Exploiting Multi-homing in Hyper Dense LTE Small-Cells Deployments

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***Abstract*—It is expected that in two-tier LTE heterogeneous networks, an extensive deployment of small cell networks (SCNs) will take place in the near future, especially in dense urban zones; hence a hyper density of SCNs randomly distributed within macro cell networks (MCNs) will emerge with many overlapping zones of neighboring SCNs. Therefore, the problems of interferences in co-channel deployment will be more complicated and then the overall throughput of downlink will substantially decrease. In order to mitigate the effect of interferences in a hyper density of SCNs scenarios, a solution based on a fully distributed algorithm for sharing time access to SCNs and multi-homing capabilities of macro cellular users is proposed to improve the overall data rate of downlink and at the same time to satisfy QoS throughput requirements of macro and home cellular users. Our tentative scheme will also reduce the signaling overhead due to the absence of coordination among small base stations (SBSs) and macro base station (MBS). Results validate our solution and show the improvement attained in a hyper density of SCNs within MCNs compared to open, closed and shared time access mechanisms based on single network selection.**

***Index Terms*—Small Cell Network (SCN), Macro Cell Network (MCN), Base Station (BS), Co-channel, Long Term Evolution (LTE), Multi-homing.**

I. Introduction

The demand for ubiquitous wireless access network and the need for high data rates are growing significantly with the omnipresence of demanding applications such as online gaming, mobile TV, Web 2.0, streaming contents, ... etc. These new services require a high rate on the bit per square kilometer that is expected to be delivered by the next generation wireless networks like LTE and WIMAX.

The operators are urged to create new ways for improving their coverage, enhancing their network's capacity, and reducing their costs of their mobile networks. A promising way to solving this problem is the use of SCNs that are considered as a novel networking paradigm based on the idea of deploying short-range, low-power, and low-cost base stations operating in conjunction with the main MCN infrastructure. SCNs are expected to provide high data rates for the next generation 5G networks, tolerate offloading traffic from the MCN, providing high capacity to homes, enterprises, or urban hot spots. SCNs are also envisioned to pave the way for a plethora of new wireless services and cover a range of cells such as micro, pico, metro, and femto cells as well as advanced wireless relays, and distributed antennas that can be installed practically everywhere.

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SCNs have also attracted the attention of standardization bodies, e.g., the 3rd Generation Partnership Project (3GPP) [1], Long Term Evolution (LTE) and LTE-Advanced (LTE-A). However, the utilization of SCNs in a realistic environment faces numerous technical challenges and issues that need to be dealt with on various network layers.

II. Motivation and related work

The success of using SCNs will lead to a proliferation of SBSs within MCNs, especially in hyper dense urban zones like downtowns, malls, residences, metropolis, ...etc, as shown in Fig.1. Accordingly, a large number of overlapping zones

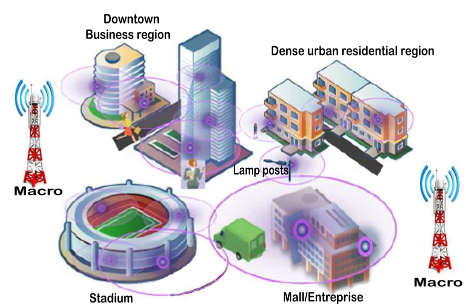

Fig. 1. Hyper-dense SCNs deployments scenario.

of SCNs shows up. The extent of the overlapping depends on the closeness of SBSs to each other (i.e the totally overlapping zones covered by SBSs installed in the flats that take the same position in each floor of the building, while partially overlapping zones occur among neighboring SCNs). The overlapping zones of SCNs have a serious impact on the degradation of the overall capacity of two-tier heterogeneous networks due to the gravity of interferences, particularly in co-channel deployments.

In two-tier heterogeneous networks, interferences are classified as follows:

- Cross-tier interferences are caused by an element of the small cell tier to the macro cell tier and vice versa (see Fig.2).
- Co-tier interferences occur between elements of the same tier, for example, between neighboring small cells. (see Fig.3).

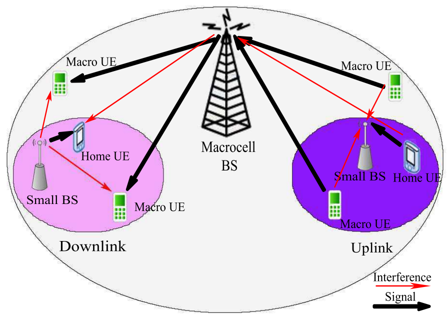

Fig. 2. Cross-tiers interferences in LTE two-tier networks.

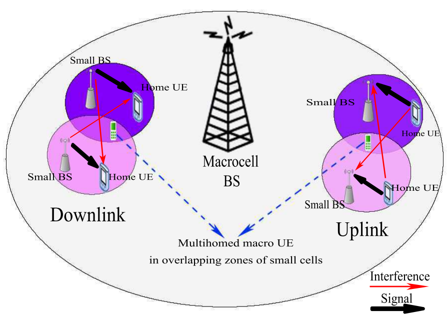

Fig. 3. Co-tiers interferences in LTE two-tier networks.

Furthermore, the selection of an access control mechanism to SCNs has dramatic effects on the performance of the overall network, mainly due to its role in defining the degree of interferences. Different approaches have been proposed:

- Closed access: only a subset of the users (home users), which is defined by the small cell owner, can connect to the SCN.
- Open access: all customers of the operator have the right to make use of any SCN.

In closed access, only registered home users can communicate with the SBS. It seems to be efficient to the home user, however it results in severe cross-tier interference from nearby macro users to home users in the uplink and to nearby macro users from SBS in the downlink. To mitigate these interferences in closed access, previous studies have considered power control [2], fractional frequency reuse techniques [3], and a spectrum sensing approach [4]. An alternative is to provide an access to the nearby macro users that cause or experience strong interference to the SCN. This is known as open access.

In the case of uplink, open access is generally preferred by home users and macro users [5]. In the case of downlink, the closed access mode is favorable for home users while macro users prefer the open access mode. To resolve the conflict in the case of downlink, a shared time access has been suggested as a compromise between home users and macro users to maximize the network throughput subject to a network-wide QoS requirement [6]. All these cited works are adapted to a single network selection in which macro indoor cellular users have the possibility to use the service of the MBS in closed access policy to SCNs or to use the service of a single SBS in open access and shared access policy. This is due to the scenarios of simulation which assume that each SBS does not overlap with another SBS.

Nonetheless, in hyper dense urban areas, where SBSs are deployed randomly, a large number of overlapping zones of SCNs will appear and a lot of macro indoor cellular users will be inside these zones. Consequently, they face difficulties in taking their decisions, especially in open mode and shared mode access policy in the way that each macro indoor cellular user will be able to select a single SBS among all available SBSs implied in the overlapping zones.

In the single network selection, a cellular user takes its required bandwidth from the best wireless access network available at its location. The selection decision of a cellular user is based on a predefined criterion like RSS [7] and available bandwidth [8] to choose the best available wireless access network. One drawback of single network selection is that the available resources from different networks are not fully exploited. Another drawback is that an incoming call is blocked if no network in the service area can individually satisfy the required bandwidth by that call. In addition, a congestion network occurs if all cellular users choose the best network at the same time [9].

Oppositely, with multi-homing capabilities, a cellular user can maintain multiple simultaneous associations with different networks. Therefore, the multi-homed cellular user obtains its required bandwidth from all networks BS(s)/AP(s) available at its location using its multi-homing capabilities. This has the benefit of supporting applications with high required data rate through aggregating the offered resources from different networks and using multiple threads at the application layer. Also, it allows for mobility support, since at least one of the used radio interfaces will remain active during the call duration. Moreover, the multi-homing concept can reduce the call blocking rate and improve the system capacity. A large set of research work has been conducted to support the multi-homing access. Convex optimization formulation in [10] for both Constant Bit Rate (CBR) and Variable Bit Rate (VBR) services is used in multi-homing access. Multi-homing of users to access points in WLANs in [11] has been studied using a potential game model and study its equilibrium. The work in [12] deals with a cost minimization problem for a multi-homed mobile terminal that downloads and plays a Video-on-Demand (VoD) stream. Another work [13] model the communication between multi-homed terminals as a multicriteria non-cooperative game so as to achieve performance-cost decision frontiers.

The major contributions of this paper can be summarized as follows:

- Our model takes into account the study of downlink in a high density of SCNs with many overlapping zones of neighboring SBSs for LTE two-tier heterogenous networks.
- A solution based on a fully distributed shared time access algorithm and multi-homing access capabilities of macro cellular users (Multi-homed devices) has been used to improve the overall network throughput and QoS throughput requirements of cellular users.
- Our solution requires no coordination among SBSs and MBS and therefore reduces the huge signaling overhead of the whole system in hyper dense zones.

III. System model analysis

A. Two-tier Cellular Network Model

In our model, we focus the study on the downlink of an LTE system. We assume that orthogonal multiple access uses TDMA scheduling or OFDMA, consequently no intra-cell interference is raised. We consider a single LTE macro cell M with radius R_M centred at an MBS (Macro Base Station) and a variable number of LTE SBSs (called Femto BSs) N_s distributed uniformly within the area covered by macro cell M. The MBS and SBS use fixed transmit powers of P_M and P_s, respectively. N_m macro cellular users are randomly distributed within the area of macro cell M and $n_{s,i}$ users are randomly distributed within the serving SBS_i. We consider a co-channel deployment when all SCNs and the MCN use the same band frequency. In our study, we take into consideration the cross-tier interferences between each SCN and MCN, co-tiers interferences among SCNs and a path loss and propagation models in order to estimate the SINR in the downlink for each user. For more details and to study different access mechanisms, we divide all the users in three categories, home users or SBS owners, macro indoor cellular users and macro outdoor cellular users.

$$N_m = N_{m_{(out)}} + N_{m_{(in)}} \tag{1}$$

N_m: represents the total number of macro cellular users.
$N_{m_{(in)}}$: represents the number of macro indoor cellular users who are under SBS and MBS coverage.
$N_{m_{(out)}}$: represents the number of macro outdoor cellular users who are under MBS coverage only.

$$N_{m_{(in)}} = \sum_{i=1}^{N_s} n_i \tag{2}$$

n_i : represents the number of macro indoor users in the area of a SBS_i.
N_s : represents the total number of SBSs within the MCN.
$n_{s,i}$: represents the number of home users in the area of a SBS_i.

B. SINR analysis in closed and open access policy

In our analysis, the estimation of the received SINR $\gamma_{m_{out}}$ of a macro outdoor user m_{out} in the downlink, when the macro user is interfered from all the adjacent SCNs, is expressed by the following equation:

$$\gamma_{m_{out}} = \frac{P_{M,k} G_{m,M,k}}{N_0 \triangle f + \sum_{j=1}^{N_s} P_{s_j,k} G_{m,s_j,k}} \tag{3}$$

where $P_{M,k}$ is the transmit power of serving macro cell M on sub-carrier k. $G_{m,M,k}$ is the channel gain between macro user m and serving macro cell M on sub-carrier k. Similarly, $P_{s_j,k}$ is the transmit power of neighboring SBS_j on sub-carrier k. $G_{m,s_j,k}$ is the channel gain between macro user m and neighboring SBS_j . N_0 is a white noise power spectral density, and $\triangle f$ is sub-carrier spacing.
The estimation of the received SINR in the downlink $\gamma^i_{m_{in}}$ of a macro indoor user m_{in}, located inside the coverage of a SBS_i is given by :

$$\gamma^i_{m_{in}} = \begin{cases} \frac{P_{M,k} G_{m,M,k}}{N_0 \triangle f + \sum_{j=1}^{N_s} P_{s_j,k} G_{m,s_j,k}} \text{Closed access} \\ \frac{P_{s_i,k} G_{h,s_i,k}}{N_0 \triangle f + P_{M,k} G_{h,M,k} + \sum_{j \neq i}^{N_s} P_{s_j,k} G_{h,s_j,k}} \text{Open access} \end{cases} \tag{4}$$

$P_{s_i,k}$ is the transmit power of SBS_i. $G_{h,s_i,k}$ is the channel gain between home user h and the SBS_i.
In the case of a home user h of a SBS_i interfered the MCN and adjacent SCNs, the received SINR in the downlink γ^i_h can be given by :

$$\gamma^i_h = \frac{P_{s_i,k} G_{h,s_i,k}}{N_0 \triangle f + P_{M,k} G_{h,M,k} + \sum_{j \neq i}^{N_s} P_{s_j,k} G_{h,s_j,k}} \tag{5}$$

C. Data rate analysis in closed and open access

Having estimated the SINR, we can now proceed with the data rate calculation. The practical data rate $r_{m_{out}}$ of macro outdoor user m_{out} can be given by the following equation :

$$r_{m_{out}} = \begin{cases} \frac{\triangle f . B_{dl} . \log_2(1+\delta \gamma_{m_{out}})}{N_m} \text{Closed access} \\ \frac{\triangle f . B_{dl} . \log_2(1+\delta \gamma_{m_{out}})}{N_m - N_{m_{(in)}}} \text{Open access} \end{cases} \tag{6}$$

B_{dl} : is the bandwidth occupied by the data sub-carriers in the downlink. δ : is a constant for target Bit Error Rate(BER), and defined by $\delta = \frac{-1.5}{\ln(5BER)}$.
The practical data rate $r^i_{m_{in}}$ of macro indoor user m_{in}, located inside the coverage of a SBS_i can be given by the following equations :

$$r^i_{m_{in}} = \begin{cases} \frac{\triangle f . B_{dl} . \log_2(1+\delta \gamma^i_{m_{in}})}{N_m} \text{Closed access} \\ \frac{\triangle f . B_{dl} . \log_2(1+\delta \gamma^i_{m_{in}})}{n_{s,i} + n_i} \text{Open access} \end{cases} \tag{7}$$

The practical data rate r_h^i of a home user h in SBS_i can be given by the following equations:

$$r_h^i = \begin{cases} \frac{\triangle f.B_{dl}.\log_2(1+\delta\gamma_h^i)}{n_{s,i}} \text{Closed access} \\ \\ \frac{\triangle f.B_{dl}.\log_2(1+\delta\gamma_h^i)}{n_{s,i}+n_i} \text{Open access} \end{cases} \tag{8}$$

IV. Our Solution : Shared time and Multi-homing access policy

A. Shared time access policy analysis

We consider the shared time access where a SBS_i allocates α_i fraction of time-slots to home users and the remaining $(1-\alpha_i)$ fraction of time-slots to macro indoor users in the downlink. Due to the absence of the coordination among SBSs and MBS, each SBS tries to maximize selfishly its throughput capacity of downlink and satisfies the QoS throughput requirements of home users. The time-slot allocation problem to maximize the overall network throughput of each SBS_i is formulated as :

$$\begin{aligned} C_{SBS_i}^{total} &= \alpha_i.\sum_{h=1}^{n_{s,i}} r_h^i + (1-\alpha_i).\sum_{m=1}^{n_i} r_{m_{in}}^i \\ &= \alpha_i T_{total}^{h,i} + (1-\alpha_i) T_{total}^{m_{in},i} \end{aligned} \tag{9}$$

$\alpha_i \in [0,1[$
In the shared time access, we have :

$$r_h^i = \frac{\triangle f.B_{dl}.\log_2(1+\delta\gamma_h^i)}{n_{s,i}} \tag{10}$$

$$r_{m_{in}}^i = \frac{\triangle f.B_{dl}.\log_2(1+\delta\gamma_{m_{in}}^i)}{n_i} \tag{11}$$

Maximize $\alpha_i T_{total}^{h,i} + (1-\alpha_i) T_{total}^{m_{in},i}$ ***subject to*** $\alpha_i.\frac{T_{total}^{h,i}}{n_{s,i}} \geq \Omega_h^i$ ***and*** $(1-\alpha_i).\frac{T_{total}^{m_{in},i}}{n_i} \geq \Omega_m^i$
-Ω_h^i : represents the average throughput requirement of a home user h in SBS_i.
-Ω_m^i : represents the average throughput requirement of a macro user m in SBS_i.

Theorem 1

The optimal value α_i^* of the time allocation of a SBS_i is given as :
- if $T_{total}^{h,i} \geq T_{total}^{m_{in},i}$

$$S_1 = \alpha_i^* = 1 - \frac{\Omega_m^i.n_i}{T_{total}^{m_{in},i}} \tag{12}$$

this solution S_1 is feasible if $\alpha_i^* \geq \frac{\Omega_h^i.n_{s,i}}{T_{total}^{h,i}}$
- if $T_{total}^{h,i} < T_{total}^{m_{in},i}$

$$S_2 = \alpha_i^* = \frac{\Omega_h^i.n_{s,i}}{T_{total}^{h,i}} \tag{13}$$

If $\alpha_i^* = 1$, it will act as a closed access SBS.
The algorithm proposed is based on Theorem 1 and executed by each SBS to search the optimal values of sharing time access α_i^* for each SBS_i in order to maximize the total throughput of users inside SBS, and to satisfy the QoS throughput requirements of home users and existing macro users inside the coverage of SCNs.

Algorithm 1 : Fully Distributed Algorithm for Sharing Time Access

```
α_i^*=1 (closed mode is activated by default in each SBS)
- each SBS sensing periodically for macro users in the area of its coverage
if (Exists)
    Input parameters : n_i, n_{s,i}, Ω_h^i, Ω_m^i ;
    get T_total^{h,i}
    get T_total^{m_in,i}
    if (T_total^{h,i} ≥ T_total^{m_in,i}) Then
        α_i = 1 − (Ω_m^i.n_i) / T_total^{m_in,i}
        if (α_i ≥ (Ω_h^i.n_{s,i}) / T_total^{h,i}) Then
            α_i^* = α_i
        end if
    else
        α_i^* = (Ω_h^i.n_{s,i}) / T_total^{h,i}
    end if
end if
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B. Multi-homing access analysis of macro cellular users

In the previous section, the shared time access policy was analyzed. In this section, we add to this analysis the multi-homing capabilities of macro cellular users. With these capabilities, macro cellular users located in overlapping zones of SCNs can maintain multiple simultaneous associations with different SCNs due to their multiple homogeneous radio interfaces. Hence, in multi-homing radio resource allocation, the macro cellular user obtains its required traffic from all available SBSs at its location using its multiple homogeneous interfaces. This has the advantage of supporting applications with high required data rate through aggregating the offered resources from different networks. The total downlink throughput capacity of a macro indoor cellular user $T_{m_{in}}$ with multi-homing capabilities located in an overlapping zone covered by a set of SBSs noted N_{over} is formulated as:

$$\begin{aligned} T_{m_{in}} &= \sum^{i \in N_{over}} (1-\alpha_i^*).\frac{\triangle f.B_{dl}.\log_2(1+\delta\gamma_{m_{in}}^i)}{n_i} \\ &= \sum^{i \in N_{over}} (1-\alpha_i^*).r_{m_{in}}^i \end{aligned} \tag{14}$$

V. Results and simulations

The simulations are event-based and developed according to 3GPP standards. The simulations' scenario is given in Fig.4. The plotted values are an average of 10000 independent simulations using Matlab. The assumed system parameter for the simulations is given in Table 1.

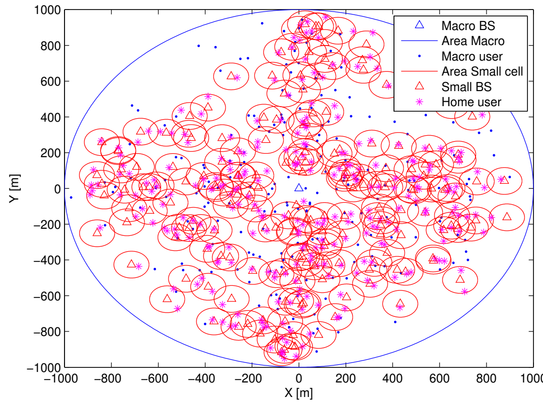

Fig. 4. Simulation of a hyper density deployments of SCNs scenario.

TABLE I
SIMULATION PARAMETERS

Parameter	**Value**
Macro cell Radius (R_m)	1000 m
Small cell Radius (R_s)	75 m
Number of macro cellular users (N_m)	200
Number of home users	1-2
Frequency	2 Ghz
MBS Power P_M	25 W
SBS Power P_s	200 mW
Channel gain G	$10^{\frac{-PL}{10}}$
PL (Path loss)	See formulas in [1]
Indoor Walls Loss (L_{iw})	5 dB
Outdoor Walls Loss (L_{ow})	20 dB
Bandwidth of downlink B_{dl}	20 MHz
Modulation Scheme	64 QAM
Sub-carrier Spacing (Δf)	15 KHz
Bit Error Rate (BER)	10^{-6}
White noise power density (N_0)	-174 dBm/Hz
home user QoS throughput requirements Ω_h^i	1 Mbps
macro user QoS throughput requirements Ω_m^i	0.1 Mbps
Number of homogenous interfaces of macro cellular users	4

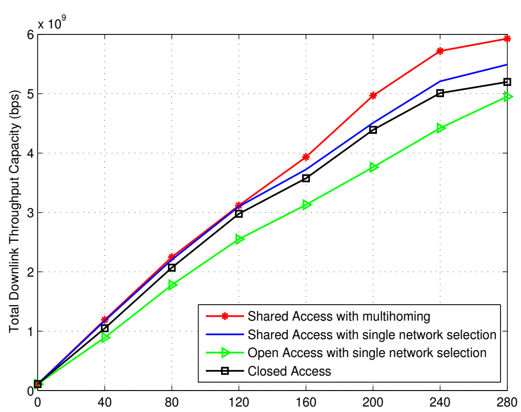

Fig. 5. Total throughput capacity of downlink.

As depicted in Fig.5, the overall throughput capacity of downlink reaches its high level when the shared access policy is used with multi-homing capabilities of macro cellular users. Shared access with multi-homing mitigates the cross-tiers interferences caused by SBS to macro indoor users in closed mode and offloads the MCN. Furthermore, it keeps the QoS throughput parameters of home users degraded in the open mode. Moreover, multi-homing improves the QoS throughput parameter of macro indoor users in overlapping zones with the increasing of SCNs compared to the shared access.

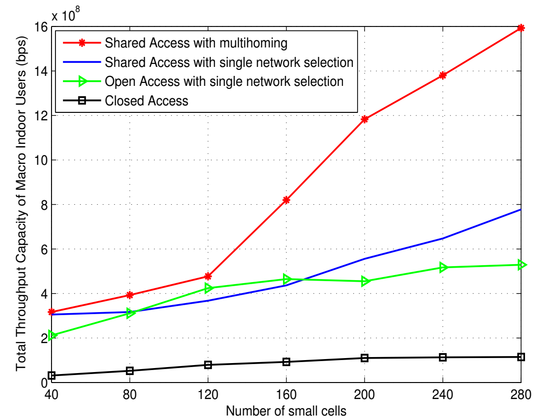

Fig. 6. Total throughput of indoor macro cellular users.

Fig.6 shows the total throughput of macro indoor users in the downlink. Shared mode with multi-homing is the suitable mode for downlink because it mitigates the interferences caused by SBSs to macro indoor users in the closed mode and the degradation of throughput capacity of macro indoor users in the open mode. What is more, multi-homing capabilities of macro indoor users in overlapping zones of SCNs increase the throughput of macro indoor with the increasing of SCNs compared to the shared access. For the reason that the greater the number of SCNs, the greater the number of macro indoor users will be inside overlapping zones.

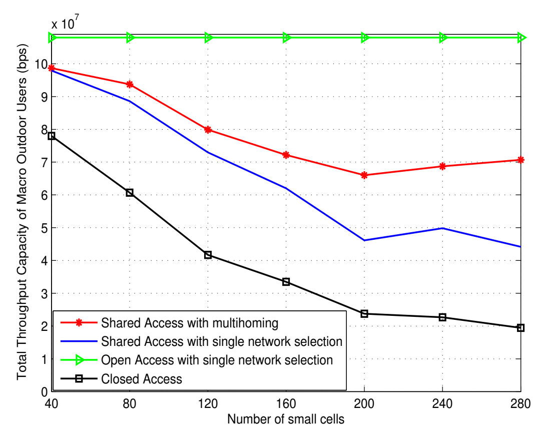

Fig. 7. Total throughput of outdoor macro cellular users.

As depicted in Fig.7, the open access is the appropriate mode for macro outdoor users in downlink because it offloads the MCN by decreasing the number of macro users using the service of MCN and increasing the throughput capacity of macro outdoor users. But, this will be at the expense of QoS throughput requirement of home cellular users that will be degraded in this access mode. In shared and closed mode, the total throughput capacity decreases due to the increase of macro indoor users at the expense of macro outdoor users by increasing the number of SCNs within MCN. Nonetheless, the shared access with multi-homing mode gives best results compared to the closed and shared access due to the simultaneous connections of macro cellular users inside overlapping zones of SCNs.

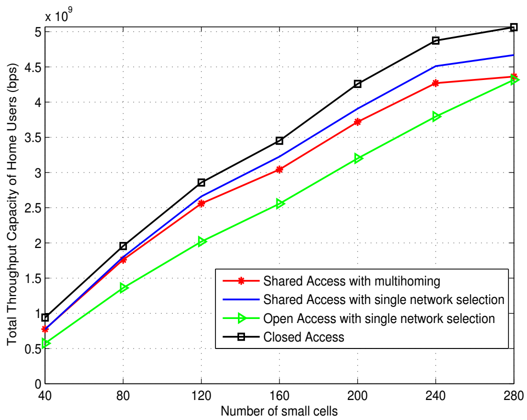

Fig. 8. Total throughput of home users.

As shown in Fig.8, the preferred access policy for home users in the downlink is closed access. Shared access policy and shared access with multi-homing are also suitable modes for home users since they take into consideration the QoS throughput requirements of home users.

VI. Conclusion

In this paper, we have studied the problem of co-channel interferences in hyper dense SCNs deployments within MCNs. Macro cellular users inside overlapping area coverage of SCNs suffer from high degradation of downlink throughput due to severe interferences from SBSs. Our proposed solution which combines shared time access policy and multi-homing capabilities of macro cellular users to SCNs is really promising. In fact, it improves the overall capacity network and QoS throughput requirements of both home and macro cellular users. Multi-homing capabilities of macro cellular users have the substantial advantage of supporting applications with high required data rate through aggregating the offered resources from different SCNs. The results corroborate our proposal and display the improvement reached compared to the open, closed, and shared time access policy based on single network selection. It is noteworthy that future studies can combine our proposal with power control methods to achieve far better results.

VII. Appendix : Proof of Theorem 1

We define a function g of α_i as :
$g(\alpha_i) = \alpha_i T_{total}^{h,i} + (1-\alpha_i) T_{total}^{m_{in},i}$
maximize $g(\alpha_i)$ subject to

$$\frac{\alpha_i . T_{total}^{h,i}}{n_{s,i}} \geq \Omega_h^i \Leftrightarrow \alpha_i \geq \frac{\Omega_h^i . n_{s,i}}{T_{total}^{h,i}} \tag{15}$$

and

$$\frac{(1-\alpha_i) . T_{total}^{m_{in},i}}{n_i} \geq \Omega_m^i \Leftrightarrow \alpha_i \leq 1 - \frac{\Omega_m^i . n_i}{T_{total}^{m_{in},i}} \tag{16}$$

Using (15) and (16)

$$\frac{\Omega_h^i . n_{s,i}}{T_{total}^{h,i}} \leq \alpha_i \leq 1 - \frac{\Omega_m^i . n_i}{T_{total}^{m_{in},i}} \tag{17}$$

$g(\alpha_i) = \alpha_i (T_{total}^{h,i} - T_{total}^{m_{in},i}) + T_{total}^{m_{in},i}$
$\frac{dg(\alpha_i)}{d\alpha_i} = T_{total}^{h,i} - T_{total}^{m_{in},i}$
- if $T_{total}^{h,i} \geq T_{total}^{m_{in},i}$, i.e $\frac{dg(\alpha_i)}{d\alpha_i} \geq 0$ then $g(\alpha_i)$ monotonically increases with increasing α_i, using (17) the solution $\alpha_i^* = 1 - \frac{\Omega_m^i . n_i}{T_{total}^{m_{in},i}}$ this solution is feasible for $\alpha_i^* \geq \frac{\Omega_h^i . n_{s,i}}{T_{total}^{h,i}}$.
- if $T_{total}^{h,i} < T_{total}^{m_{in},i}$, i.e $\frac{dg(\alpha_i)}{d\alpha_i} < 0$ then $g(\alpha_i)$ monotonically decreases with decreasing α_i, then using (17) the solution is $\alpha_i^* = \frac{\Omega_h^i . n_{s,i}}{T_{total}^{h,i}}$

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