we observe a significant improvement in the performance of femtocells.

Conclusions. A femtocell crossing scheme with soft frequency reuse is presented to reduce interference between femtocells of LTE networks, which allows effectively ensuring the quality of service transmission in wireless networks by reducing interference and increasing performance through traffic distribution.

Keywords: *4G; capacity; coverage; LTE; network planning; reuse of soft frequencies.*

Introduction

During the last decades, there has been a rapid growth in traffic consumption provided by mobile communication systems. This growth led to the fact that the physical resources (frequency-time and spatial-polarization) originally allocated for this connection and involved in it began to be exhausted. To solve the problem of further growth in the number of consumers, new types and structures of signals, methods of saving the radio frequency spectrum, new schemes of multiple, multi-station access, finding solutions for the collective use of resources and equipment were found.

Because next-generation networks should be designed in such a way as to preserve the existing network architecture. The concept of heterogeneous networks is best suited for this, i.e. networks whose radio access level has several levels of base stations with different parameters. At the same time, the existing macro coverage is preserved, and picocells and femtocells are installed in the places of the greatest concentration of subscribers. Small cells, due to the small area of coverage, allow significantly improving the system spectral efficiency, as well as to relieve the burden of macro coverage.

LTE cellular communication technologies require a huge frequency band, and therefore the spread of these technologies is held back by a shortage of free radio spectrum [1]. One of the solutions for building next-generation mobile communication networks is the transition to small cells (microcells, pico- and femtocells), which are base stations with a limited range of action and which are installed to expand the coverage area of macro-level base stations. Having a short transmission range, these small cells will allow the use of frequency reuse technologies for more efficient use of the available spectrum [2].

A femtocell is a low-power cellular base station that you can install in your home or office. Used in cases of uncertain or absent signal from the operator's cell tower, for example, in basements, outside the city, etc. Being connected to broadband cable Internet, the device receives a signal from your cell phone and further communication goes through the Internet channel. A femtocell works on exactly the same principle as a large base tower of a cellular operator.

The femtocell of 4G wireless systems generates a signal for personal mobile equipment and connects it to the operator's network via the Internet. This allows improving coverage and bandwidth for each user in the coverage area of their access point.[3]

Recent studies have predicted that 50% of phone calls and 70% of data services will take place indoors. Next-generation systems will feature more intelligent devices, and the content of their services will require more network bandwidth than available today.

Bandwidth: Shortening the distance between the femtocell and the end user leads to a higher signal level, and femtocells can serve multiple users, they can allocate more of their resources (transmission power and bandwidth) to each subscriber. Then fewer users use the same spectrum resources, which saves more resources for other users.

The main problem with the deployment of femtocells is interference with the base station by macrocells. Other functions of femtocells are also considered, including resource management, spectrum allocation management, QoS provisioning through the Internet transit network, and access to femtocells. Handover and mobility are also very important aspects in femtocell networks, as there are different types of femtocell handover to/from the macrocell.

Fig. 1 shows the deployment of soft frequency reuse with a reuse factor of Δ =4. Interference avoidance refers to frequency reuse algorithms used to deploy some constraints on transmission power and resource allocation. The soft frequency reuse scheme divides the entire cell bandwidth into two parts: cell center bandwidth is allocated to cell center users, and cell edge bandwidth is allocated to cell edge users. The main difference between strict frequency reuse and soft frequency reuse is that cell center users share allocated subbands with cell edge users in adjacent cells to improve system performance and spectrum efficiency.[4] Bandwidth allocated to the cell edge can also be used in the lower priority cell center user equipment if it is not used at the cell edge. Because of sharing resources between cell-edge and cell-center users, cell-edge users can use the entire cell-edge sub-bands. However, the bandwidth reserved for the cell center is limited for use at the cell edge. This lack of spectrum at the cell edge can sometimes result in low bandwidth for user equipment at the cell edge. This is overcome by distributing the high transmission power in the cell edge area, thus increasing the signal-to-interference and noise ratio.

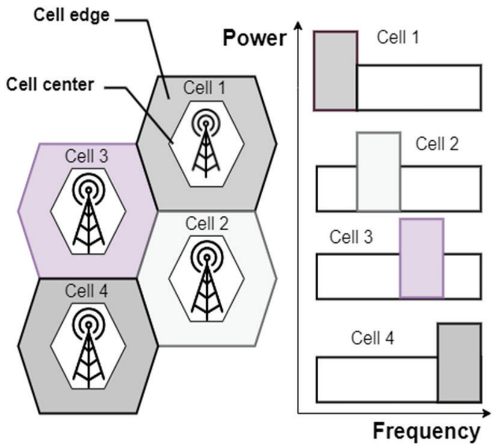

Fig. 1 Soft frequency reuse with reuse factor Δ = 4

LTE uplink requirements differ from downlink requirements for several reasons. [5] The femtocell user equipment and the macrocell user equipment act as a source of uplink cross-layer interference for the serving macrocell base station and the nearest femtocells, respectively. On the other hand, the serving base station of the macrocell and femtocell cause cross-layer downlink interference for the femtocell UEs and the nearest macrocell UEs, respectively.

A new scheme of a crossing of femtocells with frequency reuse (CFFR) for the downlink is proposed, which combines and assigns a separate set of blocks of physical resources for each femtocell, which creates interference, and a scheme for exchanging blocks of physical resources for the uplink, which effectively mitigates interference between femtocells. CFFR divides the bandwidth in each cell based on the number of interfering femto base stations. This flexible allocation of resources guarantees complete elimination of inter-cell interference in the downlink. For the uplink, the physical resource block exchange scheme swaps the interfering physical resource blocks with blocks from the interference-free zones. As a result, this prevents the loss of network resources and the simulation output shows a significant improvement in the performance of femtocells.

Downlink line

The values of the signal/interference ratio and the noise of the user's femto-equipment are negatively affected by downlink interference from neighboring cells. This also greatly reduces their bandwidth. Cells that create obstacles are allocated a separate set of blocks of physical resources. Because of this, obstacles can be mitigated. Two or more femtocells with at least one active femto-user equipment in their overlapping area form an association. The proposed CFFR scheme identifies these associations and allocates a unique set of blocks of physical resources to each member of the crossing.

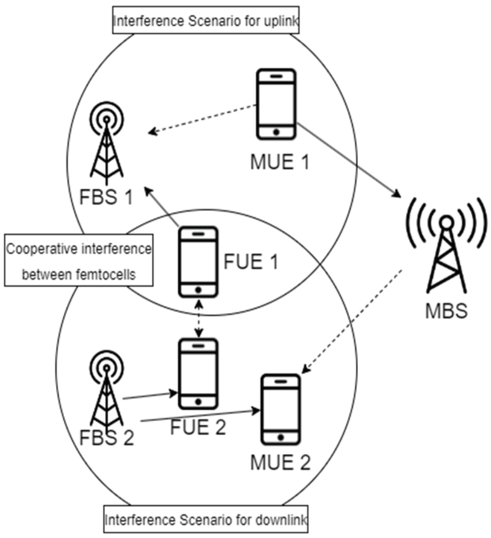

Fig. 2 Interference in femtocell networks

Fig. 2 shows that the user's macro equipment in the transmission range of the femtobase station creates interference in the uplink. Femto equipment of a neighbouring cell user also causes uplink interference if the transmission occurs on the same physical resource block. Also shown in this figure is a downlink interference scenario in a macrocell-femtocell overlay network. In the downlink, the user's femto-equipment experiences interference from neighbouring femto-base stations and overlapping macro-base stations. Any two or more clusters can share the same physical resource blocks. Therefore, there is a need to mitigate intercellular interference between femtocells.

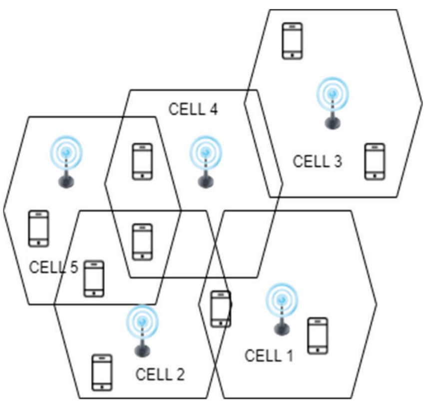

Fig.3 Combining femtocell interference

Fig. 3 shows interfering femto-base stations that are combined and form joint interference. So interference occurs when two or more femto base stations with overlapping areas transmit using the same physical resource block. This has a serious negative effect on the signal-to-interference and noise ratio values for both femto base stations and femto user equipment.

To mitigate interference between femtocells in the same channel it is necessary to allocate a separate filling of the block of physical resources to users on the edge of the cell of each cell. A block of physical resources has a time and frequency dimension. In our system, the bandwidth Bw is divided into N blocks of physical resources. The power of the signal observed by the receiver r from the transmitter t on blocks of physical resources n can be determined as:

$$S_n^r = T_n^t \, A_n^{r,t} \tag{1}$$

where $A_n^{r,t}$ is the gain of the channel between the transmitter and the receiver, and T_n^t is the transmission power on blocks of physical resources.

In the time and frequency domain, macrocells and femtocells equally use the resources available to them, so the interference is shared and received by any receivers.

So, the interference O_n^r is determined by:

$$O_n^r = \sum_{i \in M_n} T_n^m \, A_n^{r,i} + \sum_{j \in F_n} T_n^f \, A_n^{r,j} \tag{2}$$

where T_n^m denotes the transmission power of the macro user equipment in the uplink and the transmission power of the macro base station in the downlink. *Mn* and *Fn* denote the set of interfering macro and femtobase stations. T_n^f denotes the uplink femto user equipment and the downlink femto base station transmission power. Similarly, $A_n^{r,i}$ is the channel gain between the femto base station and the interfering femto user equipment in the uplink and between the femto user equipment/macro user equipment and the interfering femto base station in the downlink. User macro-equipment in the coverage area of femtocells for closed access systems is exposed to severe interference from the femto base station in the downlink, and in the coverage area of the user macro-equipment, the femto base station exhibits severe macro-interference in the uplink.

From equations (5.1) and (5.2) it is possible to determine the signal/interference and noise ratio, namely:

$$SINR_n^r = \frac{T_n^t\, A_n^{r,t}}{\sum_{i \in M'} T_n^m\, A_n^{r,i} \; + \; \sum_{j \in F'} T_n^f\, A_n^{r,j} \; + \xi} \quad (3)$$

where ξ – thermal noise on blocks of physical resources.

Channel bandwidth in LTE is determined by the modulation and adaptive coding scheme. It is based on the information available to it about the state of the channel. To determine the achievable data transfer rate, we use the theoretical Shannon equation and do not lose generality.

$$Tg = Bw.\, log_2(1 + SNR) \quad (4)$$

where *SNR* is the signal-to-noise ratio and *Bw* is the channel bandwidth. However, the interference factor between cells is not taken into account in this equation. So, the bandwidth of the block of physical resources, equation (4) can be rewritten as follows:

So, the bandwidth of physical resources can be determined by replacing *SNR* with *SINR* and *Bw* with *Bw_BPR.*

$$Tg_r = Bw_{BPR}.\, log(1 + SINR_n^r\,) \quad (5)$$

Therefore, the total bandwidth of the cell can be expressed from this equation:

$$Tg_{total} = \sum_{u=1}^{Ut} \sum_{n=1}^{Nt} Tg_{u,n} \quad [\frac{bits}{s}] \quad (6)$$

where *Ut* is the total number of users of the cell and *Nt* is the total number of physical resource blocks assigned to the users of this cell.

Power control is applied in the uplink at both the macro and femto levels to provide a realistic model. The uplink transmission power of the user equipment is adjusted using the following expression:

$$T_n^t = min\left\{tp^{max}, max\left[tp^{min}, tp^{max}\left(\frac{L}{w}\right)^{\omega}\right]\right\} \quad (7)$$

where $tp^{max}$and tp^{min} are the maximum and minimum transmission power on blocks of physical resources. The balancing factor *ω* determines how sharply the transmission power increases with increasing path losses. The *l*-percentile path loss value w defines the critical path loss above which the user equipment transmits at maximum power.

The channel gain $A_n^{r,t}$ is dependent on the distance by the losses on the path LW between the transmitter t and the receiver *r* on blocks of physical resources *n* and is expressed as:

$$A_n^{r,t} = 10^{(\frac{-LW}{10})} \quad (8)$$

Losses of femto user equipment or macro user equipment to the femto base station are defined as:

$$LW = 15.3 + 37.6\, log_{10}\left(\frac{a}{1000}\right) \;\; [dBm] \quad (9)$$

where a (in meters) is the distance between the transmitter and the receiver.

Losses of external user macro equipment for maintenance and macro base station interference

$$LW = 15.3 + 37.6\, log_{10}(a) \;\; [\, dBm] \quad (10)$$

Losses of internal user equipment to the macro base station :

$$LW = 15.3 + 37.6\, log_{10}(a) + LW_p \;\; [dBm] \quad (11)$$

where LW_{p} represents penetration losses when signals pass through walls from the interior to the street or vice versa.

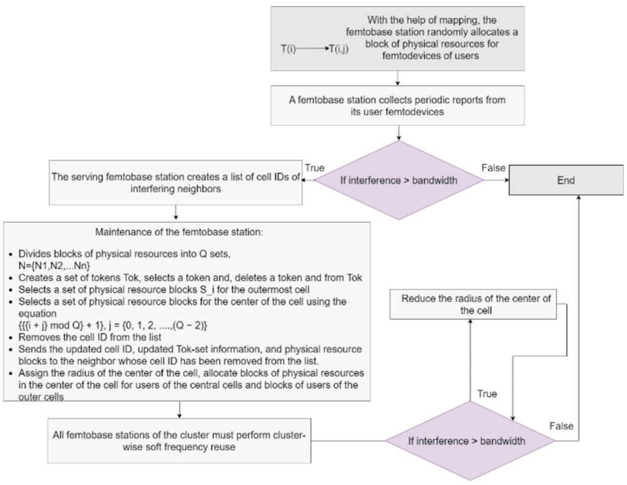

Fig. 4 Algorithm of crossing unification for reuse of soft frequency

The sequence of actions of the CFFR algorithm is shown in Fig. 4. Each femtocell distributes its physical resource blocks randomly among its users using a 1-to-1 matrix mapping. Matrix *F* contains a list of user equipment, and Matrix *P* contains a list of physical resource blocks.,. This guarantees complete avoidance of internal interference. In a telecommunications network, each femto base station collects information about the current level of interference from its femto user equipment at a very high frequency. If the user's femto equipment experiences interference above a certain threshold, the serving femto base station exchanges loading information messages over the *X2* interface with its neighbours and identifies the cell IDs of the interfering femto base stations. After defining a cluster, the serving femto base station divides the block of physical resources into N unique sets, $S = \{S1, S2, ..., SN\}$, where N is the total number of interfering femto base stations. Since the PRB is the smallest resource allocation unit in LTE, it is safe to assume that there will be enough physical resource blocks to create N distinct sets. However, CFFR is also applicable given the available subcarriers. In the next step, the serving femto base station creates a token set, $T= \{1, 2, ..., N\}$, to ensure that a distinct set of physical resource blocks is selected by each cluster cell for the cell edge. The serving femto base station then selects a token ti and a set of physical resource blocks Si for its cell end users. The sets of physical resource blocks of the cell center are selected using the equation $\{\{\{i + j\} \; mod \; N\} + 1\}, j = \{0, 1, 2, ...,(N - 2)\}$. The distance of the affected femto user equipment from the serving femto base station is the cell center radius. In the last step, the serving femto base station first removes the token t_i from T and randomly removes the cell ID from the list. It then sends a high-interference indicator to the neighbor with the deleted ID, containing the updated list of cell IDs, the updated list of tokens, and information about the physical resource block sets. This process continues until all cells in the cluster have selected their sets of physical resource blocks for the center and edge of the cell. The cell center radius can be further reduced if the user's other femto equipment experiences interference above the threshold. In case of shortage of physical resource blocks in the cell center, users can borrow physical resource blocks from the cell edge only if they are not used by the user's femto equipment at the cell edge. However, end-cell users are never allowed to borrow blocks of physical resources from the cell center to ensure inter-cell interference.

Uplink line

There may be interference in the uplink, even if there is mitigation of interference in the downlink, precisely because the users of the cell center are transmitting on the same physical resource blocks as the cellular end users in the neighbouring cell. These interferences can be reduced in the uplink by a physical resource block swapping algorithm that either swaps physical resource blocks used at the cell edge or exchanges them with available physical resource blocks from the cell center. It should be noted that the entire region of the cell edge is not affected by interference, since only part of the cell edge is in the overlapping region. When a cell edge user causes uplink interference, the serving femto base station of that user may swap physical resource blocks between the interfering user and another user in the cell edge free zone. If this is not possible, the cell center user can try to use another physical resource block if it is freely available. This helps reduce uplink interference in the femtocell network.

Simulation results

Users in the cell center can share the cell edge bandwidth without creating intra-station interference. Fig. 5 compares the CFFR cumulative downlink interference distribution function with adaptive soft frequency reuse, which allocates one-third of cellular bandwidth to users at the cellular edge. The graph shows the value of CFFR for mitigating inter-cell interference in closely spaced femtocells. With CFFR, the average interference of the user's femto-equipment is reduced by 14%. Clustered femto base stations continue to reduce their cell center radii until the interference level of the user's femto equipment drops below a threshold value. Since the cell boundary of each femtocell in the cluster operates with separate sets of physical resource blocks, the only interfering object is the overlapping macro base station.

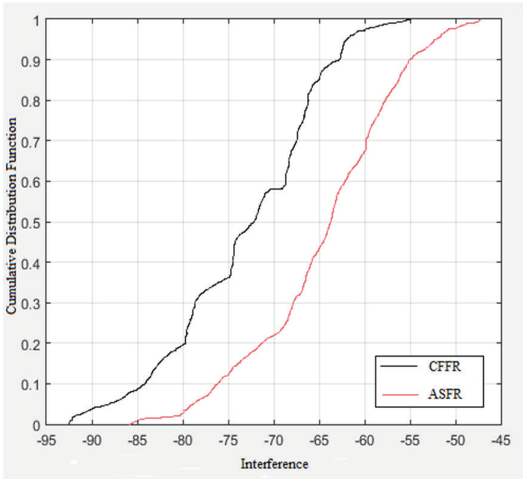

Fig. 5 User intervention in the downlink

The CFFR scheme is compared to ASFR in terms of the average downlink bandwidth of users. The graph clearly shows that even at low bandwidth in the cell edge area, our algorithm still shows a 25% throughput improvement compared to the other scheme. This can be mainly explained by the fact that our algorithm increases the value of the signal-to-interference and noise ratio, which results in more bandwidth for users.

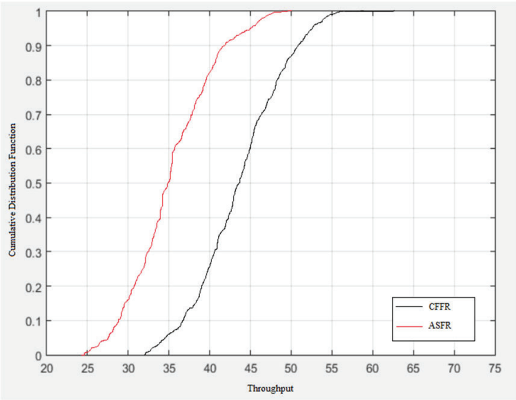

Fig. 6 Downlink user bandwidth

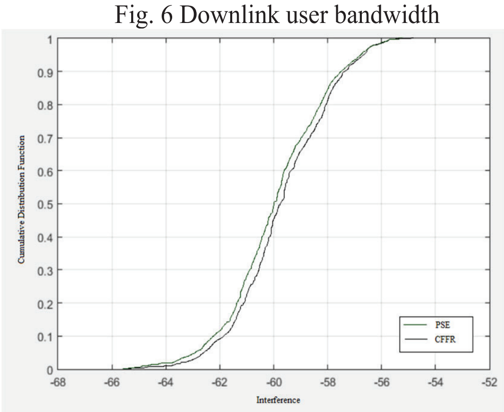

Fig. 7 Femto base station interference in the uplink

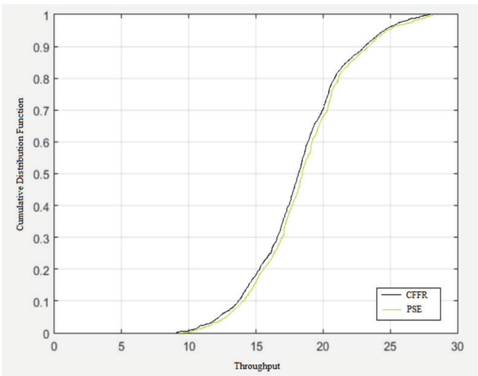

Fig.8 Femto base station throughput in the uplink

The performance of our downlink algorithms and the physical resource block exchange algorithm is shown in Figures 7 and 8 of this algorithm for uplink interference control. As can be seen in the first graph, physical resource block sharing further reduces uplink interference by controlling physical resource block reuse and performing physical resource block replacement. Reducing femto base station interference in the uplink results in improved throughput as shown in the second graph.

Conclusion

The simulation results of our downlink CFFR and uplink block exchange/move schemes show significant benefits in an LTE network. The scheme is triggered whenever the user's femto equipment experiences strong interference from neighbouring femtocells. CFFR assigns a separate set of physical resource blocks to users at the cell center and cell edge of each femtocell. The cell center radius is determined based on the distance of the affected user from the serving femto base station. The cell center radius is adjustable if each user is free of obstructions. Due to this, interference is reduced, which automatically increases the bandwidth of cells. For the uplink, the proposed algorithm for moving and exchanging blocks of physical resources swaps blocks of physical resources between users in zones that create interference and in zones without interference. Both algorithms together mitigate inter-cell interference in a densely deployed femtocell network. Significant improvements in bandwidth and reduction in interference are increasing the effectiveness of QoS in wireless networks. In future works, possible research work is related to interference between femtocells and macro networks.

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Повторне використання м'якої частоти для пом'якшення міжстільникових перешкод

Проблематика. Поява фемтостільників в мережах LTE забезпечили покриття в приміщеннях та подолали великі потоки даних для операторів. Проте виникають сильні перешкоди в сусідніх фемтосотових користувачів через обмеженість доступного спектру в стільникових мережах , що передають дані в тому самому радіодіапазоні. У щільно розгорнутих середовищах проблеми з перешкодами в фемтостільниках з одноканальним каналом спричиняють значне погіршення продуктивності. У цьому дослідженні ми послаблюємо міжстільникові перешкоди у фемтосотових мережах завдяки об`єднання фемтосот в результаті спільних перешкод та повторного використання мякої частоти в низхідної лінії звязку та у висхідній ліній переміщення та обміну блоків фізичних що створюють перешкоди.

Мета. Підвищення ефективності забезпечення якості послуг у бездротових мережах за рахунок зменшення будь-яких перешкод через розподіл трафіку, який здатний забезпечувати безперебійне підключення до користувача.

Методика. Забезпечення умов для пом’якшення міжстільникових перешкод у фемтосотових мережах на основі LTE з повторним використанням м’якої частоти.

Результати досліджень. Перешкоди є ключовою проблемою при розгортанні фемтостільників мережі LTE. Близько розташовані фемтостільники заважають один одному, якщо вони передають на одній частоті. Тому перетин фемтосот та даючи змогу їм розподіляти ресурси і повторно використовувати мякі частоти результативно зменшує перешкоди та запобігає втраті мережевих ресурсів. Схема запускається кожного разу, коли фемто-обладнання користувача відчуває сильні перешкоди від сусідніх фемтостільників. Призначаючи окремий набір блоків фізичних ресурсів користувачам на краю стільника, наша схема значно зменшує перешкоди, що автоматично збільшує пропускну здатність стільників. Результати моделювання показують переваги застосування нашої схеми, зокрема перешкоди фемто-обладнання користувача зменшується на 14% та покращується пропускна здатність на 25%. Тобто ми спостерігаємо значне покращення продуктивності фемтостільників.

Висновки. Представнено схему перетину фемтосот з повторним використанням мякої частоти для зменшення перешкод між фемтостільникам мереж LTE, що дозволяє ефективно забезпечувати якість передавання послуг у бездротових мережах за рахунок зменшення перешкод та збільшення продуктивності через розподілу трафіку

Ключові слова: *4G; ємність; покриття; LTE; планування мережі; повторне використання м'яких частот.*