Cost-effective Enterprise Small Cell Deployment with UltraSON^{TM}

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ABSTRACT

Providing effective in-building cellular coverage and capacity has been a major challenge to the wireless ecosystem. This has largely been due to the difficulties in site acquisition and high deployment and operating costs of traditional solutions.

LTE, as an evolved standard, incorporates a wide variety of Self-Organizing and Self-Optimizing Network (SON) features. The combination of improved mobility and availability of SON in LTE allows cost-effective SC deployment by changing the paradigm, from operator-deployment to end-user-deployment.

In this paper we first present an overview of the existing deployment process and estimated costs. We then present how UltraSON™ - Qualcomm Technologies, Inc.'s suite of SON features - enables unplanned and cost effective deployment of Small Cells (SC) in Small and Medium Businesses (SMB). A case study of UltraSON-enabled SC deployment on Qualcomm's campus demonstrates performance with SCs connected to a test network initially, then validated with SCs connected to a commercial network. While results and costs associated with any specific deployment will vary based on a host of factors that are beyond the scope of this paper to discuss, the case study example shown in this paper helps illustrate that with an UltraSON-enabled end-user deployment model, deployment effort can be reduced by as much as a factor of ~ 20 compared with that for traditional deployment methods. Specifically, during our case study for a 6-cell deployment, we observed that UltraSON-enabled SCs:

- Reduce deployment effort from 115 work hours (i.e. ~$10,000 technician labor cost) to 6 work hours (i.e. <$600 technician labor cost);
- Shrink overall deployment schedule from month(s) to less than a week;
- Improve coverage, and improve throughput performance for indoor users by a factor of 2 to 4 without affecting outdoor users;
- Enable enterprises to deploy SCs independently with simple guidelines, using the same resource as for Wi-Fi deployment.

More information about Qualcomm Technologies, Inc.'s work on UltraSON and SCs can be found at:

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

https://www.qualcomm.com/invention/research/projects/small-cells/ultrason

1 Introduction

The expectations of high quality wireless data access have increased over the last few years. While macro networks provide essential wide area coverage and support for high mobility users, they have been found lacking in providing suitable coverage and capacity in venues, enterprises and other indoor locations. In a recent study [1], it was found that, to this date, 61% of the enterprises in the US have noticeably poor indoor cellular coverage. This situation is particularly concerning as more than 80% of the total mobile traffic is generated indoor [2].

Clearly, new network deployment models are needed to serve the demand for wireless coverage indoors. Such deployment models would reduce the cost of deployment and operation while enabling operators to provide high quality service to their customers. In a recent survey [3] it was found that many venue and enterprise owners are willing to bear a part of the cost of deployment of a wireless network at their sites if it effectively serves all their customers. According to RCR Wireless, an ideal solution for enterprises and venues should have the following characteristics [4].

1. Easy & cost effective deployment: The indoor solution should effectively be comparable in cost and operational complexity to enterprise Wi-Fi networks.
2. Minimal impact on the overall network: Small Cell (SC) deployment should enhance user experience within the building considered, without negatively impacting the overall network quality.
3. Quick deployment: Existing processes within Mobile Network Operators (MNO) delay the deployment of indoor solution by months. As a remedy, the deployment model in enterprise should follow the Wi-Fi or residential SC model where the deployment can be conducted by the enterprise or venue owner in a matter of days, if not hours.

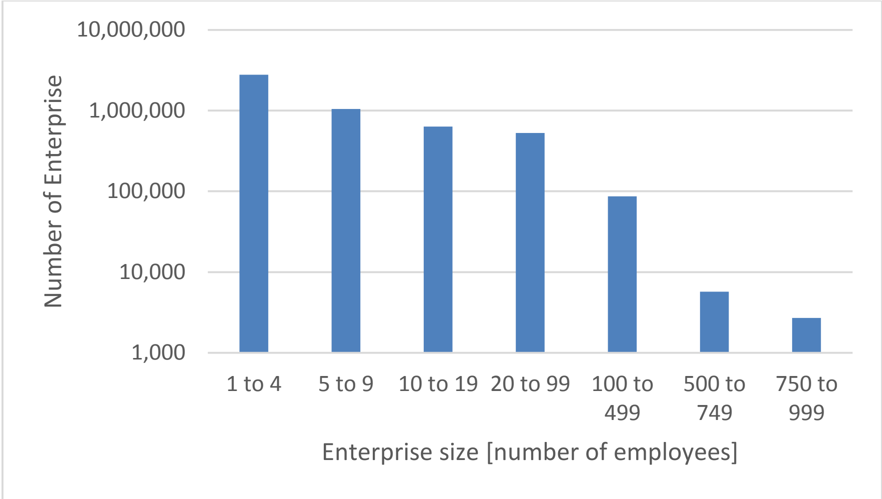

Figure 1: US Enterprise size distribution, by number of employees

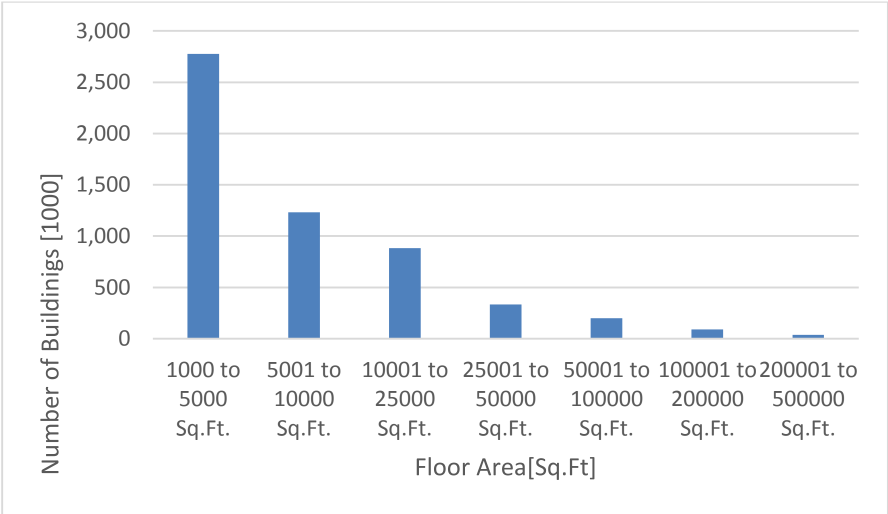

Figure 2: US Commercial building size distribution, by area.

From Figure 1 [5] and figure 2 [6] it is evident that, in the US alone, there are approximately 5 million SMB buildings with area less than 50,000 Sq. Ft.. If 61% [1] of these have poor cellular coverage, the addressable SMB market for SC in the US would be in excess of 3 million buildings. Considering the size by employees or area distribution, majority of that addressable market would not justify MNO involvement to provide coverage. Hence, alternative methods should be used. SCs with efficient SON (such as UltraSON) can more effectively provide that alternative method as demonstrated in Section 4 .

The deployment process mentioned in this document is intended primarily for the SMB market, when the needs for coverage and capacity would require deployment of up to 10 cells or for space up to 50,000 Sq. Ft. For larger building, SCs can still provide a cost efficient solution, but for such building deployment cost per SC becomes smaller, thus a technician based deployment, rather than end-user deployment becomes realistic from a cost point of view.

2 Traditional Deployment Model

Mobile Network Operators have tried a variety of solutions to address the challenge of providing effective indoor coverage and performance. Historically the expected savings from SCs in cost and complexity of deployment never materialized. Part of the issue was the inherent cost of the deployment, as traditional processes were still used for 3G SC deployment. An example of the process followed by a North American MNO to deploy 3G SC is presented in Figure 3. Following this process can delay the network deployment considerably, failing the requirements stated in Section 1 :

- Initial business case evaluation can delay a given deployment by months or years, as MNOs prioritize their indoor coverage dollars over the entire market.
- Site survey, planning and deployment further delay the deployment as multiple teams and/or subcontractors are involved, each following detailed procedures put in place to guarantee consistent quality over each of the deployments.
- Finally, optimization and monitoring may take several weeks until the system is deemed to meet the required level of performance.

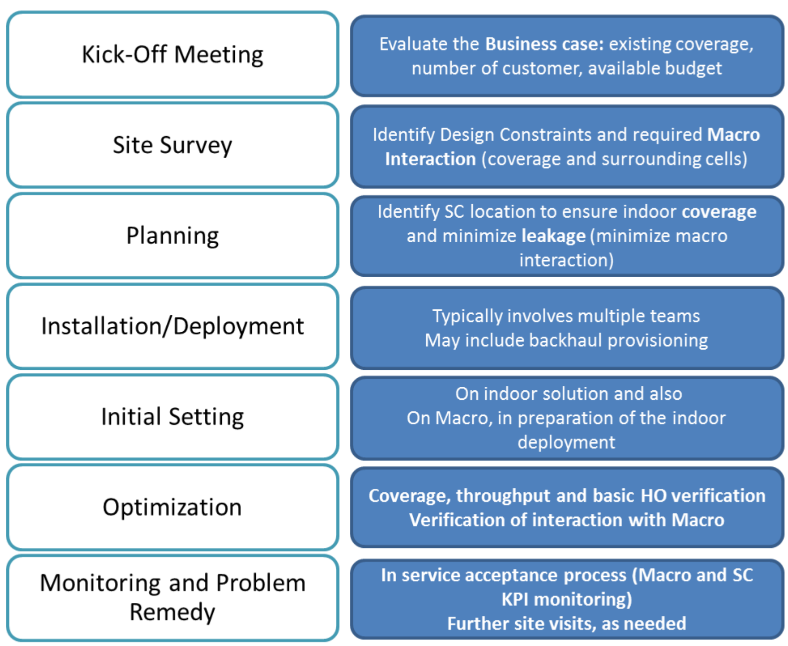

Figure 3: Typical Small Cell deployment process, for MNO based deployment

This deployment process is not only lengthy, but also costly. We have conducted interviews with SC vendors and operators to quantify the effort associated with the presented deployment process. The effort quantified from these interviews is summarized in Figure 4.

It should be noted that cost of the node itself, and cabling costs are not included in this estimate, as these will impact any type of deployment similarly. Further, the hourly labor rate used for estimation will greatly depend on the market, thus estimates need to be scaled accordingly.

Costs associated with many tasks in the table are fixed, and they do not vary (or vary only slightly) with the number of SCs, as long as the number is small (e.g. 1~10). On the other hand, costs for some tasks (e.g. "Deployment") depend directly on the number of SCs. As a result, average deployment cost per node varies non-linearly. In this example a 6-node deployment costs $1725 per node. For 10 nodes it will come down to $1053 per node. For 4 nodes it will rise to ~$2500 per node.

Task (traditional Deployment)	Effort (work-hour)	Estimated cost
Kick-off Meeting	4	$360
Site Survey	16	$1440
Planning	24	$2160
Deployment	3 (for 6 nodes)	$270
Initial Setting	24	$2160
Optimization	44	$3960
Total, for 6 nodes	115	$10350
Average per node	19.2	$1725

Figure 4: Effort for traditional deployment process and associated cost

We believe that the deployment cost estimated above is conservative compared with quotes enterprises tend to receive from MNOs. From our interview of a commercial hospitality facility in California, we learnt that the facility received quotes ranging from $20,000 to $80,000 from some operators offering turnkey planning and deployment of a 6-SC network to cover common area of the facility. But for an operator offering UltraSON-enabled commercial SCs, the facility simply had to pay the operator monthly corporate subscription (<$200 total for up to 10 SCs) without any out of pocket deployment charges! The facility itself was supposed to do the deployment with the help of simple deployment guidelines. In the next section we elaborate how UltraSON can significantly reduce deployment costs to make this possible.

3 UltraSON: Enabler of Cost-effective Enterprise Deployment

UltraSON is Qualcomm Technologies, Inc.'s suite of SON features implemented in small-cell software, running on FSM – Qualcomm Technologies, Inc.'s modem and processor chipset for SCs. UltraSON exchanges information with other SCs and macro cells over standardized interfaces.

Depending on an operator's preference, UltraSON features can also interact with a centralized server in the network. UltraSON features pertaining to this paper are summarized in Figure 5. Basic description of each feature can be found in [7], [8], and [9]. Here we will review each feature in relation to the deployment process and how it contributes to cost effective deployment.

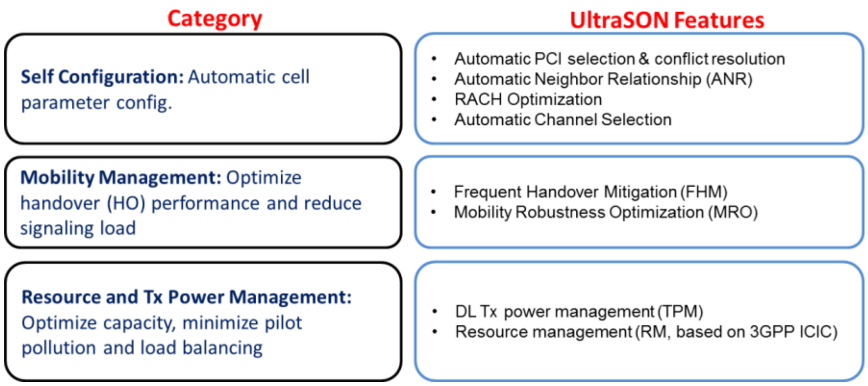

Figure 5: UltraSON Suite of features

For end-user SC deployment, the deployment process summarized in Figure 3 can be simplified to only 3 steps: Planning, Deployment, and Operation. Benefits of UltraSON for each step are summarized in Figure 6. Benefits of UltraSON for each of the deployment steps are explained in the following sections.

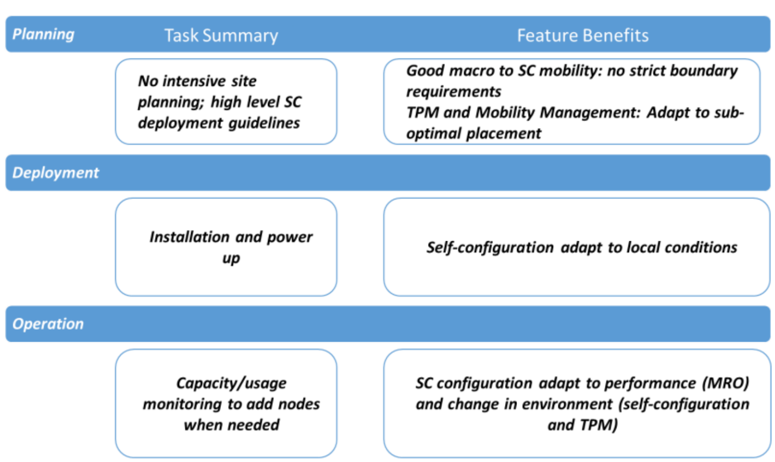

Figure 6: Simplification of deployment process with UltraSON

3.1 Planning

For LTE, unlike previous technologies, the standard already addresses many of the mobility challenges between macro and SC, assuming the necessary features (e.g. eCGI reporting, Forced DRX, Autonomous Gaps) are enabled on the network. With efficient mobility between macro and SC, in addition to UltraSON, the detailed planning process presented before can be reduced to simple guidelines. Such guidelines can be summarized in 2 simple steps:

- Dimensioning i.e. to determine the number of cells required for coverage and capacity. For a given frequency of operation, dimensioning process is effectively as simple as dividing the building area by the expected area per cell, which itself depends on the macro coverage, as shown in Figure 7.
- Uniform node placement within the building to ensure consistent coverage throughout, as is illustrated in the case study in section 4

Existing Macro Coverage Conditions	Typical SC Area [Sq.Ft]		
	Open Floor Plan	Mix Building	Enclosed Space
Weak, “2 bars” (-105 dBm or below)	7000	7000	4500
Medium, “3 bars” (-95 dBm or below)	7000	5500	3000
Strong, “4 bars” (-85 dBm or below)	7000	4000	2500

Figure 7: Typical area per cell for different macro coverage conditions for medium frequency band (1800 to 2600 MHz) for coverage and capacity dimensioning

The guideline based deployment is further helped by many of the UltraSON features:

- UltraSON’s Mobility management features, specifically Frequent Handover Mitigation (FHM) and Mobility Robustness Optimization (MRO) eliminate the need to carefully plan HO boundaries.
- UltraSON’s self-configuration features, in particular PCI selection and Automatic Neighbors Relationship (ANR) are used instead of lengthy initial setting.
- Transmit Power Management (TPM) compensates for inaccuracies in the dimensioning process while still ensuring good coverage and minimum leakage outside the building. Effectively, TPM replace part of the design and optimization steps.

3.2 Deployment

During the deployment phase the same UltraSON features come into play to ensure good user experience without the need for lengthy optimization:

- Initial PCI selection ensures that the risk of PCI conflict between adjacent cells is limited by detecting PCIs already used in the area, and avoiding them.
- Similarly, ANR uses Network Listen (NL) to add to the Neighbor Relationship Table (NRT) the neighboring cells, including SC, LTE Macro, or even IRAT cells.
- TPM adapts to the actual conditions by monitoring the local conditions through NL.

- Resource Management feature defines the initial PRB usage to minimize potential inter-cell interference.

3.3 Operation

UltraSON features are not only active at the initial deployment, but form a close loop system during operation:

- PCI selection algorithm takes into account user experience and updated conditions, e.g. new neighboring nodes, to change PCI assignment as needed.
- NRTs are automatically updated, not only using updates from NL and X2, but also considering the conditions observed by the user using UE ANR.
- During operation, TPM continues to monitor RF conditions through NL and also takes into consideration user KPIs, in particular HO KPIs. Effectively, if the SC detects that it causes HO failures in the network, it would adjust its transmit power as an attempt to minimize such failures.
- MRO also contributes to the reduction of optimization effort. As an alternative to manual optimization of HO parameters by operator technicians, MRO acts as an outer loop to optimize the HO parameters for an overall reduction of HO failures in the network.
- FHM optimizes user experience by applying different HO policies to different users based on their mobility patterns. Working in conjunction with FHM, MRO optimizes HO parameters for various HO policies.
- Resource Management (Including 3GPP ICIC) constantly monitors UE RF conditions and adjacent cell loading and dynamically adapts resource partitioning to minimize inter-cell interference.

4 Enterprise Deployment Case Study

The ease of SC deployment is illustrated in a case study [10]. In this case study, a 30,000-Square-Foot-building on Qualcomm's office campus, located at the edge of macro coverage is considered and depicted in Figure 8. This building is representative of a commercial building with users coming and going at different times of the day as they are using the facilities: Fitness center, library or the cafeteria. With such usage, capacity requirements vary over the day - peaking during lunch hours when 100s of users may be present.

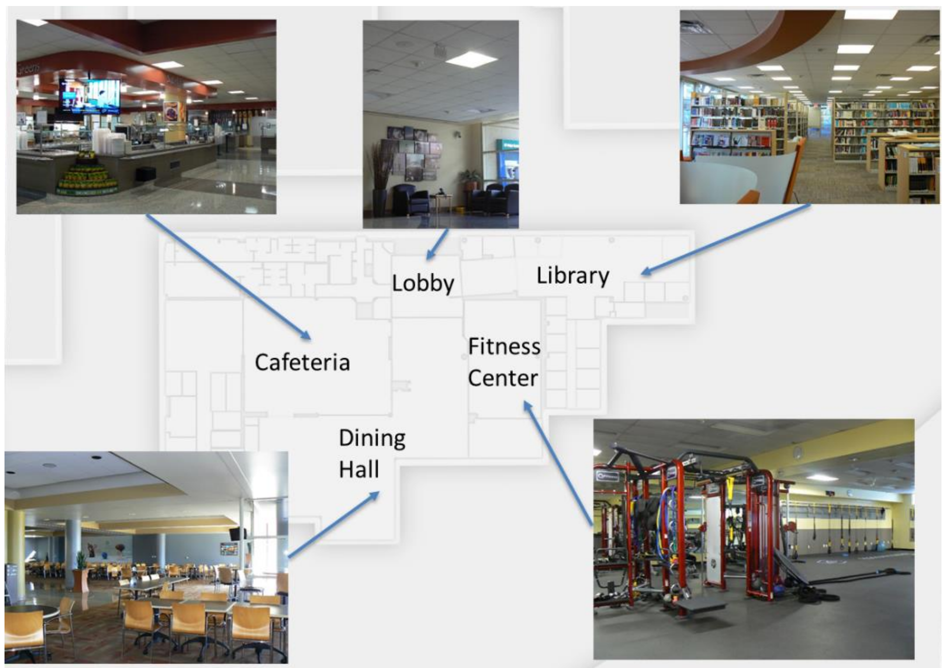

Figure 8: 30000 Sq. Ft., mix-purpose, building used for deployment case study

Deployment over this building was conducted over a 1 week period, with an overview of the time presented in Figure 9. The effort associated with each step is further detailed in following sections.

The associated cost for this effort is also summarized in Figure 9. In this case, the cost is based on the actual labor cost, but this cost would vary by region and enterprise. For a fair comparison and consistency with Figure 4 (traditional deployment costs), costs of running cables (power, Ethernet etc.), and costs of SCs themselves are not included in this table.

Task (traditional Deployment)	Effort (work-hour)	Estimated cost	Task (with UltraSON)	Effort (work-hour)	Estimated Cost
Kick-off Meeting	4	$360	NA		
Site Survey	16	$1440	Site Survey	2	$180
Planning	24	$2160	Dimensioning	1	$90
Deployment	3 (for 6 nodes)	$270	Deployment	3 (for 6 nodes)	$270
Initial Setting	24	$2160	NA		
Optimization	44	$3960	NA		
Total, for 6 nodes	115	$10350	Total, for 6 nodes	6	$540.00
Average per node	19.2	$1725	Average per node	1	$90

Figure 9: Comparison of deployment effort breakdown and cost for a 30,000 Sq. Ft sample building

For fair comparison, same hourly labor rate is used for traditional and UltraSON-enabled deployment. Main differences between cost estimates for traditional deployment and UltraSON-enabled deployment are explained as follows:

- Planning is reduced to a simple dimensioning process and associated site survey for final node placement. Compared with traditional deployment, site survey effort is reduced to focusing on identifying the final location, not considering extensive measurement campaign.
- Deployment is reduced to installation of the nodes, after which point the self-configuration algorithm take care of the necessary setting adjustments.
- Similarly, manual optimization is replaced by UltraSON's self-configuration, transmit, resource and mobility management algorithms.

We can infer that appropriate SON techniques can help reduce the cost per node by an order of magnitude. For this 6-cell deployment case, total estimated savings were about $10,000. On a per node basis this translates to cost reduction by a factor of ~20.

4.1 Dimensioning

Instead of a traditional design, a simple dimensioning was done considering few basic inputs to determine the number of nodes required in this building.

This building is considered as a mix-morphology building with different areas of the building separated by hard partitions. Through a basic survey, the existing macro coverage was estimated to be weak to medium so the 5500 Sq. Ft. per cell area was used (c.f. Figure 7), leading to 6 cells to be distributed over the building.

For the initial node placement, uniform placement was targeted, as illustrated in Figure 10, where the center of each circle represents the candidate cell location. It should be noted that the east side of the building was not targeted for coverage, explaining the uncovered section by the SC on the left of the figure.

4.2 Site Survey

In order to finalize the site locations, a site visit with the building facility manager was conducted. During this site visit, based on the initial node location, the building manager recommend alternative location based on visual impact and accessibility. As illustrated in Figure 10, during this site visit the building manager imposed change in location for 2 of the sites. This network change, as will be seen in further section did not cause any performance issues.

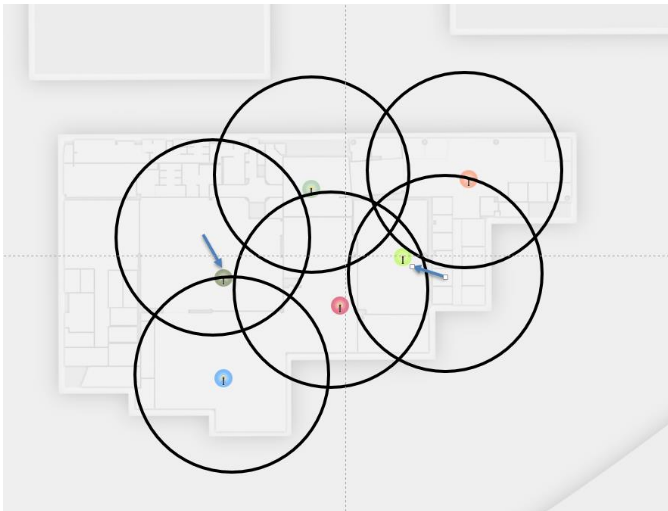

Figure 10: Final node placement based on facility manager inputs: 2 of the nodes were moved in this process

4.3 Deployment

Actual deployment of the SC was limited to node installation, connection of power and LAN cables, and finally powering-up each node.

After each of the nodes was powered-up, no further manual adjustments were made. Each node was able to detect the surrounding cells to prevent PCI conflicts, each node was able to detect both surrounding macro and SC to populate its respective NRT. The resulting configuration is illustrated in Figure 11.

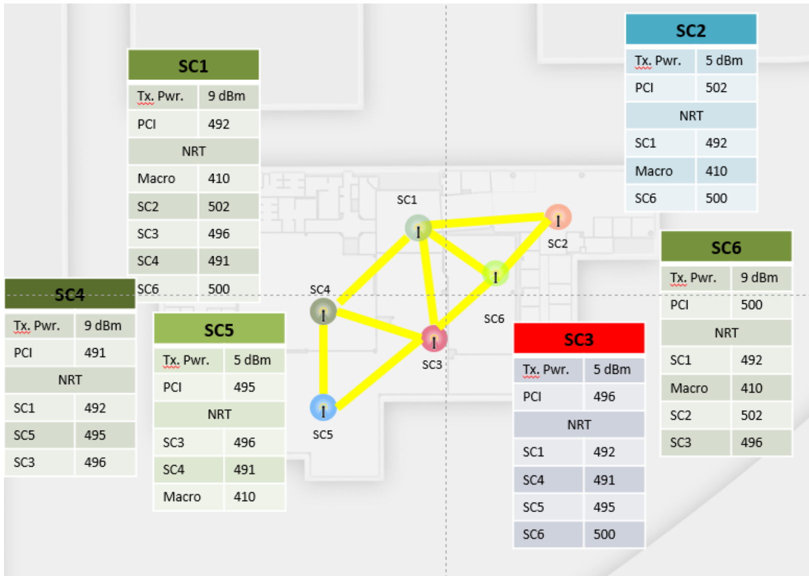

Figure 11: Final SC network configuration, at the conclusion of the deployment

As mentioned in Section 3 , all the configuration was autonomously done through UltraSON, notably:

- Initial PCI selection was done, and eventually corrected to adapt to eventual conflict arising due to node outside the NL range that had selected the same PCI.

- NRTs were set over time based not only on NL, but also on X2 and UE report.

- TPM selected the minimum power to meet the coverage and quality target, based on the detected signal level.

Effectively, TPM relies on NL to measure the RSRP of surrounding cells, and adapt the power to the measured conditions. The direct benefits, when cells are deployed according to the proposed guidelines, is that good indoor coverage is provided, while minimizing the leakage outside the building. Limiting the leakage outside the building has 2 main benefits. First is to ensure that the cell capacity is not used by the UEs in the immediate vicinity of the building, thus staying true to the capacity dimensioning guidelines. Second, and equally important, it to minimize the number of HO boundaries between macro and SC.

4.4 UltraSON-enabled Deployment in a Commercial Network

The example above is based on deployment of a test network within a controlled environment. After successful deployment on the test network, the system was upgraded by installing 6 commercially available SC, connected to an operator’s live core network.

5 Performance Summary

In the example shown in this paper, deployment of UltraSON-enabled SCs was not only cost-effective, but it also showed notable performance improvement in the network, without impacting outdoor users. Improvements were observed in the test network, as well as the commercial network.

5.1 Test Network Performance

The test network, operating on a10MHz FDD channel, was tested in different ways. First the coverage and performance improvement, compared with macro-only case was evaluated by distributing multiple UEs over the coverage area, both indoor and outdoor. Secondly a UE was used to collect performance data over a representative area, while the network was loaded. From these 2 tests, following observations were made:

- Coverage, estimated by RSRP increased by over 16 dB, from -107 dBm with macro only to -91 dBm when the SC were deployed.
- Over all the UEs distributed across the building facility, when UltraSON-enabled SCs were deployed, average DL throughput improved by 4 times compared with macro-only case i.e. from ~4 Mbps to ~17 Mbps.
- A fifth of the UEs that did not receive reliable service with macro-only network, received coverage and throughput, comparable with other UEs, when SCs were deployed.
- Median user experience, estimated from DL throughput, was ~7Mbps.

5.2 Commercial Network Performance

The commercial SC network operates with different bandwidth than the existing macro, thus performance results are scaled and presented as "equivalent throughput" for both UL and DL. For performance evaluation, single user performance was measured over 27 locations, inside and outside the building. Unlike the test network, no deliberate loading was introduced, as the network was carrying commercial traffic. Effectively, the measured performance is a true reflection of what a user could observe at similar location and similar time. Summary of the equivalent UL and DL throughput performance is given below.

- For DL, equivalent median throughput with UltraSON-enabled SCs was 25 Mbps, and that for macro was about 13 Mbps. Thus UltraSON-enabled small SCs almost doubled the median user throughput on DL.
- For UL, UltraSON-enabled SCs (median equivalent throughput ~ 16 Mbps) showed substantial improvement over macro cell (~6.5 Mbps).

Both the DL and UL performance gain show the benefits of adding capacity when SC are deployed. Of course, the results shown are necessarily dependent on a host of factors, and each individual deployment will vary in complexity, cost and results. This paper is provided as an illustration of the benefits of UltraSON deployment, using some typical characteristics, and is not to be construed as a commitment that these results will occur in any given situation.

6 Conclusions

In this paper we have provided one example implementation that demonstrated that UltraSON-enabled SCs show characteristics that are desirable for SMB deployment. Specifically, for this 6-cell deployment example, UltraSON-enabled SCs:

- Reduce deployment effort from 115 work hours (i.e. ~$10,000 technician labor cost) to 6 work hours (i.e. <$600 technician labor cost);
- Shrink overall deployment schedule from ~1 month to ~1 week;
- Improve coverage, and improve throughput performance for indoor users by a factor of 2 to 4 without affecting outdoor users;
- Enable enterprises for independent deployment with simple guidelines, using the same resource as for Wi-Fi deployment [10].

Performance gains from UltraSON-enabled SCs were validated in a building on Qualcomm office campus, not only in a test network, but also in a commercial network.

Simple and cost-effective SC deployment based on UltraSON can enable operators offer SCs to SMBs as mere regular subscriptions. On the other hand, operators using traditional deployments have been quoting large amounts, ranging from $20,000 to $80,000 for such deployments. Thus UltraSON can help operators tap new market segments hitherto unreachable due to prohibitively high costs.

UltraSON facilitates deployment of SCs by enterprises. UltraSON-enabled small cells, together with proper network setting minimize impact on existing macro network performance, effectively unlocking the market for massive SC deployments and addressing the 1000x data challenge [11] one SC at a time.

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