Neighborhood Small Cells for Hyper-Dense Deployments: Taking HetNets to the Next Level

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ABSTRACT

As mobile data demand continues to increase exponentially due to existing and emerging devices and applications, mobile networks need to prepare for 1000X traffic growth over the next decade. In addition to utilizing more spectrum one powerful technique to address this data demand is through network densification, i.e., provisioning more nodes to serve a geographical area and thereby achieving cell splitting gains. However, traditional operator planned macro and small cell deployments cannot be scaled cost-effectively to achieve network densification due to high site acquisition/rental, backhaul, and RF planning/engineering costs. In this paper, we present a new network deployment model termed “Neighborhood Small Cells” (NSC) consisting of very dense deployment of small cells providing both indoor and outdoor coverage to meet future data demand in a cost-effective manner. This unplanned or semi-planned (in RF sense) deployment model has significant advantages over traditional operator planned deployments. First, it leverages consumer site and backhaul as much as possible, thereby reducing two major contributors to CAPEX and OPEX. Second, the NSC model inherently enjoys an organic growth in capacity by providing capacity where the users are. Third, when accompanied by SON (self-organizing network) algorithms, NSC network can be deployed with no or minimal RF planning in a plug-n-play manner. UltraSON™ is a suite of SON features designed by Qualcomm Research to enable such deployments. NSC model enhances user experience and offers both 3G and 4G network operators a viable solution to address the ever increasing data demand. In this paper we focus on 4G LTE NSC networks.

More information about Qualcomm’s work on small cells can be found at

http://www.qualcomm.com/research/projects/smallcells and

http://www.qualcomm.com/solutions/wireless-networks/technologies/smallcells

1 Introduction

The advent of smartphones has served as catalyst for significant increase in mobile broadband data traffic on cellular networks. The mobile data demand continues to grow exponentially (70-100% annually) [1]. In the not so distant future, there will be a need to support 1000x more mobile data traffic compared to traffic carried by today's cellular networks due to more smartphone and tablet like devices as well as an increase in data consumed per user. This data demand needs to be met at a low cost to the operator as well as the end user to sustain and further fuel wireless data growth. Addressing this 1000x data demand in a cost-effective manner presents formidable technical challenges and requires innovative solutions. Given that today's cellular technology standards are already designed to operate at very high radio link spectral efficiencies (e.g., LTE Rel. 10 has peak downlink spectral efficiency of 30 bps/Hz), radio link level enhancements at PHY/MAC layers alone will not solve the problem. A multi-pronged approach is needed incorporating: 1) Network densification, i.e., deploying more base stations, each with a small coverage footprint, in geographical areas with high data demand, 2) additional spectrum, and 3) significant improvement in system efficiency (e.g., efficient use of existing spectrum, optimal use of multiple technologies concurrently) [2]. In this article, we focus on network densification aspect while pointing the interested reader to [2] for more details on the other two aspects.

Network densification boosts capacity by providing cell-splitting gains due to increased spectrum re-use. In addition, it brings users close to base stations, thereby improving signal to interference and noise ratio (SINR), which provides additional improvement in capacity. However, network densification by deploying more traditional macro-base stations is unviable due to difficulty in finding suitable installation sites as well as high costs of installing/maintaining macro-base stations. Rather, network densification through use of small cells (i.e., base stations with small form factor and low transmit power) is more promising. Offloading users from macro to small cells not only increases overall capacity but significantly enhances experience of both macro and small cell users. Splitting traffic into macro cells and small cells increases the share of available data pipe for all users and thus boosts users data rates. Further, technological advances in the last several years have dramatically reduced the cost of small cells compared to traditional macro cells. Considering these benefits, 3GPP made small cells an integral part of LTE in Rel. 10 (LTE Advanced) by developing the concept of HetNets, i.e., heterogeneous networks consisting of mix of macro cells and small cells (aka pico cells, metro cells). LTE Rel. 12, which is in its study phase, also has small cells as one of the key areas for LTE evolution [3]. Several major operators worldwide are either in process or planning to roll out HetNet deployments to densify their networks in the next few years. Such HetNet deployments consist of a few to tens of small cells deployed by an operator to meet high data demand in specific areas (e.g., malls, downtown areas, event venues). These traditional HetNet deployments can meet near-term mobile data demand, but cannot scale well to meet 1000x data demand of the future. Even though the small cell equipment cost has been dramatically reduced, there are significant hurdles for scalability of such an operator-deployed network densification when deploying hundreds of such cells. Operator driven small cell deployments incur high costs in terms of site acquisition/rental, provisioning of backhaul, and RF planning/engineering for installation. As result, a new network deployment paradigm is needed where wide-spread network densification can be achieved in a low cost manner by removing the aforementioned hurdles. In this paper, we present a new deployment model termed "Neighborhood Small Cells (NSC)" that can achieve this goal.

2 Neighborhood Small Cells (NSC) Network

An NSC network consists of small cells deployed by the end user or an operator with no or minimal RF planning in a variety of places including user residences, small offices, enterprise buildings, public places, lamp posts, cable junction boxes at street corners, etc. Unlike traditional "closed" access small cells (aka femtocells) deployment model[1], NSCs have "open/hybrid" access to serve all subscribers belonging to an operator[2]. Open access small cell deployment has the advantage that users can be served on the best downlink, resulting in better performance [3]. Whether located indoors or outdoors, open access NSCs provide coverage and capacity for both indoor and outdoor users and thus serve the entire neighborhood. An illustration of the NSC network concept is shown in Figure 1. NSCs co-exist with traditional macro network and they can either share spectrum with the macro network or can be deployed on their own dedicated spectrum. As illustrated, NSCs handle indoor user traffic and also serve users passing-by on the street or moving in moderate speed vehicles. A key feature of NSCs is that they provide contiguous coverage and seamless mobility experience to users in the neighborhood by supporting handovers among NSCs as well as between NSCs and macro cells. Users not offloaded to NSCs (e.g., high mobility users) are served by the macro cells.

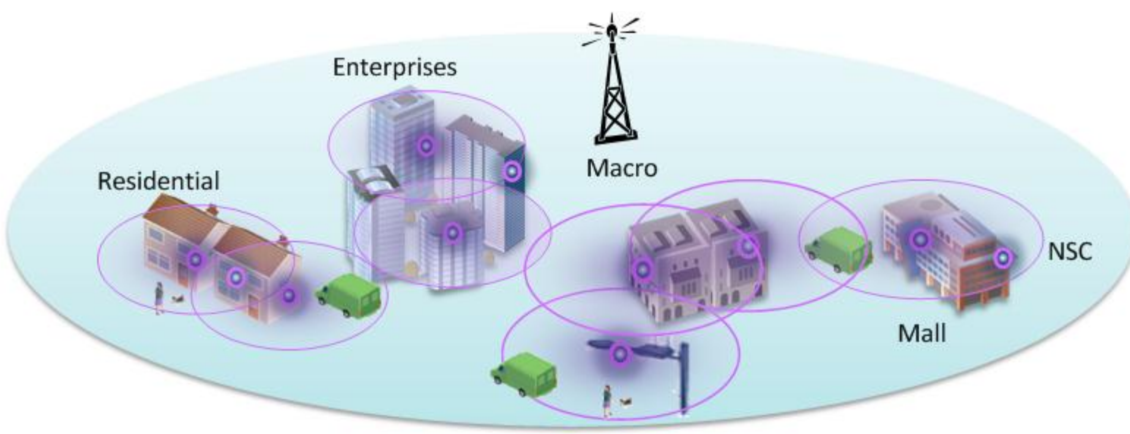

Figure 1 Neighborhood Small Cell Network

Key defining characteristics of a NSC network are 1) they are deployed in unplanned or semi-planned (in RF sense) manner and 2) they leverage existing site and potentially backhaul as well. A robust and easy, plug-and play NSC deployment can be achieved through use of self-organizing network (SON) techniques. Some features of UltraSON™ will be discussed in more detail in later sections.

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[1] With closed access, a small cell serves only a limited set of users who belong to the closed subscriber group (CSG). A closed access small cell acts as interferer for non-CSG users.

[2] Hybrid access is a mix of closed and open access, where a set of users can be given higher priority/preference in terms of offered services and their quality.

Another factor favoring NSC model is its suitability for higher RF bands (e.g., 2.6 GHz, 3.5 GHz), where new licensed spectrum is likely to be available for future use. Traditionally, macro-networks cannot be deployed in higher RF bands due to higher propagation loss in such bands compared to cellular bands. However, NSCs can still provide good coverage and capacity at higher bands due to their smaller coverage footprint requirements. In fact, a dense NSC network, when augmented with additional spectrum, can meet 1000x data demand as we show next through extensive simulations.

2.1 Scability and Cost Benefits

A large portion of today's network deployment and operating cost can be attributed to site acquisition and installation, site rent, and backhaul. Operators have to perform RF planning to find the optimal locations to place macro cell-sites and then send technicians to install them. Backhaul needs to be provisioned if it is not already available. Not only do the above require a lot of effort from the operator but the site rent, utilities, and backhaul are all recurring costs that contribute to high OpEx.

The NSC model eliminates or reduces much of the above costs. While numerous cells are needed to meet the 1000x challenge, each small cell comes with a far lower price tag than does a macro cell. Dense placement of small cells provides coverage redundancy. SON techniques enable small cells to autonomously adapt their transmit power to ensure adequate coverage, thus making extensive RF planning unnecessary. Plug-and-play capabilities of small cells mean end-users can install them without any assistance from the operator. There is no site acquisition required for the deployment of these small cells as end-users' premises can be used. Similarly, existing backhaul at those locations can be leveraged. (Operators may need to incentivize the users for sharing their backhaul with others.) The combination of the above allows operators to grow their network capacity immensely while keeping the deployment costs significantly lower compared to traditional macro or HetNet deployment. At the same time, NSCs can more effectively meet user needs as they are inherently deployed where users and thus data demand are.

Overall, NSCs can be viewed as the next step in HetNet evolution. NSCs complement traditional planned macro and small cell deployments and benefit both operators and users by bringing down the cost of mobile data access.

3 NSC Simulation Model

For comparison of the gains offered relative to a traditional macro network, we assume a baseline 10 MHz LTE Rel. 8 macro-only deployment at 2 GHz. NSCs are deployed on an additional 10 MHz carrier at 3.5 GHz. A 2 GHz macro carrier serves as underlay network for regions where NSCs cannot provide coverage. Effectively, we assume a dedicated channel NSC deployment in-line with expectations that some of the future spectrum will be solely dedicated for small cells. It is worth noting that a co-channel macro plus NSC deployment can also provide gains similar to the dedicated channel case with increasing NSC densification because the channel effectively becomes dominated by NSCs at high NSC density. Also, note that the analysis presented here pertains to downlink (DL) capacity gains obtained with NSCs. Significant gains can be achieved in uplink as well.

To evaluate capacity gains offered by a NSC network, we simulate NSCs in a dense urban city environment with detailed RF propagation modeling for an accurate analysis.

3.1 Dense Urban City Model

The macro-base stations are deployed in a hexagonal layout with inter-site distance of 500 m and follow 3GPP D1 model [5]. A dense urban city is modeled as a collection of rectangular building blocks dropped randomly in a typical hexagonal macro cellular network layout as shown in Figure 2. As per the 3GPP "Dual-stripe" urban model [5], each building block has two multi-floor apartment buildings. Each apartment block is 50 m x 50 m and consists of two buildings (north and south) and a horizontal street of 10 m width between them. The number of floors in each building is randomly chosen between 2 and 6. On each floor, there are 10 apartment units in two rows of five. Each apartment is 10 m x 10 m (i.e., approximately 1076 sq. ft.). Assuming a population density of 20000 population per sq. km and 2 people per apartment, we drop 720 apartments per macrocell (i.e., sector).

NSCs (shown by black asterisk) are dropped randomly in different apartments. NSC location in an apartment is assumed to be random. The density of NSCs is varied to study gains achieved with densification. For reference, at 100% penetration with one NSC per apartment, there are 720 NSCs per macrocell.

User equipment (UEs, aka mobiles) depicted by pink circles are dropped randomly in the city layout. Given that a large portion of data traffic comes from indoor users, 70% of the users are dropped indoors and remaining 30% users are dropped outdoors. NSC and UE locations are assumed to be statistically independent since in a NSC network users can be in the same apartment as the NSC as well as in other indoor and outdoor locations. We assume 25 or 200 simultaneously active UEs downloading data on the downlink. A small number of simultaneous data connections represent a relatively unloaded network while a large number of data connections represent a loaded network at the peak hour of data demand or due to increased number of data connections in the future.

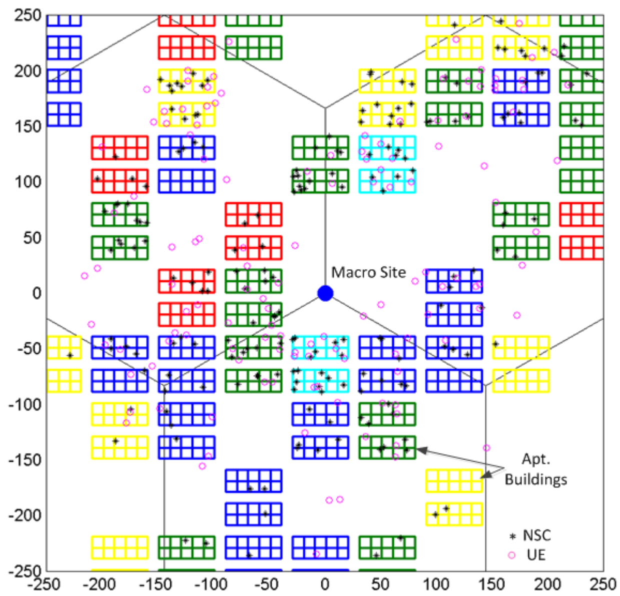

Figure 2 Sample Dense Urban (DU) layout showing apartment buildings (different colors indicate different floors)

3.2 Path Loss Modeling

Once the city layout is created, RF propagation between different cells and UEs is modeled extensively for an accurate assessment of the performance. For links between a macrocell and a UE, standard 3GPP D1 model [5] (path loss exponent of 3.76) is used with 3D antenna pattern and a penetration loss of 20 dB. For links between a NSC and a UE, 3GPP urban dual-stripe model [5] is used with some modification. Indoor links have a path loss exponent of 2 while indoor SC to outdoor UE links have path loss exponent of 3.76. Losses due to internal walls within an apartment and between apartments and external building wall are modeled (internal wall loss is 5 dB; external wall loss is 20 dB). In addition, for UEs inside the building or in a different building, effect of floor losses is modeled as well (floor loss is 18.3 dB). Since 3GPP dual-stripe model is defined at 2 GHz, for NSC deployment at 3.5 GHz we include additional 8 dB path loss for NSC to UE links based on 3.5 GHz vs. 2 GHz field measurements.

3.3 Simulation Parameters

Key simulation parameters for downlink capacity evaluation are listed in Table 1.

Table 1 Key Simulation Parameters

Technology	LTE Rel. 8
Spectrum	Macro-only baseline: 10 MHz @ 2 GHz Macro + NSC: 10 MHz macro @ 2 GHz + 10 MHz NSC @ 3.5 GHz
Transmit Power	Macro: 46 dBm, NSC: 20 dBm
Antenna Configuration	2x2 MIMO
Channel Model	TU3, zero spatial correlation between Tx and Rx antennas
Traffic model	Full Buffer
Scheduler	Proportional fair, frequency selective

Technology	LTE Rel. 8
Association rule	If NSC SINR > -6 dB, a user is associated with the NSC layer. Otherwise it associates with the macro layer.
Interference Modeling	Interference from all cells is modeled. Unloaded cells transmit common reference signal (CRS).

A system level simulator that models link and rate adaptation according to channel conditions is used. Also note that no backhaul limitation is assumed to show the offered over-the-air (OTA) capacity by a dense NSC deployment. In the future, backhaul data rates are also expected to increase and therefore the gains shown here are likely to be achieved.

4 NSC Capacity Results

NSC performance is evaluated in terms of improvement in UE DL throughput or equivalently DL capacity. We focus on DL median and tail (5 percentile) throughput gain achieved with NSC deployment (10 MHz macro + 10 MHz NSC) relative to baseline macro-only (10 MHz) deployment. Performance is evaluated for different NSC penetrations {2,5,10,20,30,50}%, which correspond to {14,36,72,144,216,360} NSCs per macrocell, respectively.

Figure 3 shows gain in DL median throughput for 25 and 200 simultaneously active UEs per macrocell. As evident, significant capacity gain is achieved in both cases. For example, even at moderate penetration such as 10%, DL median throughput gain of ~25x to 55x is achieved with an additional 10 MHz NSC carrier. Gains are attributed to cell splitting as well as improvement in SINR compared to macro deployment as users get closer to their serving NSC. As shown in Figure 4, UEs can achieve significantly higher DL SINR with NSC compared to macro-only deployment due to proximity to NSCs. It is worth noting that some UEs who have slightly reduced DL SINR when offloaded to NSC layer can still achieve better throughput than macro-only scenario because NSCs have significantly reduced loading compared to a macro cell, which otherwise will have to serve all the users.

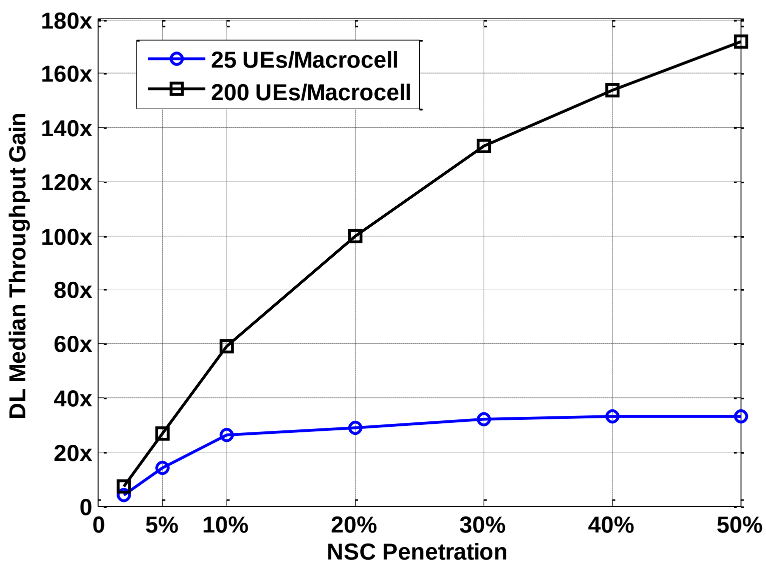

Figure 3 Gains in median DL user throughput for a (10 + 10) MHz NSC deployment relative to the baseline of 10 MHz macro carrier, for 25 or 200 active users per macrocell area

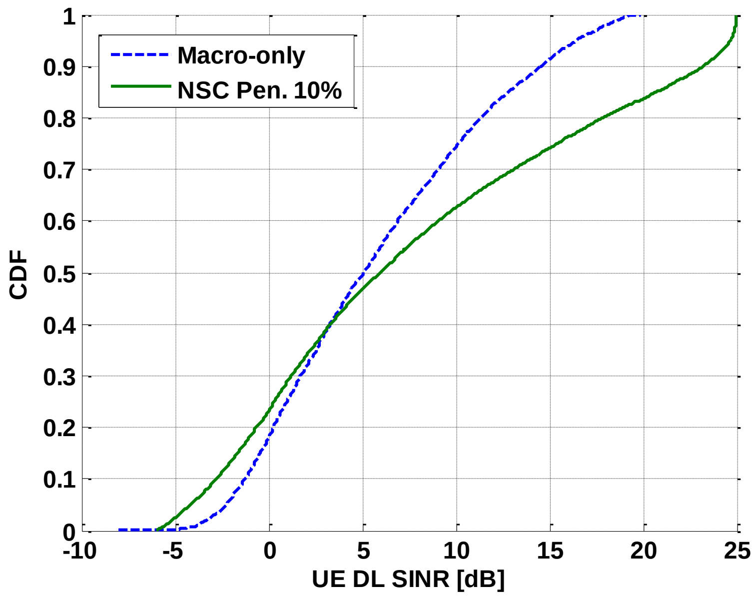

Figure 4 Comparison of UE DL SINR for macro-only deployment vs. NSC deployment with 10% penetration (SINR is computed assuming all cells transmit at their max. Tx power)

Considering the 25 UE case in Figure 3, as NSC penetration increases an NSC serves only one user with high probability. Thus, with increasing NSC penetration full cell splitting is approached and hence throughput gain saturates. With higher loading (200 UEs), gains continue to grow with NSC penetration due to continued cell splitting, i.e., as penetration increases, the average number of UEs associated with one NSC drops. For example, at 20% NSC penetration and 200 UEs we observe close to ~100x median throughput gain in Figure 3.

It is worth noting that reasonably good gain is achieved in median throughput at low NSC penetration (2% onwards) as well. This is because a significant fraction of users can be offloaded to the NSC layer from the macro layer. As shown in Figure 5, more than 50% users can be offloaded to the NSC layer even at low NSC penetration. At high NSC penetration, a majority of the users (~95%) are offloaded to the NSC layer.

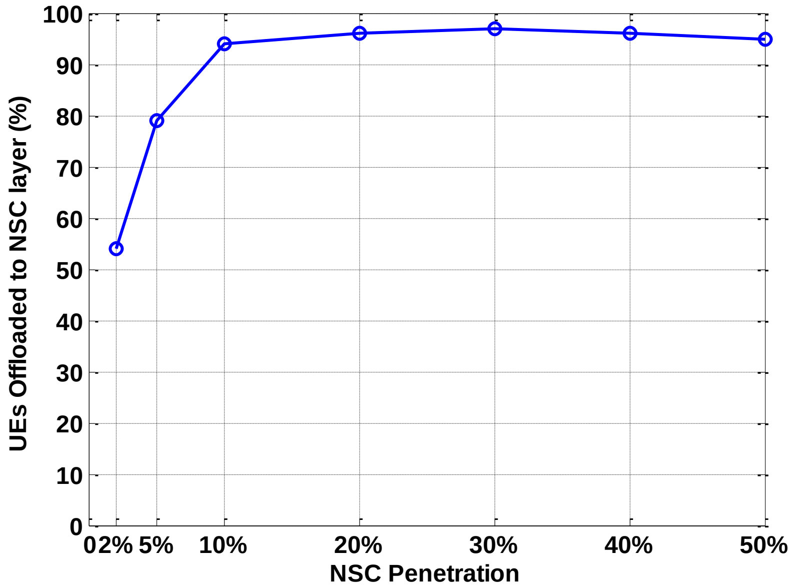

Figure 5 Percentage of UEs offloaded to NSCs as a function of NSC penetration

This significant offloading to NSC layer occurs for both indoor and outdoor users as shown in Figure 5 for 25 active UEs per macrocell scenario. While both indoor and outdoor UEs see significant gains, indoor UEs achieve higher gains with increasing NSC penetration because of two factors. Firstly, with increasing NSC penetration, an indoor UE is more likely to be offloaded to the NSC layer as a close-by NSC can be found. Secondly, indoor UEs experience relatively higher SINR improvement because as they get closer to a serving cell, their serving cell channel quality improves while at the same time they are less affected by interference from other NSCs due to shielding from internal and external walls; outdoor users do not benefit from such shielding.

This analysis shows NSCs provide significant DL median capacity gain for both indoor and outdoor UEs even at low/moderate NSC penetrations. For uniform user experience, it is important to improve performance of all UEs, i.e., it is desirable to have good improvement in tail throughputs as well. This is indeed the case as shown tail throughput gain results in Figure 7. Tail throughput gains of the order of 10x or more are achieved at even moderate (e.g., 5%) NSC penetration. Thus, an NSC deployment results in dramatic system-wide performance improvement.

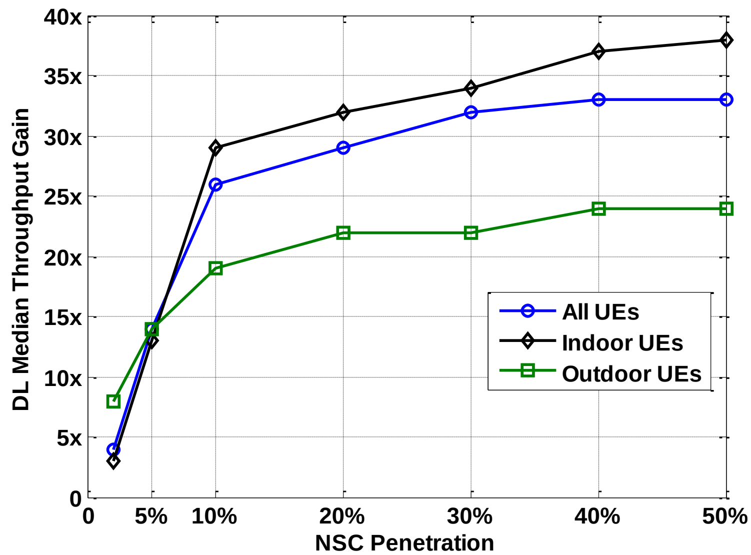

Figure 6 Comparison of indoor and outdoor UE median throughput gains

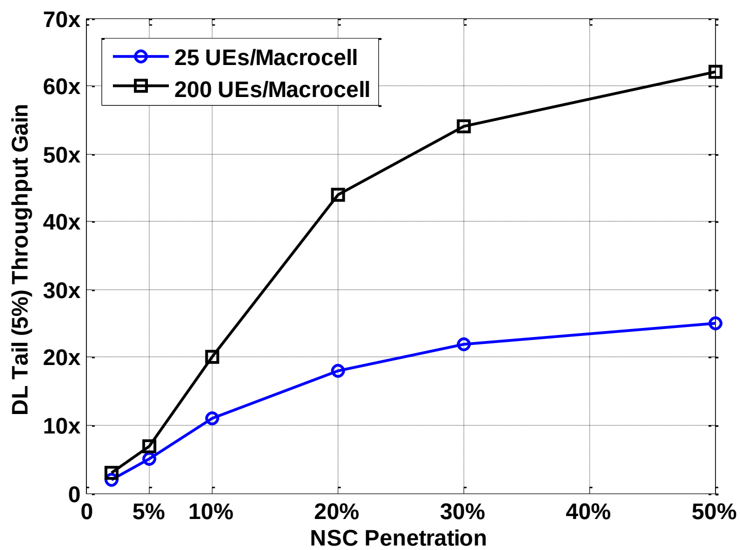

Figure 7 Gains in tail DL user throughput relative to the baseline of 10 MHz macro carrier, for 25 or 200 active users per macrocell area

4.1 Reaching 1000x capacity with NSC

As shown through earlier results, NSC deployment can provide gains of the order of 10-100x when a single 10 MHz carrier is dedicated to NSCs. This suggests that future 1000x data demand can be met by providing additional spectrum to NSCs. Figure 8 shows DL median throughput gain with a NSC deployment of 110 MHz (10 MHz macro + 100 MHz NSC) relative to a baseline 10 MHz macro-only deployment. Note that LTE's carrier aggregation (CA) feature can be used to serve users on wider BW allocated to NSCs.

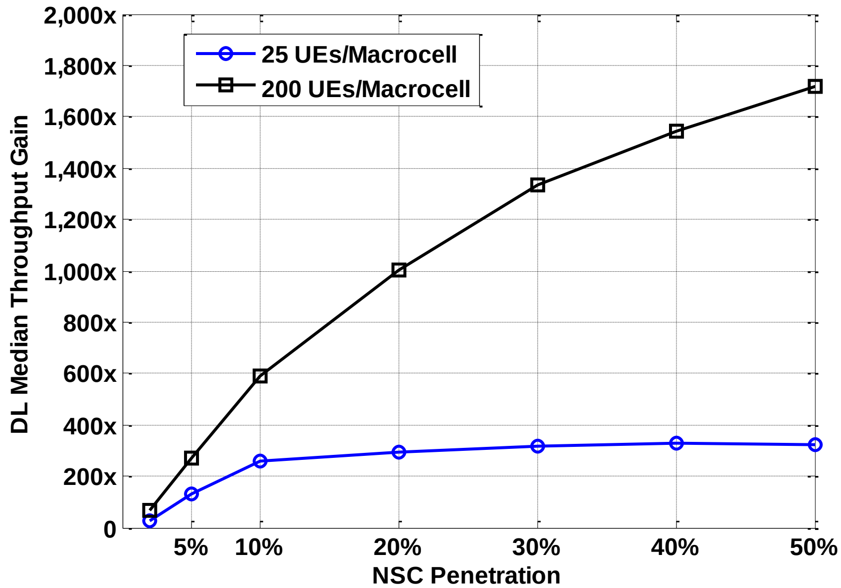

Figure 8 Gains in median DL user throughput for a (10 + 100) MHz NSC deployment relative to the baseline of 10 MHz macro carrier, for 25 or 200 active users per macrocell area

As shown, 1000x DL median capacity gain can be achieved when serving 200 UEs and 20% NSC penetration (~145 NSCs per macro cell). Given the benefits of NSC model and its potential for providing several orders of magnitude higher capacity than traditional macro networks, NSC model will hold the key to meet future data demand. Next, we address deployment requirements and enablers to realize the full potential of this new deployment model.

5 Deployment Challenges and Solutions

The deployment challenges for neighborhood small cells result primarily from the fact that unlike a macro network, the small cells are installed by subscribers without any network planning and site-specific system configuration settings. These devices are required to be plug-n-play with self-configuration capabilities. Another important challenge is to offer seamless mobility within this unplanned network to prevent any service interruption or degradation in user experience. Neighbor discovery and frequent handover mitigations are important to optimize handover performance and reduce signaling load. In addition, transmit power management of small cells is needed to optimize capacity offload while minimizing pilot pollution under dense small cell deployments. Furthermore, radio resource management techniques such as interference coordination and load balancing are important to optimize capacity and user experience. As the small cell backhaul may be shared by other devices, Tx power and radio resource management methods need to take into account backhaul constraints. Also, in order to convince small cell owners to allow access by other users, resource management should give priority to small cell owner's devices, especially under limited backhaul capacity.

5.1 Mobility Management

Effective mobility management is essential for the viability of the neighborhood small cells solution. The mobility management problem basically boils down to ensuring all mobiles, including legacy, are supported in idle and connected modes in a neighborhood small cell network. Figure 9 shows all the various possible transitions a mobile has to traverse through in a neighborhood small cell network in both idle and connected modes: Macro-to-Small Cell, Small Cell-to-Small Cell, and Small Cell-to-Macro.

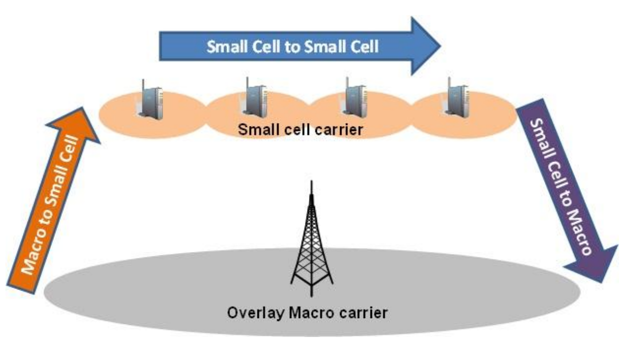

Figure 9 Scenarios for Mobility Management in a Neighborhood Small Cell Network

The following subsections describe various mobility management challenges specific to neighborhood small cell deployment for the scenarios illustrated in Figure 9.

5.1.1 Idle Mobility

5.1.1.1 Discovery

For Small cell-to-Small cell and Small cell-to-Macro mobility, the discovery is not a challenge as it can happen naturally due to channel degradation of the serving cell.

For Macro-to-Small cell mobility, a mobile device needs to discover small cells when it is on the overlay macro network, even in good channel conditions since channel degradation may not happen due to the fact that the small cells are deployed on another frequency. This challenge can be addressed in multiple ways. One method is to configure a higher search threshold on the macrocells. This ensures that the UE searches the small cell frequency even under good macro signal quality. The downside of this approach is some impact on the UE's battery life as the UE will need to perform a search every time it wakes up irrespective of macro signal quality. An alternative approach is to prioritize the small cell frequency. This ensures that the UE searches the small cell frequency at least once every 60xN seconds where N is the number of high priority frequencies. This approach can still enable small cell discovery (although not as fast as having a higher search threshold) and at the same time reduce the impact on the battery life as the UE searches only once per minute. UE autonomous search on the small cell frequency is another method for enabling small cell discovery. By changing the periodicity of these searches, a tradeoff between discovery time and UE battery life can be achieved. However, this requires UE changes. An alternative approach is to use cell reselection beacons to enable small cell discovery. In this approach, the small cell transmits narrow beacon bursts on the macro-only channels to temporarily reduce the macro signal quality and trigger a search when the UE is near the small cell. Proper beacon design can ensure fast discovery while minimizing impact on nearby voice/data users.

In the case where the operators providing the overlay macro network and the neighborhood small cell network are different, the mobile device can be provisioned to search for the home operator in the background. That is, the operator of the neighborhood small cell network can provision its PLMN (Public Land Mobile Network) identifier at the mobile device as Home PLMN (H-PLMN). This would make mobile device periodically (with minimum period of 6 minutes) search for the PLMN of its neighborhood small cell network.

5.1.1.2 Paging Load Optimization

It may not be desirable to let a small cell handle the same paging load as that of a macrocell due to its lower processing power, capabilities and backhaul capacity. Hence, paging optimization schemes are needed to limit the size of the paging area and hence, paging load under the resource constrained small cells. Paging area in LTE is managed by the Tracking Area Code (TAC).

In order to limit the paging area of a small cell to a geographical area covered by one macrocell, all small cells can use the cell identity of their strongest neighboring macrocell to decide on their initial paging area code. Because multiple macrocells are typically associated with a single paging area code, say 'n' macrocells, then by adopting the above scheme, roughly, the paging area under small cells is reduced by the factor of '1/n'.

After this initial selection, if the paging load at any small cell turns out to be greater than what it can handle, the small cell can update its initial selection and select a different tracking area code.

If too many paging areas are created, it can lead to too many UE registrations at paging area boundaries, as whenever a UE enters a new paging area, it needs to perform a registration. To address this problem, the small cell can change its paging area code to be the same as the neighboring paging area, in case it experiences too many frequent registrations from the neighboring paging area.

In LTE, the concept of UE-specific TAC list can also be used to address the issue of frequent registrations at the paging area boundaries. In this concept, if too many registrations from neighboring TACs are received from a UE, then those TACs can be added to the UE's TAC list by MME (Mobility Management Entity). For any of the TACs present in its TAC list, the UE does not perform registrations and is paged on all of them, i.e., the benefit needs to be contrasted with the increase in paging load.

5.1.2 Connected-Mode Mobility

5.1.2.1 Selection of Physical Layer Identifier

Available physical layer identifiers are limited and hence have to be re-used among the cells. In LTE, there are 504 unique Physical Channel Identifiers (PCIs). While re-using these PCIs, there are two main issues to avoid: a) Collision and b) Confusion.

PCI collision occurs when two neighboring cells with overlapping coverage area share the same PCI. This is a serious problem as mobile devices in that overlapping area cannot distinguish between the signals coming from the two cells, causing loss of processing gain, synchronization issues, and high decoding errors.

PCI confusion occurs when PCI reuse happens among the neighboring cells of the same cell. This leads to cell identification problem, where the serving cell is unable to uniquely identify its neighbors from their PCI. Consequently, when a connected mode UE moves towards one of these cells, the serving cell is unable to initiate a handover to the correct cell. Figure 10 illustrates PCI confusion problem.

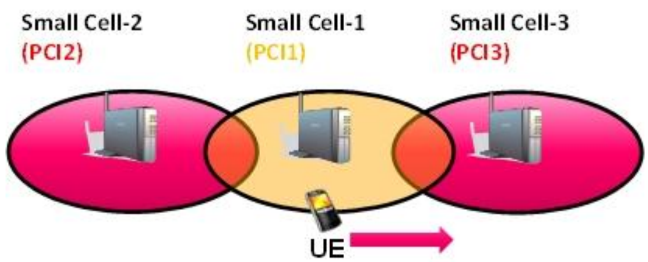

Figure 10 Case of PCI Confusion. Small Cell-1 cannot uniquely identify Small Cell-2 and Small Cell-3 from their physical layer identifier (PCI).

In a macrocell deployment, careful RF planning ensures that PCI collision or confusion does not happen. However, in neighborhood small cell deployment, where deployment is unplanned, PCI collision/confusion may occur and hence need to be handled.

To avoid PCI collision/confusion, a small cell can use a UE-like receiver/sniffer, a.k.a. "Network Listening Module" (NLM) to detect physical layer identifiers of the neighboring cells and hence, avoid selecting the ones that are already being used in its neighborhood. In addition, to address hidden node problems where the small cells cannot detect each other but a UE in the middle can detect both, UE reports and X2 message exchange can used to detect and resolve PCI collision/confusion. For example, the small cell can ask the UE to report cell identity of the neighboring cells, in addition to their PCIs. Since cell identity of each cell is unique, two neighboring cells with different cell identities but same PCI can indicate collision/confusion.

5.1.2.2 Neighbor Discovery

When a mobile device served by a small cell leaves the small cell coverage area, it needs to be handed out to a neighboring small cell or macrocell. For handover to take place, accurate information of the neighboring cells is required at the small cell (i.e., PCI to Cell ID mapping). Absence or incompleteness of this information can cause the mobile devices to have call drops.

For neighbor discovery, a small cell can use the NLM to detect its neighboring cells. This mechanism allows the small cell to construct its Neighbor Relation Table (NRT) at boot-up without any assistance. However, NLM at the small cell location may not be able to detect all neighboring cells that the small cell users within the coverage area can detect. This may cause handout failures. To resolve this problem, the small cell can utilize UE reports and X2 message exchanges in addition to its NLM functionality to generate a complete NRT.

Automatic Neighbor Relation (ANR) framework in 3GPP can be utilized to discover neighboring cells via UE reports. Small cells can request the UEs to report the PCI and Cell ID of neighboring small cells. With this information, each small cell can establish an X2 connection with its neighbors and exchange neighbor relation information with them. This allows each small to enhance their NRT based on the UE reports and X2 messages received from the neighbors.

5.1.2.3 Frequent Handover Mitigation

In a neighborhood small cell deployment, due to small coverage area of small cells, an active high speed UE may go through frequent handovers between small cells. Stationary or slow moving UEs can also experience frequent handovers due to shadowing and/or channel fading when they are located in areas where pilots from different small cells are about the same strength (i.e., pilot pollution). Figure 11 illustrates these scenarios.

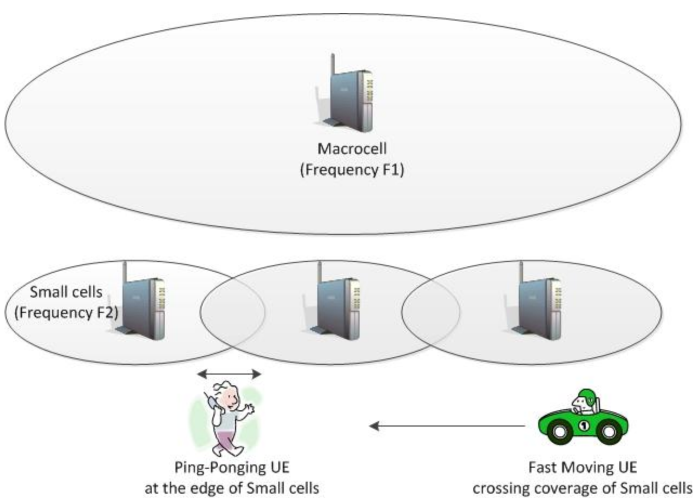

Figure 11 Scenarios of frequent handovers in neighborhood small cell deployment

Frequent handovers between small cells are undesirable as they can cause packet losses and/or packet delays leading to voice artifacts and/or poor user experience. They also can lead to large signaling load at the small cell gateway and/or core network. Thus, it is desirable to take appropriate action to avoid such frequent UE handovers in small cell deployment. A three step approach is proposed:

1. Determine if a UE is experiencing frequent handovers.
2. Classify frequent handovers based on cause (high speed UE or ping-ponging UE).

3. Determine actions based on the number of frequent handovers and their classification.

To determine frequent UE handovers, UE handover information needs to be obtained. In LTE, this information can be obtained from “UE History Information” IE [7], which is passed during the handovers from one cell to the other. This IE contains information for the cells (up to 16) that a UE has been served by in active state prior to the target cell. For each of these cells, it contains cell identity, cell type (i.e., macro, small cell, etc.) and the time UE stayed in that cell. By checking the average time UE stayed on each cell for a few of the past cells, a small cell can determine if frequent handovers are happening.

To understand if frequent handovers are ‘ping-pong’ handovers, the small cell can check the last few handovers in UE history information to see if a cell identity is getting repeated. If that is the case, then it can classify them as ‘ping-pong handovers’, otherwise, they can be assumed to be ‘fast moving handovers’.

If handovers are ‘frequent handovers’ and are classified as ‘fast moving handovers’, then the small cell can initiate inter-frequency handover to a macrocell on the other carrier. The idea here is to send the fast moving UE to a clean macrocell carrier where the number of handovers would be reduced due to large coverage of macrocells.

If handovers are ‘frequent handovers’ and are classified as ‘ping-pong handovers’, then the small cell can make it more difficult for this UE to handover to the ping-ponging (or neighboring) cells through the adjustment of UE specific handover parameters. If delaying handovers to the ping-ponging cells does not work (i.e., frequent handovers continue), inter-frequency handover to the macrocell may be initiated by the small cell, as a fallback option.

In addition to above methods, forward handover can be effective in improving the handover performance. Forward handover is applicable to handover scenarios where the target cell is not prepared by the source cell. In such cases, the target cell can fetch the UE context from the source cell to reduce handover interruption and NAS recovery signaling.

Additional improvements to handover performance can be obtained by monitoring handover failure scenarios and adjusting handover policy to reduce handover failures. The Mobility Robustness Optimization feature of the LTE standard defines several techniques for handover failure monitoring, including message exchange between source and target cells to monitor failures that the source cell would otherwise not be aware of. The standard leaves the handover policy adjustments to implementation. UltraSON™ has the ability to adjust the handover parameters specifically according to UE and cell specific scenarios to reduce the handover failures. UltraSON™ maintains knowledge of handover successes and failures over several hours and days, and is able to identify patterns of failures that need to be addressed. Improved handover robustness allows the system to raise the mobility threshold above which UEs have to be moved to the macro frequency, thereby providing better offload to small cells.

5.2 Transmit Power Management

A dense deployment of small cells in a neighborhood while providing improved capacity via spatial reuse results in two main challenges which affect user mobility:

- Islands where multiple small cells are at nearly equal strength resulting in users, stationary or mobile, experiencing very frequent handovers between small cells.
- Smaller coverage footprints: Since the density of small cells in a geographical area is very large, the coverage area per small cell ends up being much smaller than the coverage area of a macrocell. As a result, pedestrian or vehicular users moving within the network experience much more frequent handovers between small cells.

These mobility related challenges can be mitigated, in addition to the schemes in Section 5.1.2.3 , by correctly calibrating the small cell downlink transmit power level. Each small cell can monitor the surrounding RF using the network listen module (NLM) and UE measurements. Each small cell performs RF measurements of other small cells' pilot channel and determines its own transmit power level. NLM measurements can be done at the power-up and repeated periodically to monitor any changes in the neighborhood. Furthermore, UE measurements can be used to enhance the NLM measurements and address RF mismatch issues.

Figure 12 illustrates the need for power calibration from the mobility point of view. It shows a dense urban neighborhood with 18% small cell penetration. In Figure 12(a) each small cell transmits with a fixed power of 20 dBm. As an example and to illustrate the benefits of Tx power calibration, in Figure 12(b) each small cell calibrates its transmit power level and transmits at 20 dBm or 0 dBm depending on the RF signal strength observed from other small cells. The contour plots depict difference in received pilot power from the strongest RSRP and second strongest RSRP.

Without power calibration a significant portion of the neighborhood sees another small cell within 3 dB from the strongest. Furthermore, channel fading can cause stationary or mobile users to experience frequent handovers. This simple power calibration schemes can minimize the creation of such regions.

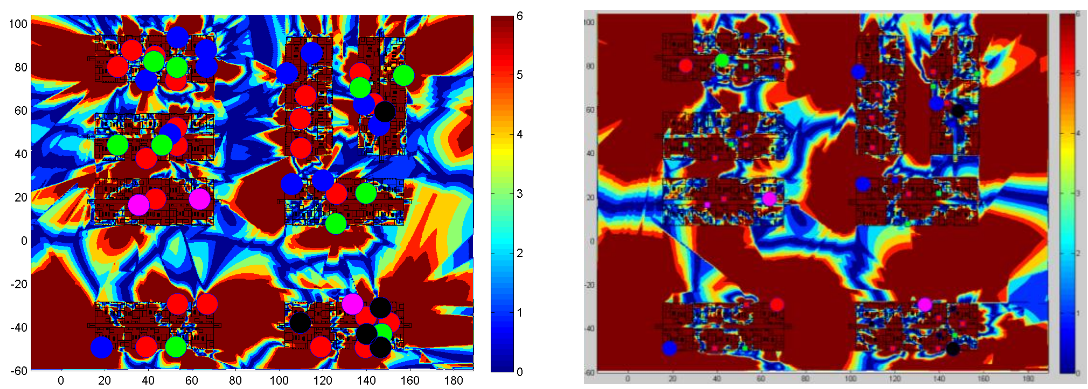

Figure 12 Pilot pollution regions: (a) plot on the left shows pilot pollution without power calibration (b) plot on the right shows pilot pollution with power calibration

Figure 13 shows the coverage footprint of small cells. In Figure 13(a) each small cell transmits at the same 20 dBm power level. In Figure 13(b) each small cell calibrates its transmit power level and transmits at 20 dBm or 0 dBm depending on the RF signal strength from other small cells. The mobility benefits of power calibration can be quantified by the number of handovers experienced by users. A mobile user traveling along the white route experiences about six handovers when small cells transmit at a fixed power. With power calibration the number of handover experienced is about one along the route.

Reducing the Tx power of some of the small cells reduces pilot pollution but on the other hand can impact the capacity offload to small cells. Hence, intelligent Tx power management algorithms are needed to optimize the capacity offload while minimizing pilot pollution. Furthermore, joint Tx power management, scheduling and resource coordination among multiple small cells can further optimize the system capacity. For example, soft Fractional Frequency Reuse can be used where a cell site user is served at a lower Tx power in the same resource block as a cell edge user in a neighboring small cell at a higher Tx power. This can result in better frequency reuse and improvement in the overall system capacity.

Transmit power management should also take into account backhaul limitations. For example, a small cell with lower backhaul capacity should in general transmit at a lower power to avoid attracting many users and hence causing congestion due to limited backhaul.

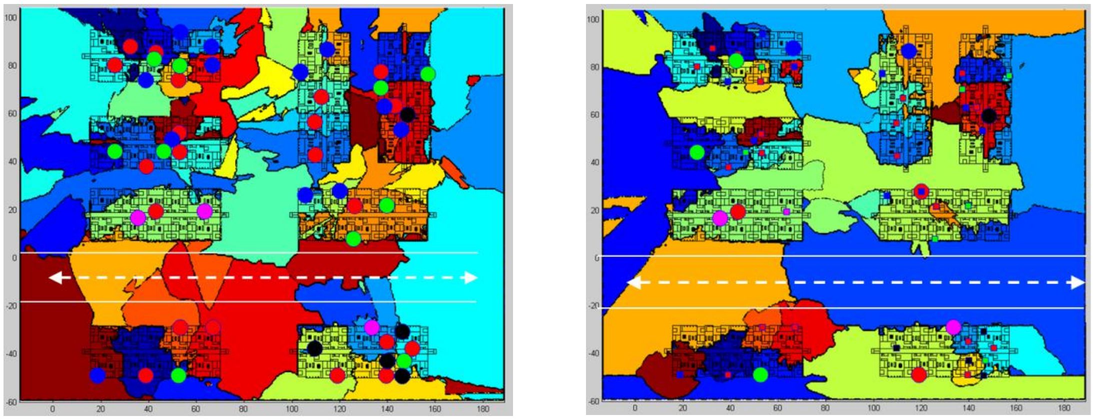

Figure 13 Small cell coverage footprints: (a) plot on left shows coverage footprints without power calibration (b) plot on the right shows coverage footprints with power calibration

5.3 Radio Resource and Interference Management

In conjunction with Tx power management, radio resource and interference management is needed to further optimize system capacity and user experience. In particular, time and frequency resource partitioning and coordination can be used to mitigate the co-channel and adjacent-channel interference between small cells and macro cells as well as between small cells. This can leverage the Inter-Cell Interference Coordination framework in 3GPP.

Neighborhood small cells may become channel element (CE) limited due to their extended coverage area and open/hybrid access mode of operation. Resource limitations need to be handled properly to ensure a certain level of Quality-of-Service (QoS) for the small cell owner. This is particularly important to convince the users to allow public use of their small cell device and backhaul.

When a small cell runs into channel element limitations, the small cell owner needs to be prioritized. This prioritization can be achieved by handing over other users to the macro network. Small cell coverage can also be adjusted based on long-term CE usage statistics.

User experience on neighborhood small cells depends on the signal quality as well as the small cell loading. One other important aspect of resource management is to maximize the user throughput via intelligent load balancing between small cells and macro cells. The small cell can estimate the macro load by monitoring the macro transmission or get load information through the X2 interface if available. Load balancing can be performed over the long term by adjusting the handover/reselection parameters for small cells or by adjusting their Tx power. In addition, short term load balancing can be achieved via handover between small cells or between small cells and macro cells.

5.4 Backhaul Management

Neighborhood small cells leverage existing backhaul, the quality of which varies widely. Most of such backhaul may be consumer-grade and may be shared by multiple users. Provisioning of customer's backhaul open to all users presents interesting opportunities and challenges for the operators. It is possible for the total traffic from the users on a small cell and other traffic from the owner to exceed the available capacity of the backhaul.

When a small cell runs into backhaul limitations, the small cell owner needs to be prioritized by handing over other users to the macro network or limiting the backhaul usage of other users via radio resource management and scheduling. Small cell coverage can also be adjusted based on long-term backhaul usage statistics. In addition to these, the total backhaul usage by the small cell may need to be monitored and controlled in order to prevent impact on other Internet traffic that share the same backhaul. The small cell may need to estimate the backhaul availability and limit its backhaul traffic in order to prevent any impact.

6 Conclusions

It is expected that mobile traffic will increase by 1000x in the next decade. This paper presents a highly scalable, low-cost, new deployment model Neighborhood Small Cell that has the answer to supporting future traffic requirements. The model capitalizes on existing consumer sites and backhaul to reduce both CAPEX and OPEX while allowing significant offloading of users from the macro network, providing huge throughput improvement through cell splitting gains. The feasibility of network planning at these high penetrations is questionable, meanwhile the lack of planning can limit user experience if not addressed properly. This paper presents a suite of self-organizing features addressing this challenge especially in the areas of interference, mobility, and resource management that provides a powerful solution for meeting the exploding data demand.

7 References

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