Enabling Hyper-Dense Small Cell Deployments with UltraSON™

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Qualcomm Technologies, Inc.

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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 how very dense deployment of small cells can 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 can leverage consumer site and backhaul as much as possible, thereby reducing two major contributors to CAPEX and OPEX. Second, when accompanied by SON (self-organizing network) algorithms, small cells 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 Tehcnologies, Inc. to enable such deployments. Such a small cell deployment model enhances user experience and offers both 3G and 4G network operators a viable solution to address the ever increasing data demand.

More information about Qualcomm Technologies, Inc.'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 also has small cells as one of the key areas for LTE evolution [3]. Multiple 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 how a new deployment paradigm together wth UltraSON features can help achieve this goal.

2 Small Cells

Traditionally cellular networks rely exclusively on macro cells to provide coverage. As demand for data capacity increases, macro network alone cannot meet the data demand. An economic way to add capacity to the network is to deploy small cells wherever needed.

Small cells can be 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, light posts, cable junction boxes at street corners, etc. Unlike traditional "closed" access small cells (aka femtocells) deployment model[1], small cells with "open/hybrid" access 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 small cells can provide coverage and capacity for both indoor and outdoor users and thus serve the nearby neighborhood. An illustration of the small cell network concept is shown in **Error! Reference source not found.**. Different types of small cells 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, indoor small cells handle indoor user traffic and also serve users passing-by on the street or moving in moderate speed vehicles. A key feature of small cells is that they provide contiguous coverage and seamless mobility experience to users in the neighborhood by supporting handovers among the small cells as well as between small cells and macro cells. Users not offloaded to small cells (e.g., high mobility users) are served by the macro cells.

It is worth mentioning that higher frequency bands (e.g., 3.5 GHz) are being considered for cellular technology in many countries. Such bands have higher propagation loss compared to cellular bands and are not suitable for macro cells. However, small cells have smaller coverage footprint requirements and can still provide good coverage and capacity at higher bands. This makes small cells the ideal candidate to utilize the high frequency bands.

[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.

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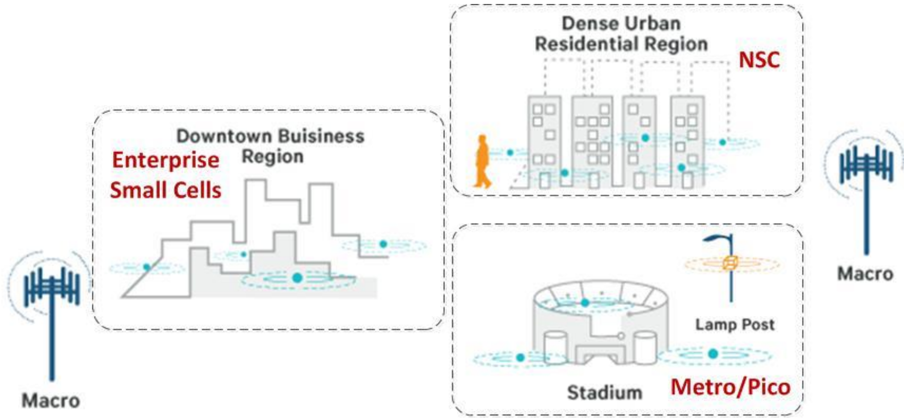

Figure 1 Network with macro cells and different types of small cells

2.1 Types of small cells

Small cells can generally be classified into 3 categories.

2.1.1 Metro/Picocells

Metro or picocells are typically deployed by operators in outdoor public venues and hotspots such as stadiums and also on light posts. They transmit at relatively high power levels.

Picocells are often used by operators to fill coverage holes when the network is initially deployed. The density of picocells is low in that stage and the main requirement is seamless handover with macro cells. As their density increases, there is more coverage overlap among picocells and between picocells and macro cells. It is important that UltraSON be enabled at that stage.

Picocells often share the same channel with macro cells. To ensure maximum traffic offload from macro cells to picocells, FeICIC should be supported in addition to UltraSON.

2.1.2 Enterprise small cells

Enterprise small cells are deployed in office buildings or shopping malls by contractors or IT technicians. Their transmit power is typically lower than that of picocells.

They can be deployed sparsely for coverage improvement. In that case, they have minimal coverage overlap with macrocells. Other than handover with macro cells, there is not a strong requirement for SON features.

When enterprise small cells are used for capacity offload, they will be deployed in high density and UltraSON features should be enabled to ensure robust operations. In particular, when they are deployed in a cluster, UltraSON maximizes coverage and capacity cluster-wise via joint optimization across enteire cluster.

2.1.3 Neighborhood Small Cells (NSC)

Neighborhood small cells are deployed by the users in residential areas or in small businesses such as coffee shops. Since the end users cannot be assumed to have any understanding of cellular technology or network optimization, it is essential that these small cells support a sophisticated set of SON features like UltraSON that allow them to configure and optimize themselves continuously.

Key defining characteristics of a NSC network are 1) they are deployed in unplanned 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 UltraSON.

A dense NSC network, when augmented with additional spectrum, can meet 1000x data demand as we show from extensive simulations captured in **Error! Reference source not found.**.

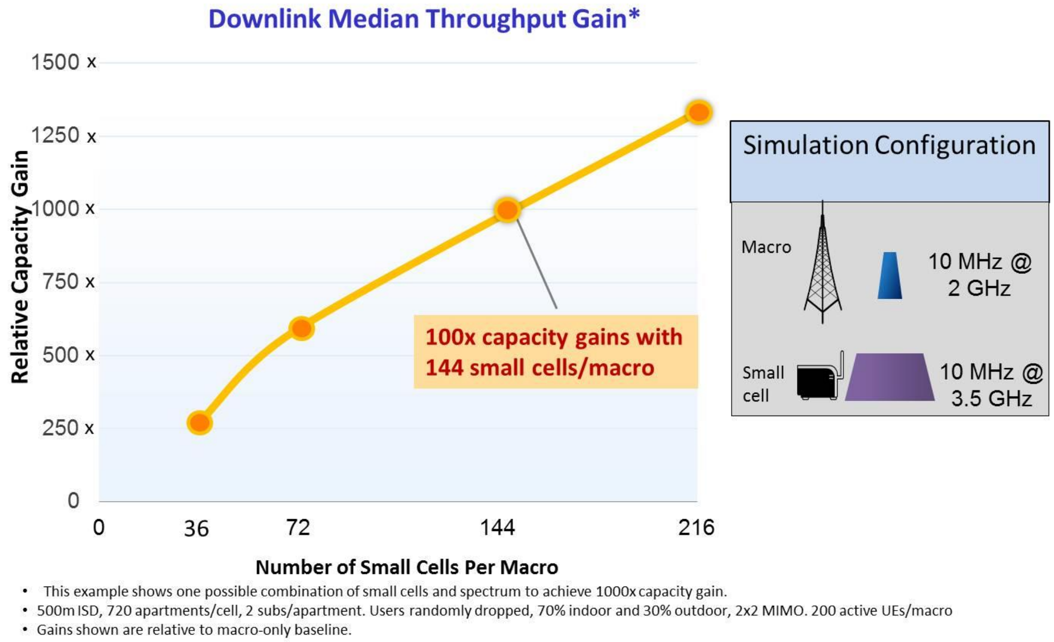

Figure 2 Achieving 1000x throughput with NSC and additional spectrum

2.2 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.

Unplanned small cell deployment model that leverages existing sites and backhaul 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, small cells can more effectively meet user needs as they are inherently deployed where users and thus data demand are.

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

3 Overcoming Deployment Challenges with UltraSON

The deployment challenges for neighborhood small cells result primarily from the fact that unlike a macro network, the small cells can be 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. As the density of small cells increase, handovers become more likely. It is important to avoid excessive handovers to reduce signaling load to core network and also optimize handover performance. 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. Existing backhaul leveraged by small cell may be shared by other devices and may not be properly dimensioned for small cell traffic, it is thus necessary to design the SON features to account for backhaul-limited scenarios and preserve the small cell owner's user experience.

The following sections describe how UltraSON features can overcome the above challenges of unplanned small cell deployment. It is worth noting that 3GPP standards already defined the basic framework for certain SON features such as Automatic Neighbor Relation (ANR) without specifying the detailed algorithm. UltraSON utilizes this framework and added thealgorithm and implementation details. Individual features can be customized further based on the needs of different deployment scenarios.

3.1 Self-Configuration

With unplanned small cell deployment, operators will not be configuring individual small cells. In addition, RF environment will continue to vary after deployment of a small cell. Hence each small cell has to continuously monitor the RF environment and re-configure itself as needed at startup and during regular operations. A key feature that is leveraged for small cell self-configuration is Network Listen (NL), which is supported by Qualcomm Technologies, Inc.'s FSM chipsets. The small cell will periodically listen to the downlink to measure signal level and detect presence of other cells in the vicinity.

3.1.1 Automatic PCI Selection

A small cell deployed without planning has to select its PCI to avoid collision and confusion with its neighbors.

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. **Error! Reference source not found.** illustrates PCI confusion problem.

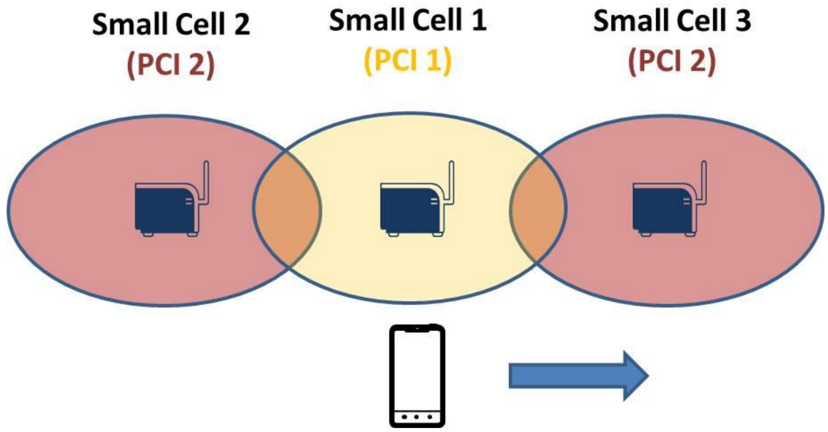

Figure 3 Case of PCI Confusion. Small Cell 1 cannot uniquely identify Small Cell 2 and Small Cell 3 from their PCI

UltraSON is capable of autonomously detecting and resolving PCI conflicts between neighboring cells, including serving cell having the same PCI as a direct neighboring cell, and two neighboring cells of the same serving cell having the same PCI. Network Listen is used to detect PCIs already used by neighbors. UE reports containing PCIs of cells nearby and message exchange with other cells via X2 are also used to supplement the results obtained from Network Listen.

3.1.2 Automatic Neighbor Discovery

A small cell also has to maintain its neighbor list to ensure proper handovers of UEs to other cells. Incorrect or incomplete neighbor information can cause UEs to have call drops as they move away from their serving small cells.

For neighbor discovery, a small cell can use the NL to detect its neighboring cells. However, the small cell 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 NL functionality to generate a complete Neighbor Relation Table (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.

In addition to the 2 features described above, UltraSON self configuration is capable of storing the self-derived configuration parameters and deciding, upon a reboot, whether to re-use these parameters or initiate new self-configuration based on various factors. This avoids delays in start-up and stable operation by avoiding unnecessary self-configuration in scenarios when the surrounding RF environment has not changed after a reboot.

3.2 Backhaul-Aware Operations

Small cells may leverage existing backhaul, the quality of which varies widely. For example, backhaul in residential buildings based on home broadband service may be consumer-grade and 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, it will offload user(s) to other cells in vicinity if possible. 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 home devices sharing the same backhaul. The small cell may need to estimate the backhaul availability and limit its backhaul traffic in order to prevent any impact.

3.3 Mobility Management

Effective mobility management is essential for the viability of a network with hyperdense small cells solution. Such dense small cell deployment creates more cell boundaries and potentially more handover events. The mobility management problem basically boils down to avoiding excessive handovers while ensuring robustness of necessary handovers for all mobiles, including legacy ones.

3.3.1 Frequent Handover Mitigation

In a dense 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). **Error! Reference source not found.** illustrates these scenarios.

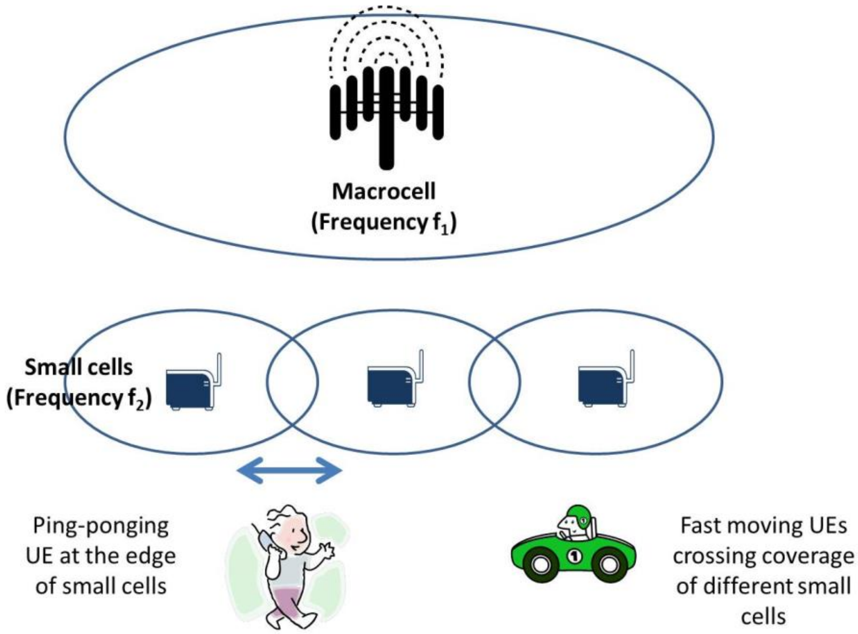

Figure 4 Scenarios of frequent handovers in neighborhood small cell deployment

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.

3.3.2 Forward Handover

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. This is particularly relevant in scenarios where the signal of the UE's serving cell degrades rapidly, for example, when the user moves around a building and suddenly loses line-of-sight path to the cell.

3.3.3 Robust Mobility

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[T] has the ability to adjust the handover parameters specifically according to UE and cell specific scenarios to reduce the handover failures. UltraSON[T] 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.

3.4 Dynamic Resource and Tx 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.

3.4.1 Tx Power Management

These mobility related challenges can be mitigated, in addition to the schemes in Section 3.3.1 , by correctly calibrating the small cell downlink transmit power level. Each small cell can monitor the surrounding RF using the network listen and UE measurements. Each small cell performs RF measurements of other small cells' pilot channel and determines its own transmit power level. NL 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 NL measurements and address RF mismatch issues.

Figure 5 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 5(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 5(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.

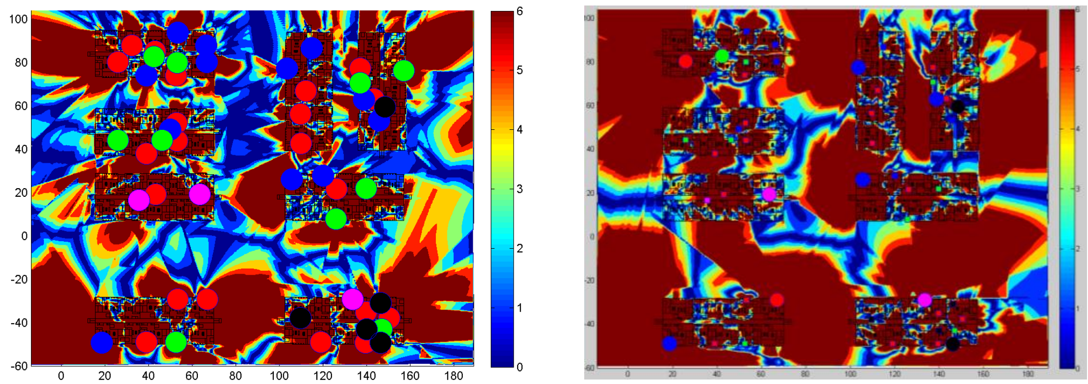

Figure 5 Pilot pollution regions: (a) plot on the left shows pilot pollution without power calibration (b) plot on the right shows pilot pollution with power calibration

Figure 6 shows the coverage footprint of small cells. In Figure 6(a) each small cell transmits at the same 20 dBm power level. In Figure 6(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.

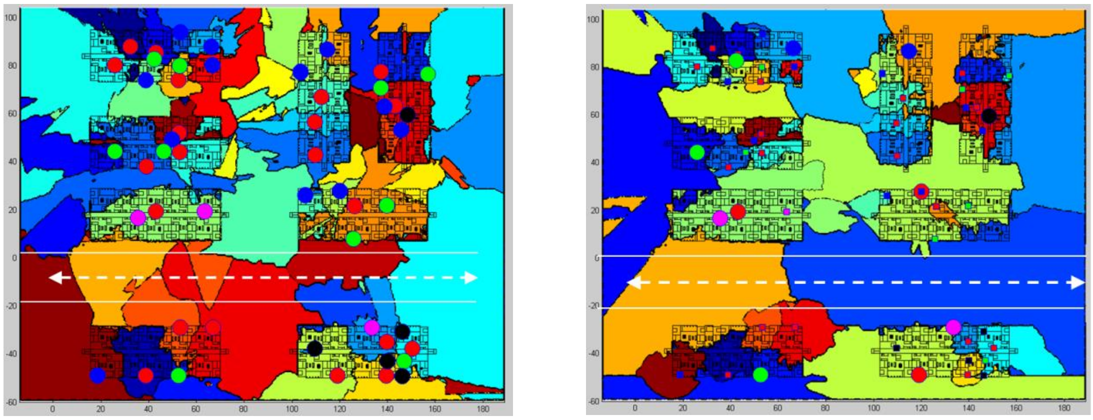

Figure 6 Small cell coverage footprints: (a) plot on left shows coverage footprints without power calibration (b) plot on the right shows coverage footprints with power calibration

3.4.2 Resource Partitioning and Coordination

In conjunction with Tx power management, radio resource and interference management is needed to further optimize system capacity and user experience. In particular, users near cell edges are subject to interference by neighboring cell's transmission. Time and frequency resource partitioning and coordination can be used to mitigate the co-channel and adjacent-channel interference between neighboring cells by orthogonalizing their airlink resource usage for their respective cell-edge users. This can leverage the Inter-Cell Interference Coordination (ICIC) framework in 3GPP.

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.

3.4.3 Load Balancing

When a small cell runs into CE 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 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.

4 SON Architecture

SON features can be implemented in centralized or distributed architecture.

In centralized SON (C-SON) architecture, there exists a centralized node (e.g. SON server) that oversees operations of all small cells and controls their behavior. The centralized node receives input from small cells on network metrics and determines policies for small cells and updates their configuration as it deems appropriate. Such architecture requires frequent exchange of information between the centralized node and the small cells. When the network contains only a few small cells, the overhead is minimal. As the density of small cells increase, the amount of overhead grows drastically. This creates extra load on the backhaul and requires strong computation power in the centralized node. The advantage of this architecture is that the centralized node has network-wide knowledge of key metrics and can thus perform global optimization. However, the scalability of this architecture is dependent on the backhaul bandwidth and the computation power of the centralized node. The need for statistics upload by small cells followed by decision at the centralized node and subsequent update of small cells' behavior also adds potential latency in the response of small cells.

With distributed SON (D-SON) architecture, small cells operate autonomously. A small cell has knowledge of the current RF and loading conditions in the vicinity through its own measurements and input from UEs and other small cells. Based on these information, small cells can respond to change in RF environment and load distribution withour incurring much latency. There is no need to frequently report network metrics to a SON server. The only backhaul overhead is information exchange with neighboring small cells. The amount of overhead at the core network does not increase much with the density of small cells, thus making the architecture scalable.

4.1 Hybrid SON Architecture

Both centralized and distributed SON architectures have their own limitations. While the centralized architecture allows network-wide optimization, the processing requirement in the centralized node grows with the number of small cells in the network. The responsiveness of small cells to change in RF environment can be affected by limitations in the SON server's processing power when the number of small cells is large. For features that involve a large amount of input before a decision is made, the backhaul and the SON server can easily become overloaded. The distributed architecture ensures faster response by small cells to the changing environment but small cells lack knowledge of the network status outside of its vicinity.

A hybrid SON architecture combines the best of centralized and distributed architecures. The SON server can focus on determining and updating network policies and parameter ranges based on long-term network statistics collected from individual small cells over time. This avoids the need of frequent upload of network metrics by small cells to the centralized node. Small cells can then autonomously adapt to the changing environment as long as it conforms to the guidelines provided by the SON server.

Here are some examples of how UltraSON[T] features can function with elements from both architectures.

- PCI Selection: The centralized SON server pre-allocates a pool of PCIs which the small cells can choose from based on NL measurements, UE reports and information exchange with neighboring cells. The SON server may further adjust the range of PCIs based on collision and confusion statistics.

- Tx power management: Small cells determine their Tx power based on measured signal level from NL and UE registration attempts while staying within the range of allowed Tx power defined by the centralized SON server. The range of Tx power for individual small cells can be fine-tuned as the SON server analyzes long-term load and mobility statistics around each small cell.
- Mobility management: Centralized SON server pre-determines the range of mobility parameters. Each small cell uses a combination of UE mobility history, MRO messages from cells nearby via X2 and UE measurements to update those parameters.

5 Conclusions

It is expected that mobile traffic will increase by 1000x in the next decade. This paper presents a way to deploy small cells in high density while avoiding huge costs in planning and reducing recurring costs on rent and backhaul. 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 SON 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.

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