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Heterogeneous 네트워크에서 Pico 셀 범위 확장과 주파수 분할의 성능 평가

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Performance Evaluation of Pico Cell Range Expansion and Frequency Partitioning in Heterogeneous Network

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ABSTRACT

In the presence of a high power cellular network, picocells are added to a Macro-cell layout aiming to enhance total system throughput from cell-splitting. While because of the different transmission power between macrocell and picocell, and co-channel interference challenges between the existing macrocell and the new low power node-picocell, these problems result in no substantive improvement to total system effective throughput. Some works have investigated on these problems. Pico Cell Range Expansion (CRE) technique tries to employ some methods (such as adding a bias for Pico cell RSRP) to drive to offload some UEs to camp on picocells. In this work, we propose two solution schemes (including cell selection method, channel allocation and serving process) and combine new adaptive frequency partitioning reuse scheme to improve the total system throughput. In the simulation, we evaluate the performances of heterogeneous networks for downlink transmission in terms of channel utilization per cell (pico and macro), call blocking probability, outage probability and effective throughput. The simulation results show that the call blocking probability and outage probability are reduced remarkably and the throughput is increased effectively.

Key Words : Picocell, Cell Selection, Cell Range Expansion, Frequency Partitioning, Effective Throughput, Call Blocking, Outage Probability, Channel Utilization.

Ⅰ. Introduction

Data traffic demand in cellular networks today is increasing at an exponential rate. As the link efficiency is approaching its fundamental limits, further improvements in system spectral efficiency are only possible by increasing the node deployment density. In already dense deployments today, cell splitting gains are significantly reduced due to already severe inter-cell interference. Moreover, site acquisition costs in a capacity limited dense urban area can get prohibitively expensive. Challenges can be overcome by adding some base stations with lower transmit power (the low power nodes such as picocell, femtocell, relay node, etc.) to the deployment of traditional macro base stations. A network that consists of a mix of macrocells and low-power nodes, where some

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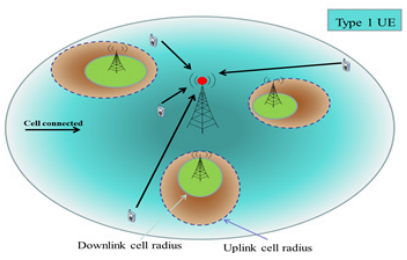

Fig. 1 (a). type 1 UEs

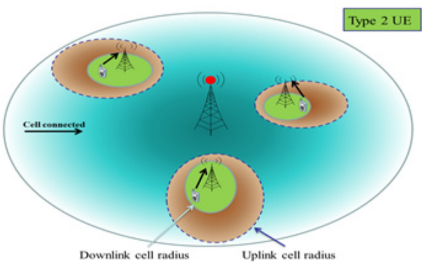

Fig. 1 (b). type 2 UEs

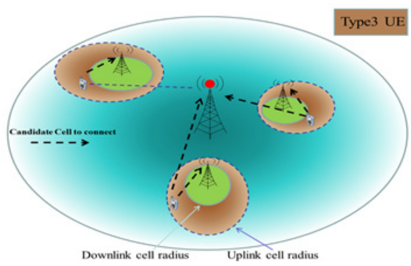

Fig. 1 (c). type 3 UEs

may be configured with restricted access and some may lack wired backhaul, is referred to as a heterogeneous network (HETNET)[1-2].

Several cell selection methods which can achieve pico cell range expansion have been investigated in [3], [5], [8]. Interference challenges in macro-pico cells deployments are described in [11]. In [4], they discussed the three cell selection methods and compared those methods in the simulation with full buffer model. In [9], [10], [12], the adaptive frequency partitioning schemes are investigated. The goals of this paper are to evaluate the picocell based HETNET deployment and identify the impacts when picocells are deployed in macrocell area. And we aim to evaluate the system performances in the presence of cell range expansion techniques and frequency partitioning schemes in the given traffic model system. At first, we propose two solution schemes and combine new frequency partitioning reuse scheme. In the simulation, we evaluate the performances in heterogeneous networks for downlink transmission in terms of channel utilization per cell (pico and macro), call blocking probability, outage probability and effective throughput. The results show that our proposed two solution scheme for macro-picocell deployment can achieve an much larger effective throughput gain comparing to the conventional solution schemes.

The rest of the paper is organized like as following: The network model is described for the works of proposed three types UEs solution schemes in section 2. In section 3, the new adaptive frequency partitioning reuse scheme is proposed. In section 4, the proposed two solution schemes for each type UE call are described in detail. The solution formulations of performance objectives are formulated in the section 5. In section 6, the simulation results are shown and discussed in detail. and then in section 7, the conclusions of this paper are concluded.

Ⅱ. System Model

We consider a cellular layout as one macrocell and several picocells and some UEs arrive in macrocell coverage with Poisson distribution with rate λ calls/second .

As shown in figure 1, we divide UEs into three types[13]:

Type 1 UEs set: in Fig.1(a), UEs which arrive outside of all picocells uplink coverage and inside of macrocell coverage. Those UEs belong to Type 1 UEs set.

Type 2 UEs: in Fig.1(b), UEs which arrive inside of any picocells downlink coverage. Those UEs belong to Type 2 UEs set.

Type 3 UEs set: in Fig.1(c), UEs which arrive outside of any picocell downlink coverage and inside of any picocell uplink coverage. Those UEs should make a decision that which cell to connect. Those UEs belong to Type 3 UEs set.

As shown above, we divided UEs into three sets. In later sections, we will show our proposed solution scheme in detail in terms of cell selection, channel allocation and serving process for three types UE call one by one.

Ⅲ. Adaptive Fractional Frequency

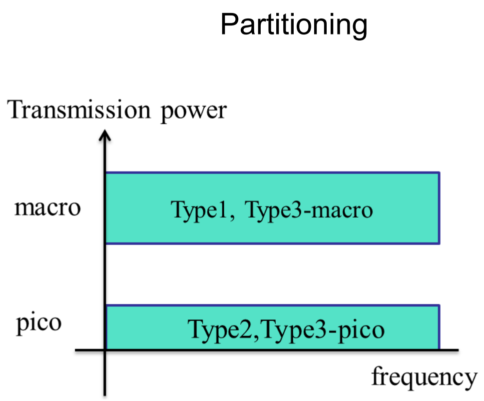

Fig. 2(a). frequency traditional reuse 1

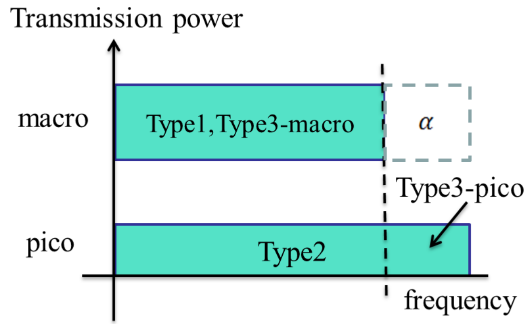

Fig. 2(b). proposed adaptive fractional frequency partitioning

When range extension techniques are employed, the coverage area of picocells will extend and the number of pico UEs (PUEs) will increase. However, the type 3 pico UEs who are associated with picocell will suffer noticeable interference from macrocell. Therefore, wireless cellular operator can employ two approaches to utilize the spectrum in a wireless overlay network.

The first approach is that two tiers share the licensed spectrum such that macrocell and picocell operate in co-channel frequency reuse. See figure 2 (a), it is called frequency traditional reuse 1. Another approach is that the licensed spectrum is divided up into separate portions and each tier operates in a dedicated spectrum portion. There are both pros and cons of these two usages. With shared spectrum usage, each radio tier has more available amount of spectrum but some UEs suffers higher cross-tier interference. On the other hand, with partitioned spectrum usage, the cross-tier interference is lower, but the available amount of spectrum is reduced.

In order to cancel the interference for type 3 pico UEs and ensure the available amount of spectrum, it is reasonable to reserve a part of frequency resources only for type 3 pico UEs operation as a protected band. In the protected band, since the interference from macrocell is removed, the type3 pico UEs can have comparable signal quality with other UEs. As a result, the cell edge performance can be improved effectively. This approach, which is shown in figure 2 (b), is called proposed adaptive fractional frequency partitioning.

In figure 2(a), with frequency traditional reuse 1, type3 pico UEs at edge of picocell will suffer the interference from macrocell. The basic concept of the proposed method is that the “muting band” (i.e. protected band) is only used for type3 pico UEs to prevent the interference from macrocell. we can improve the cell edge user spectral efficiency effectively by protecting these users. The basic principle of this frequency partitioning strategy is as follows:

1. Macro is assigned at least 50 % of the total bandwidth[12].

2. The muting band change dynamically according to the different solution strategies for type 3 UEs. The muting band rate α is defined as:

$$\alpha = \frac{Number\,of\;Type\,3\;Pico\;UEs}{Number\,of\,(\,Type\,1\,\mathrm{and}\,3\;UEs\,)},$$

where Type 3 Pico UEs is represented as the type 3 UEs which connect to picocells. In the next section, we will discuss two different strategies for type 3 UEs, so the number of type 3 pico UEs will be different for the different strategies. That leads to the different α for the different strategies.

Ⅳ. Solution Strategies

4.1. Solution Strategy for Type 1,2 UEs

When the new call drops into type 1 or 2 UEs set, the cell selection method, call channel allocation and serving process are described as following:

Type 1 UEs set: While those UEs can get a best serving from macrocell and weak interference from picocells, we let those UEs connect to macrocell unconditionally.

Type 2 UEs set: While those UEs can get a best serving from picocell and no strong interference from macrocell, we let those UEs connect to picocells unconditionally.

Notably, all type 1, 2 UEs will be scheduled on unmuted channels. When new call arrives, serving BS should allocate one channel for this call once cell selection of the call is done. Due to the high channel competition in macrocell BS, which has been mentioned in the previous section, macro BS checks whether the estimated SINR (signal to interference and noise ratio) of type 1 new call is larger than the given threshold before it allocates one channel to the call. If the estimated SINR of type 1 new call is larger than the given threshold , one channel is scheduled for the call. When the call ends, this channel is released into macro BS. Otherwise call is blocked. But for the case of the call belongs to type 2UEs set, pico BS randomly chooses one channel to allocate to the call, since there is low channel competition in pico BSs. Cell selection, channel allocation and serving process for type 1, 2 UEs call are shown as figure 3.

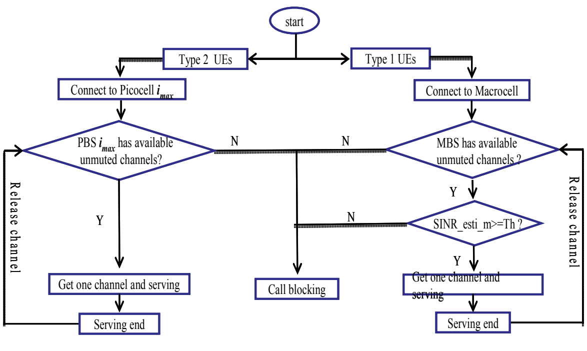

Fig. 3. Channel allocation and procedure for type 1, 2 UEs

4.2 Solution Strategy for Type 3 UEs

In this subsection, two strategies are investigated for cell selection, channel allocation and serving process for type 3 UEs. One is called adaptive bias based scheme, in which we try to add an adaptive bias for all picocells as taking account of the UE location environment before using Max DL RSRP cell selection method. The other is call channel based scheme, in which we try to implement cell selection on the basis of channels in picocells and signal quality.

4.2.1. Adaptive Bias Based Scheme (ABBS)

Type 3 UEs set: UE who belongs to Type 3 UEs set will be in a dilemma over connecting to macro or picos. In order to select the optimal cell, the bias value for picocells at the j^{th} UE in type 3 UEs set, B_j, is investigated[5]:

$$B_j = 10 * \log\left(\frac{\sum_{i=1}^{N_p} S_{i,j} + P_N}{\sum_{i=1}^{N_p} S_{i,j} - \max_{1 \le i \le N_p} S_{i,j} + P_N} \right),$$

where $S_{i,j}$, N_p and P_N represent the RSRP of the i^{th} (i is the pico cell index) of the j^{th} UE, the number of picocells, and the background noise power, respectively. From the above formulation, it is expected that the optimum offset value differs UE-by-UE. Furthermore, this offset value is used to offload the UEs connected to macrocell to the picocells.

For downlink Max RSRP-based cell selection using CRE, the UE selects the cell index based on the following criteria.

$$i_{RSRP,j} = \arg\max_{0 \le i \le N_p} S'_{i,j} \quad \text{and}$$

$$\begin{cases} S'_{i,j} = 10^* \log(S_{i,j}) & Macrocell : i = 0 \\ S'_{i,j} = 10^* \log(S_{i,j}) + B_j & Picocell : 1 \le i \le N_p \end{cases},$$

where i represents the selected call index (i=0 is the index of macrocell) based on the RSRP-based criteria. This offset value is signaled via UE specific higher layer signaling as specified in[7].

Cell selection method in adaptive scheme is

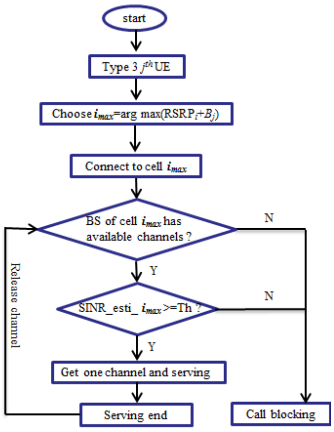

Fig. 4. System process for type 3 UEs in ABBS

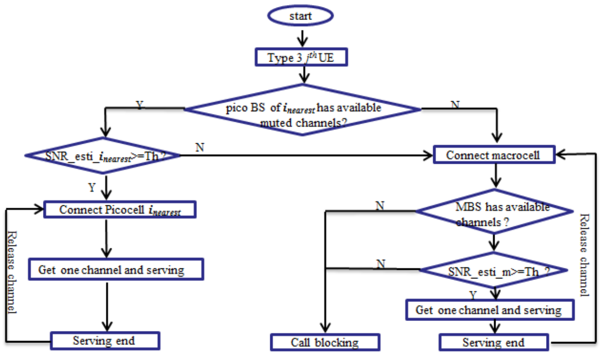

Fig. 5. System process for type 3 UEs in CBS

also described by the following figure. When arrived type 3 call has selected a cell base station (BS) to connect, in the next step, this BS should schedule one channel for the call. Notably, type 3 macro UEs will be scheduled on the high competitive unmuted channels. type 3 pico UEs will be scheduled at the limited muted channels to be serving, so there will also be a high channel competition phenomenon for both type 3 macro UEs and type 3 Pico UEs. So in channel allocation algorithm for type 3 UEs in figure 4, BS of cell i_{max} checks whether it has available channels in it. If it has available channels, let the BS of cell i_{max} check whether the estimated SINR of cell i_{max} of the call if it is allocated one channel is larger than the given threshold before allocating channel for the call. If the estimated SINR of cell i_{max} is larger than the given threshold, one channel will be allocated to the call. Otherwise this call is blocked. When call ends, the channel is released into the available set of associated BS of cell i_{max} .

4.2.2. Channel Based Scheme (CBS)

The goal of introducing picocells into the presence of macrocell networks is to offload a part of high traffic load into the added picocells. In view of this goal, when the call arrives belongs to type3 UEs set, firstly, we drive it tries to connect to picoells, the nearest picocell BS checks whether it has available channels or not in its available channel set, if it has available channels, the call connects to the nearest picocell. Otherwise, the call connects to macrocell to compete the unmuted channels.

When the new call cell selection has been done, the next step cell BS should do is to channel allocation for the new call. The case of call belongs to either type 3 macro UEs set or type 3 pico UEs set, high channel competition phenomenon is existed. BS would like to allocate the limited channels to the call which has the better estimated SINR. This process is very similar to the channel allocation and serving process in the bias scheme. The cell selection process, channel allocation and serving process for type 3 UEs call of channel base scheme can be described as in figure 5.

V. Simulation Conditions

5.1. Traffic Model

We assume that each cell has N_{ch} total channels for downlink transmission. The new call is just scheduled to get serving on one channel. The call arrival process is Poisson distribution with rate λ calls/second in macrocell coverage, and the call holding times are exponentially distribution with mean $1/\mu$ second[6].

5.2. Call Blocking Probability

When a new call arrives, it should select a cell to connect via the cell selection schemes as mentioned in the previous sections, firstly, and then the selected cell schedules one channel for this call until this call serving ends. This channel is released after call serving ends. During this call holding times, this channel cannot be scheduled for other call which wants to get serving from the same cell. The call blocking probability P_b is given the ratio of number of calls which failed to get serving to the number of total calls arrived during simulation times. It is expressed as:

$$P_b = \frac{Number\,of\,calls\,failed}{Number\,of\,calls\,arrived}.$$

5.3. Channel Utilization

Channel utilization of each channel for each cell reflects that not only the effective per channel utilization in this cell but also how many probability of interference occurrence that the neighbor cells will suffer from this cell. In our proposed schemes, we muted several channels which just are scheduled for type 3 pico UEs. So the per muted channel utilization (Type 3) and per unmuted channel utilization (Type 2) in each picocell are individually counted. Here we denote the per channel utilization U of one cell as ratio of sum of serving times of all succeeded calls per channel to the simulation time. That is given as following:

$$U = \frac{servedTimes\,of\,succeeded\,calls\,per\,channel\,per\,cell}{SImlation\,Times}.$$

5.4. SINR and Outage Probability

For the k^{th} UE in the overall network, its SINR (signal to interference plus noise ratio)is expressed as[6]:

$$SINR_k = \frac{S_{i,k}}{\sum_{n=0}^{N_p-1} I_{n,k} * \vartheta_n + P_N},$$

where N_p is number of picocells, $S_{i,k}$ is the RSRP of the k^{th} UE from the serving cel l index i. And i=0 is refer to macrocell. $I_{n,k}$ is the interference of the k^{th} UE from the nth interference cell (N_p-1 interference cell in total). ϑ_n is an indicator function which is 1 when interference occurs and 0 otherwise. The channel utilization in each cell will reflect whether the interference occurs or not. P_N is the noise power.

Then call outage is defined that SINR of the call is less than a given threshold. The outage probability P_o is ratio of number of the outage calls to the number of the calls served.

$$P_O = \frac{Number\,of\,the\,outage\,calls}{Number\,of\,the\,calls\,erved}.$$

5.5. System Throughput

We define the effective throughput to evaluate the system throughput. The effective throughput, T, is expressed as a function of call blocking probability and outage probability[6].

$$T = \frac{\lambda(1-P_o)(1-P_b)}{\mu * N_{ch}}.$$

Table 1. simulation parameters

parameter	Macro	Pico
Layout	Marocell (omni) 1	9 Picocell (omni)
radius	1000m	
Power	46dBm	30dBm
shadowing	8dB	10dB [2]
Pathloss	128.1 +37.6*log10(R)	140.7 +36.7*log10(R)
Total channels	20	
Call inter-arrival time	Exponential distribution	
Call serving time	Exponential distribution	
System bandwidth	10MHz	
Noise	-174dBm/Hz	
Threshold	10dB	

Ⅵ. Simulation Results and Analysis

In this section, we will investigate the system performance using our proposed strategies. In LTE Rel 8 systems, cell selection is fulfilled by comparing RSRP of DL from all neighbor cells. The cell which provides larger RSRP is selected as the serving cell. The max RSRP scheme is that overall UEs selections base on downlink max RSRP, channel allocation rule is "first come first

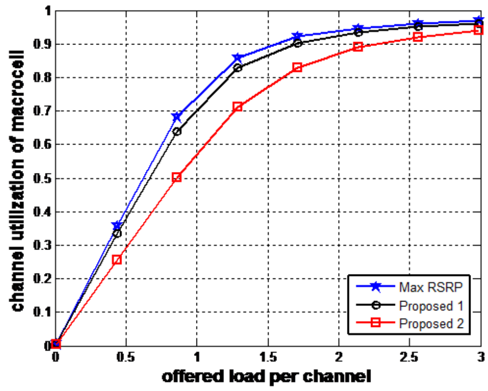

Fig. 6. Channel utilization in macrocell

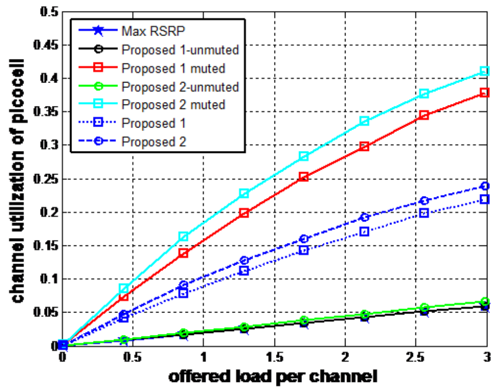

Fig. 7. Channel utilization in each picocell

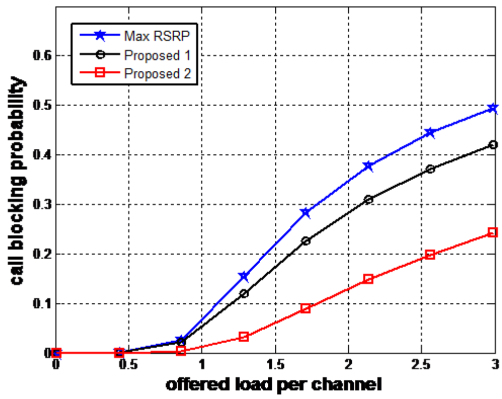

Fig. 8. Call blocking probabilities of different strategies

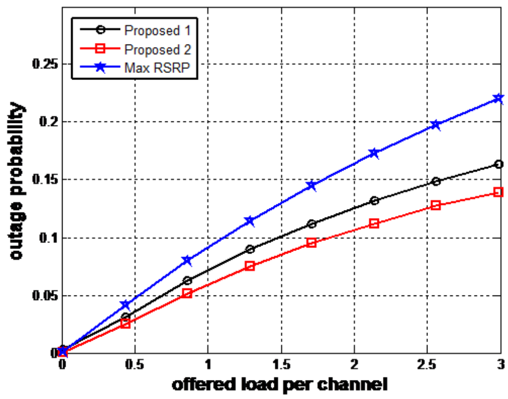

Fig. 9. Outage probabilities of different strategies

served". The max RSRP scheme will be as a reference scheme to compare with and our proposed solution strategies, the proposed strategy 1 (solution strategy for type 1, 2UEs + ABBS) and the proposed strategy 2 (solution strategy for type 1, 2UEs + CBS). The proposed adaptive fractional frequency partitioning reuse scheme is applied for proposed strategies and the frequency reuse 1 is applied for the max RSRP scheme. The performances are represented in terms of the per channel utilization in macrocell, the per channel utilization in each picocell, the total system call blocking probability, the total system outage probability, CDF of UE SINR distribution and system effective throughput.

6.1. Simulation Assumptions

Our simulation will base on the following snapshot assumption. One macrocell BS with 9 fixed picocells BSs are deployed. The coordinates of 9 picocells are (0, 750), (-375*3^0.5, 375), (-375*3^0.5, -375), (0, -750), (375*3^0.5, -375), (375*3^0.5, 375), (-400, 0), (200, -200*3^0.5), (200, 200*3^0.5), respectively. We assume 10 dB as the threshold due to the singe macrocell is deployed in simulation. The rest of simulation assumptions and parameters are described in Table 1.

6.2. Simulation Results

In figure 6, it shows that channel utilizations in macrocell for proposed strategies are less than the max RSPR scheme. That's because more type 3 UEs are connected to the near picocell with our proposed strategies. Especially, more type 3 UEs with proposed strategy 2 connect to picocell than that with proposed strategy 1.

In figure 7, it shows the utilization of per unmuted channel which is scheduled for type 2 UEs (pico UEs) and shared with macro UEs in

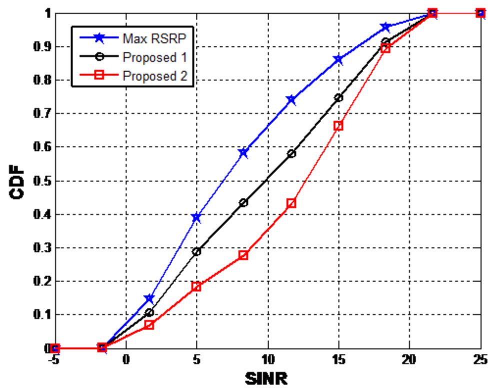

Fig 10. CDF of SINR (< 20 dB) of different strategies

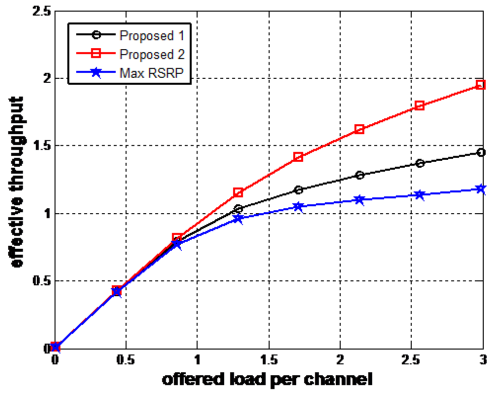

Fig 11. effective throughputs of different strategies

each picocell, utilization of per muted channel which is just scheduled to type 3 pico UEs in each picocell. The much higher channel utilization is shown because of limited muted channels which are scheduled for type 3 pico UEs. Channel utilizations of proposed strategy 2 in each picocell are more effectively than that of proposed strategy 1 for both unmuted channels and muted channels due to different numbers of type 3UEs which connect to the near picocell and different numbers of muted channels of two proposed strategies.

In figure 8, it shows call blocking probabilities of three schemes against with offered load per channel. Both of our proposed strategies can reduce the total UEs call blocking because of we drive some type 3 UEs to connect the near picocell. It's easy to see that proposed strategy 2 has obvious advantages than proposed strategy 1.

In figure 9, from the outage probability perspective, the proposed strategy 2 scheme is a competitive choice. Even when more UEs connected to picocells with using proposed strategy 2 than that of proposed strategy 1, those UEs are scheduled in muted channels to cancel the interference from macrocell and accept the high quality signals.

In figure 10, the CDF of SINR of UEs whose SINR is less than 20 dB for three schemes are shown. For UEs SINR which is less than 20dB, our proposed strategies achieved the better performance than that of max RSRP. That's because of BSs always schedules the limited channel to UE which connects to it and has a high estimated SINR which is larger than the given threshold in proposed strategy 1 and proposed strategy 2. The channel for the arrived call having a low signal quality will be not scheduled and hence be outage directly.

In figure 11, the total system effective throughputs of our proposed strategies are shown. We can see that our proposed strategies show much better performance than the max RSRP when the offered load per channel is very high. And the effective throughput gain will become much larger as the offered load per channel increases. The reason for that is our proposed strategies just make the arrived call of UE which has the high signal quality be scheduled and get serving, while in conventional schemes, the arrived call of UE will be scheduled and serving once BS has available channels.

Ⅶ. Conclusion

In our works, we proposed two new call solution strategies for the defined type 1, 2, 3 UEs (for type 3 UEs: adaptive bias based scheme (ABBS) and channel based scheme (CBS)), with the proposed fractional frequency partitioning reuse scheme to evaluate system performances at the macro-pico cells deployments for HETNET downlink transmission. We compared the system performances between the two proposed solution schemes and Max RSRP cell selection scheme in terms of resource utilization in both macro and pico, system call blocking probability, system outage probability and system total effective throughputs. The simulation results show that the system performances are enhanced with our proposed schemes due to driving more edge macrocell UEs to offer load to be served by neighbour picocells, comparing to the traditional scheme – Max RSRP scheme. There are both pros and cons for the two proposed strategies. The advantages of the proposed strategy 2 become more notable because of more type3 UEs connect to picocell than that of proposed strategy 1 in term of call blocking probability, outage probability, effective throughput. while for the perspective of overall channel utilization, the proposed strategy 1 is the competitive choice. when the proposed strategy 1 is applied, many additional benefit of per channel utilization in each picocell will be granted with very little wastage of per channel utilization in macrocell.

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