XXXI SIMPÓSIO BRASILEIRO DE TELECOMUNICAÇÕES - SBrT2013, 1-4 DE SETEMBRO DE 2013, FORTALEZA, CE

LTE Pico Nodes Indoor Deployment Aspects

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***Abstract*— Technology evolution over the last few years added many demands on mobile networks. To be able to support new requirements and to keep customers satisfied, network operators need to increase the capacity, coverage, and performance of their networks.**

Recently, low power nodes have appeared in the Long Term Evolution (LTE) context as a promising method to satisfy future demands. In this paper, the 3rd Generation Partnership Project (3GPP) indoor pico model for LTE heterogeneous networks is investigated by means of simulations for different scenarios to better understand the impacts of wall penetration on coverage area, load balance and system performance.

It has been found that the coverage area of pico nodes is limited in the indoor environment. In most cases, the transition zone area (i.e., where the optimal cell selections differ in downlink and uplink) is covered by a building wall. Users in an indoor transition zone area have lower degradation in their Signal to Interference-plus-Noise Ratio (SINR) levels compared to users in outdoor area. Since low power nodes are more protected to interference and so have better channel conditions than macro nodes, low power nodes are able to handle a greater traffic load.

***Keywords*— Indoor deployment, heterogeneous network.**

I. INTRODUCTION

In future wireless mobile networks, improvements on network performance and capacity are the main tasks to support the high demands of new services such as video streaming, Internet browsing, and cloud-based services.

Many methods have been taken for such improvements, such as: densifying the macro layer (adding more macro-cells) or improving the macro layer (using higher bandwidth etc). But due to exponential traffic growth and the fact that the radio link performance is approaching the Shannon bound limit, these methods become insufficient and the need for new approaches becomes more demanding [1].

Heterogeneous networks are a new method of deployment, which place low power nodes within macro-cells. It is cost effective, flexible, has ability to increase network capacity and improve users experience. However, in heterogeneous networks deployment, there is a high difference in transmit power between macro and pico nodes. Since the coverage area of macro-cells is much larger than that of pico-cells, there can be an imbalance in the network traffic when many users tend to connect to macro-cells [2]. In this case, many users could be connected to a node that does not have enough resources for all users while other nodes are almost free.

Imbalanced traffic between macro-cells and pico-cells motivates to offload users from macro-cells to pico-cells, which can be done by adding a handover bias to pico-cell Reference Signal Received Power (RSRP) in the cell selection mechanism so that users in a macro-cell preferentially select the pico-cell node even when it is not the strongest cell. In this way, the downlink coverage area is extended depending on the bias value. This method is called Range Expansion (RE) cell selection [3].

By using this new cell selection in heterogeneous networks, more users are offloaded from macro-cells toward pico-cells and so the load balance is improved. The higher the bias value is, the more interference the users in the range expansion area suffer from macro-cells power in the downlink when their SINR levels could be bellow 0 dB. A mechanism of interference coordination between cells should be applied for users in range expansion area in order to improve the offloading gain.

The problem of mitigating interference is more challenging in heterogeneous networks than in homogeneous networks, in which the interference issue can be handled by carefully network deployment and frequency reuse planning. However, in heterogeneous networks, the cell nodes differ from each other in their own characteristics [4]. The use of different backhauls adds more challenges on interference coordination schemes since each backhaul has different bandwidth and delay constraints. Pico-cells and relays are using X2 interface for exchanging signals, while femtocells use third party backhaul connection such as Internet (xDSL), in which the delay might be an important issue to be considered [5].

A previous work [6] has addressed the outdoor pico deployment aspects and showed the advantage of capturing hotspot traffic to achieve load balance between nodes and higher performance. In this paper, deployment aspects of indoor pico nodes for heterogeneous networks are addressed. The main contribution is to investigate effects of wall penetration on load balance, coverage area and system performance.

In the remainder sections, the paper is organized as follows. In Section II, the simulator assumptions are described. Pathloss analysis for pico coverage is presented in Section III. In Section IV, the main simulation results are presented and discussed. Finally, conclusions and perspectives are drawn in Section V.

II. SIMULATOR ASSUMPTIONS

The model-1 of the indoor pico deployment defined in [7] is implemented and investigated using a Matlab based simulator provided by Ericsson Research AP. Two environments considering different Inter Site Distance (ISD) systems have been considered. For the former, the ISD is 500m with carrier frequency equal to 2GHz and for the latter the ISD is 1732m with carrier frequency equal to 700MHz. Two deployment positions are investigated: 0.5 and 1.5 times the macro radius,

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which is given by $\text{Radius}_{\text{macro}} = \text{ISD}/3$ for 3-sector sites. The optimal cell selections for both downlink and uplink, i.e, RSRP and minimal pathloss, are used.

The model consists of a single floor, where the floor height is 6 meters. The floor contains 16 rooms of 15m x 15m, each one with a long hall of 120m x 20m. Two pico nodes are placed in the middle of hall at 30m and 90m with respect to the right/left side of the building, as depicted in Figure 1.

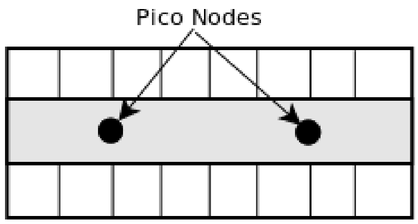

Fig. 1. Sketch of indoor hotspot environment.

The model includes the sub-carrier frequency modeling and multipath dependent loss, wall penetration loss and shadowing. Distance dependent path-loss parameters are adjusted for each frequency band. Shadowing correlation is 0.5 within each layer, but 0 between the layers. In uplink and downlink, both fairness as well as channel quality are considered for scheduling users. The macro station power is 46dBm and the pico station power is 30dBm. Power control is applied in the uplink by targeting a received signal to noise ratio of 10dB with a fractional compensation $\alpha = 0.8$. Antenna configuration used is 2x2 Multiple Input Multiple Output (MIMO) for both base stations and user terminals with cross polarized antennas. The enhanced Inter-Cell Interference Coordination (eICIC) is not considered in the simulator.

The system consists of 9 macro cell plans and wrap-around to eliminate unwanted border effects. Each macro cell has 25 full-buffer users. A percentage of total users within each cell are clustered as a hotspot and remaining users are uniformly distributed over the whole cell plan. The hotspot zone has the same size and center of building.

In the first case, the reference deployment @ 0.5 times macro radius is investigated with hotspot density equal to 50%. In the second case, exact system parameters as reference case are used but distance between macro node and building is varied to 1.5 times macro radius. Finally, exact system parameters as reference case are used but hotspot density within the building is varied for lower and larger values than in reference case. Figure 2 shows the deployment scenarios considered: reference case @ 0.5 and another case @ 1.5.

III. Pathloss Analysis for Pico Coverage Area

The coverage area of indoor pico node in different positions related to macro node is illustrated by a path-loss analysis for one macro node path-loss and one pico node path-loss excluding fading. In this analysis, wall penetration loss and antenna-gain difference between macro node antennas and pico node antennas are considered. In Figure 3, the path-loss analysis for indoor pico coverage areas considering two

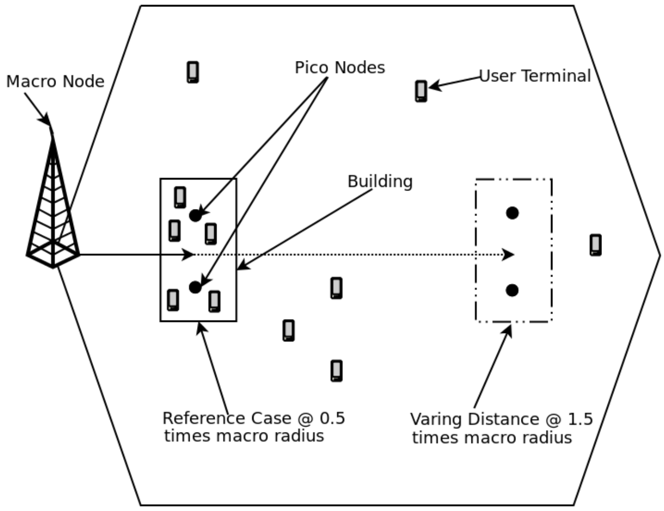

Fig. 2. Deployment Scenarios: reference case @ 0.5 and another case @ 1.5.

deployment positions and two ISD systems (500m and 1732m) are shown. The macro antenna faces the long side of the building.

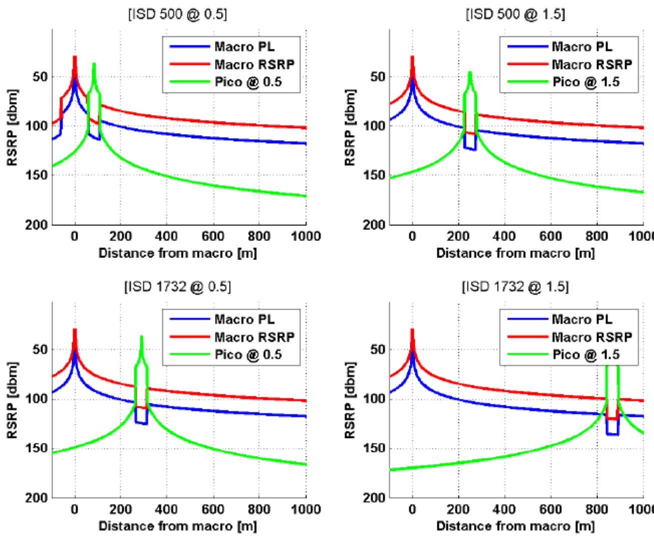

Fig. 3. Pathloss analysis for pico coverage area at different positions with two ISD systems.

As it can be seen in Figure 3, the green lines represent the pico node signal strength at different positions related to macro radius (0.5, 1.5 times $\text{Radius}_{\text{macro}}$). The red lines represent the macro node with RSRP and the blue lines represent the macro node pathloss. The pico coverage area can be seen between the two points where the green lines intersect with red and blue lines.

Due to higher macro node power, lower pico antenna height and building wall penetration loss, the pico coverage area is limited to indoor environment where the transition zone area is hidden within the building wall. The power difference between received signals from macro and pico nodes in indoor is better for pico nodes. Pico nodes provide higher received signal indoor than macro nodes, and it is reversed outdoor. As it can be seen in Figure 3, as the pico nodes move toward the cell-edge, the power difference is improved. The power difference between received signals is maximum for an ISD of 1732m @ 1.5, so that pico users get better SINR levels and thus better performance. It is worth noting that the power difference between received signals by using minimal pathloss is larger in indoor and smaller in outdoor, therefore, coverage area using minimal pathloss as cell selection gives a larger coverage area for pico node.

IV. Simulation Results

In the following, effects of wall penetration on load balance, coverage area and system performance are evaluated. The performance evaluation of the reference case is presented in Section IV-A. Section IV-B investigates the system performance by varying the building position. Finally, the performance assessment is dealt by varying hotspot density in Section IV-C. As both ISD systems have the same relative behavior, as seen in Section III, only results for 500m ISD system are shown in this Section.

A. Reference Case Analysis

For the reference case, 50% of total users are clustered within the building @ 0.5 times macro radius. Figure 4 shows users distribution for this deployment scenario.

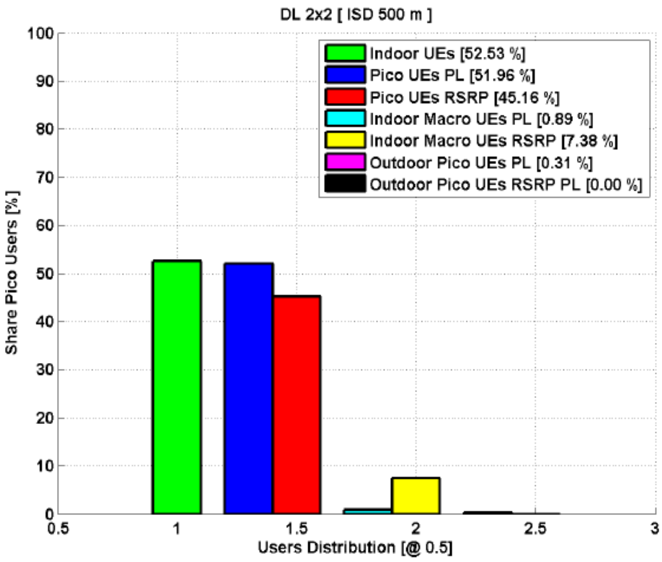

Fig. 4. Users distribution for the reference case.

From Figure 4, using pathloss as cell selection, pico nodes are able to offload more users than by using RSRP since coverage area is larger. However, for both cell selections, pico nodes are unable to offload all the indoor users. The distance between macro node and building is quite small for this position, thus macro nodes have 7.38% of indoor users using RSRP but only 0.89% using pathloss. Most of users in transition zone area are indoor, where there exist only 0.31% from outdoor out of 6.8% (51.96% - 45.16%). Both pico nodes are unable to offload any user from outdoor by using RSRP.

Figure 5 shows downlink bit rates for pico and macro users by using both cell selection schemes in the macro+pico deployment compared with macro users in pure macro deployment.

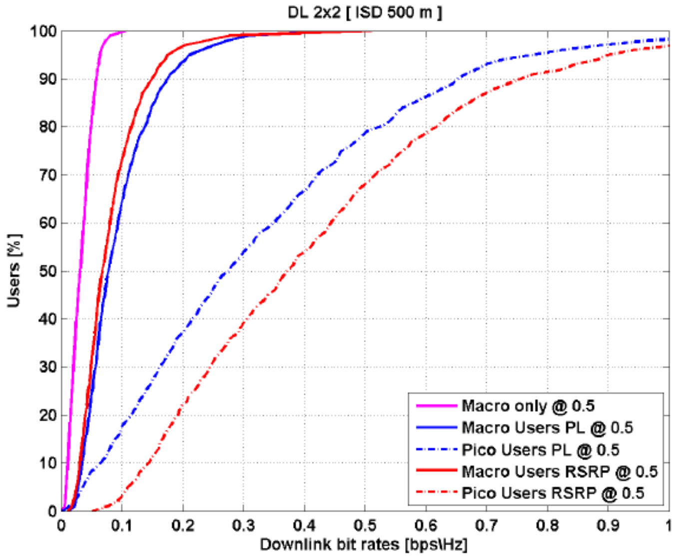

Fig. 5. Downlink bit rates for the reference case.

From Figure 5, downlink bit rates of macro and pico users were improved in macro+pico deployment comparing with a pure macro system. Wall penetration protects indoor users from the macro interference, thus pico nodes have better power difference indoor. Pico users, which are mostly indoor, experienced better channel conditions and so higher downlink bit rates. Pico users with RSRP cell selection have higher downlink bit rates where they are less loaded and optimal for downlink. Macro users in macro+pico deployment have their downlink bit rates improved since macro nodes are less loaded and have more resources per user comparing with macro nodes in a pure macro system. Note that, there is no much degradation for users in transition zone area where they have an acceptable performance since they are indoor.

Figure 6 shows the corresponding uplink bit rates for pico and macro users by using both cell selection schemes in the macro+pico deployment compared with macro users in pure macro deployment.

As it can be seen in Figure 6, most of indoor users offloaded toward pico nodes obtained reduced distance to their serving node and so higher uplink bit rates. Macro users also had their performance improved from less loaded macro nodes. Also, there are no drawbacks for users in transition zone area, since they are connected to the optimal node for uplink.

B. Varying Building Position Analysis

For the second scenario, the same system as in the reference case is considered, but @ 1.5 times macro radius. Figure 7 shows the users distribution by varying the building position @ 1.5 times macro radius.

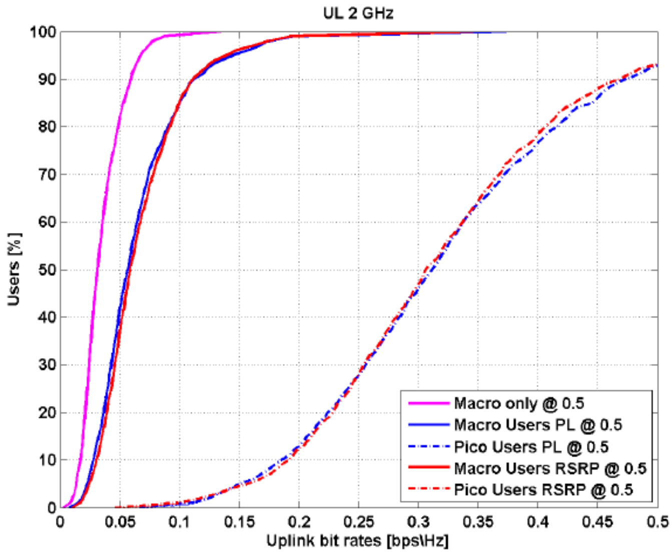

Fig. 6. Uplink bit rates for the reference case.

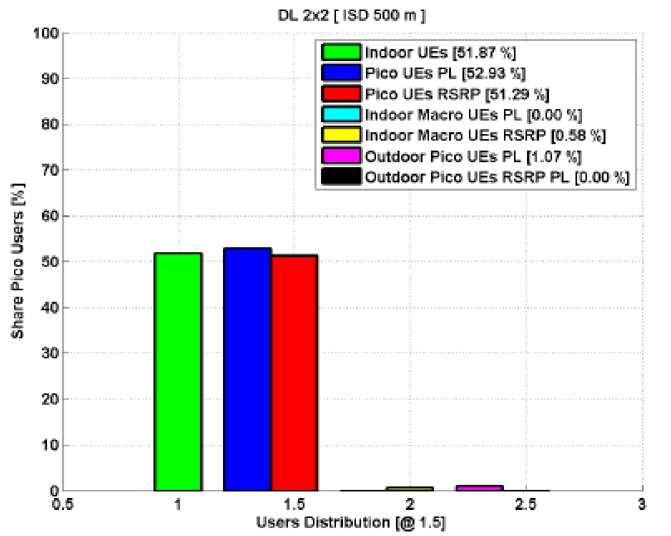

Fig. 7. Users distribution by varying the building position @ 1.5 times macro radius.

From Figure 7, most of indoor users are offloaded toward pico nodes. Indoor macro users are now 0% using minimal pathloss and 0.58% using RSRP as compared with 0.89% and 7.38% respectively, obtained in the reference case. The coverage area for pico nodes has increased when we moved to the cell-edge, where pico nodes are able to offload 1.07% from outdoor compared with 0.31% in the reference case using minimal pathloss.

Figure 8 presents downlink bit rates by varying the building position compared with the reference case.

The effect of moving pico nodes to the cell-edge can be seen from downlink bit rates shown in Figure 8. The downlink bit rates for both macro and pico users were improved. More users are offloaded toward pico nodes, which improves load balance between nodes. Also, power difference between macro and pico nodes were improved and thereby indoor pico users

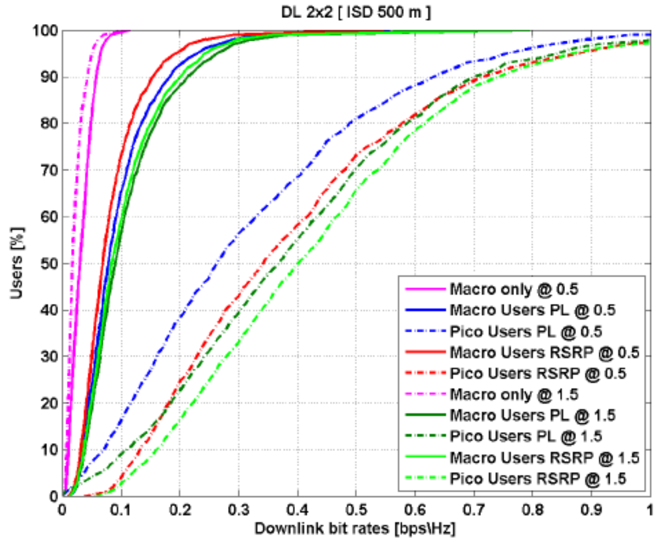

Fig. 8. Downlink bit rates by varying the building position compared with the reference case.

have better channel condition. On the other hand, macro nodes have more resources per user where low rate cell-edge macro users in reference case are offloaded toward pico nodes.

Figure 9 shows uplink bit rates by varying the building position compared with the reference case.

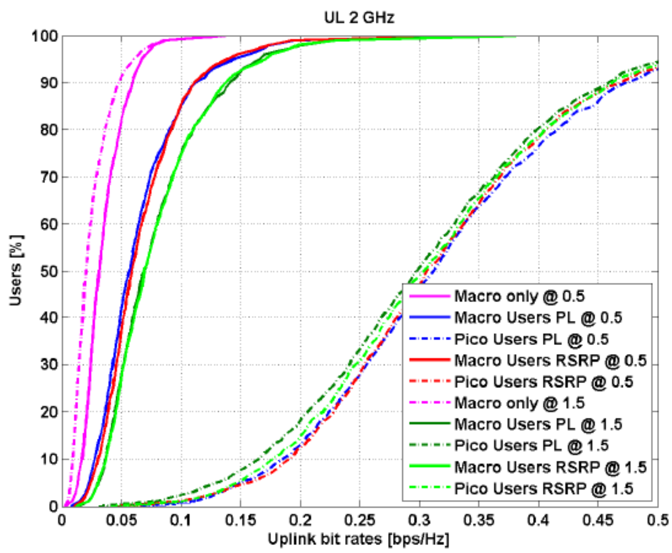

Fig. 9. Uplink bit rates by varying the building position compared with the reference case.

As it can be seen in Figure 9, most of the pico users are indoor in both scenarios and thus they maintain the same distance to the serving node. In varied scenario @ 1.5 times macro radius, macro users close to the building or offloaded from indoor cause a higher interference that affects pico nodes on uplink when compared with the reference scenario. Therefore, pico users have their performance a little degraded in the varied scenario. Also, pico nodes in the varied scenario are more loaded than in reference scenario. Macro users have their uplink bit rates improved since low rate cell-edge users are offloaded toward pico nodes and thus more resources are available per user.

C. Varying Hotspot Density Analysis

In this section, the system performance is evaluated by varying the hotspot density in the same system as in the reference case for different values such as 25%, 75%, and 90%. Figure 10 shows the 50^{th} percentile of downlink bit rates for different systems and by varying the hotspot density with lower and higher values than in reference case.

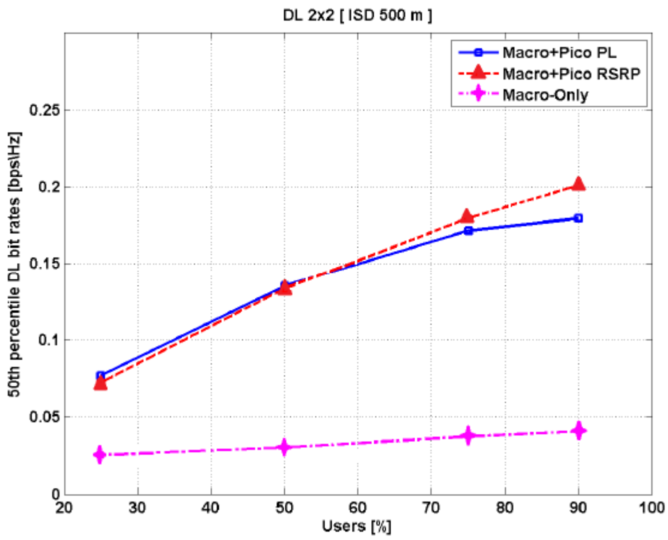

Fig. 10. 50^{th} percentile of downlink bit rates for different systems and hotspot densities.

As shown in Figure 10, the overall system performance is affected when the hotspot density is reduced to 25%. Since pico nodes coverage area is limited to indoor, the pico nodes have load share around 25% while macro nodes 75%. For our system, the number of pico nodes is two times the number of macro nodes, thus this load share between nodes is considered unfair. Therefore, imbalanced load traffic degrades the overall system performance. On the other hand, as the hotspot density increases, the overall 50^{th} percentile of the system improves since load balance between nodes improves. Since pico nodes are more protected indoor, they are able to handle more load share than macro nodes.

Figure 11 shows the 50^{th} percentile of uplink bit rates for different systems and by varying the hotspot density with lower and higher values than in reference case.

As it can be seen in Figure 11, the same discussion for the downlink is valid. As the load balance between nodes is improved, 50^{th} percentile of uplink bit rates for the overall system is improved. But when the hotspot density increased, the number of indoor users offloaded toward macro nodes increased, which cause more interference that affects pico nodes on uplink.

V. Conclusions

Generally, the pico-cell coverage area is controlled by macro-cell power, deployment position and cell selection. In

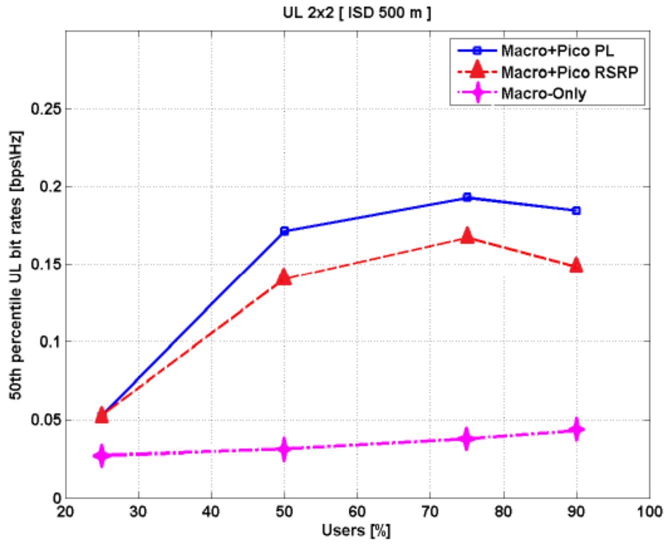

Fig. 11. 50^{th} percentile of uplink bit rates for different systems and hotspot densities.

indoor pico deployment, other factor that controls the pico coverage area is added. Due to wall penetration attenuation, the pico nodes coverage area is limited to indoor. The transition zone area, i.e., where the optimal cell selection differs in downlink and uplink, is to large extent covered by building wall in most of the cases.

Wall penetration usually protects indoor users from macro interference, thus indoor users maintain better channel conditions when compared with outdoor users. Moving building and indoor pico nodes further away from macro nodes, the pico coverage area is increased and the SINR levels of pico users inside the building is improved. Also, load balance between nodes has a larger effect on the system performance. Pico nodes can handle larger load share than macro nodes, since pico nodes have better channel conditions indoor.

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