The Hype & Reality of Small Cells Performance

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Heterogeneous networks (HetNets) consist of large (macro) cells with high transmit power (typically 5 W – 40 W) and small cells with low transmit power (typically 100 mW – 2 W). The small cells are distributed beneath the large cells and can run on the same frequency as the large cell (co-channel), or on a different frequency. As an evolution of the cellular architecture, HetNets and small cells have gained much attention as a technique to increase mobile network capacity and are today one of the hot topics in the wireless industry. Many of the initial deployments of small cells are of the co-channel type. Standards such as LTE have focused on incorporating techniques to improve the performance of co-channel deployments in earlier releases of the technology standard leaving the handling of multi-frequency deployment type to later releases. In all, operators today have multiple options of small cell deployment scenarios, operational techniques and technology roadmaps to choose from.

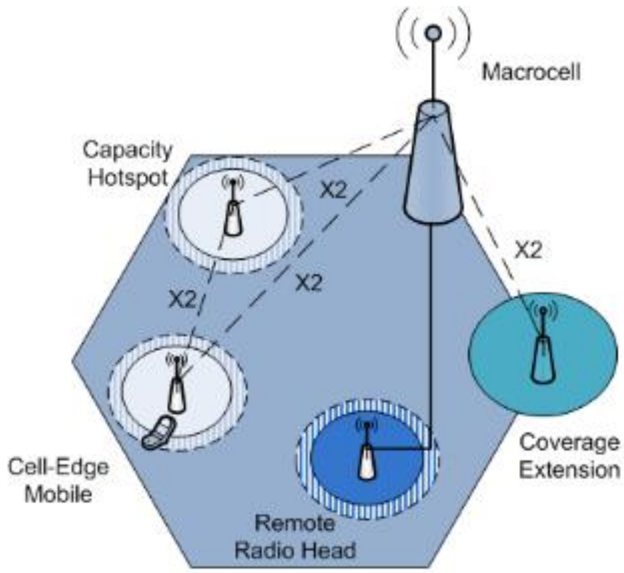

Figure 1 Simplified Heterogeneous Network Architecture.

To illustrate some of the deployment issues related to small cells, I will provide in this article a qualitative review of small cell performance and explore their impact on the operator's small cells deployment strategy. The focus is on co-channel deployments which aside from being common in this early stage of HetNet evolution, they provide for a complex radio frequency environment.

Throughput Performance: The overall throughput experienced by users on both downlink (base station to the mobile subscriber) and uplink (mobile to base station) paths will generally increase as small cells are deployed. This applies to both users camped on the macro cell and those on the small cells, but for different reasons:

a. The users on the macro cell will benefit as more small cells are added because fewer users will share the common capacity resources. Therefore, the more small cells are added, the better likelihood a user on the macro cell will experience higher throughput; meanwhile,
b. Users on the small cell will experience better throughput than those on macro cell because of higher probability of line-of-sight connection to the serving base station.

If the mobile subscribers are uniformly distributed over the coverage area, then the likelihood a user will experience a certain level of throughput is approximately similar as the number of small cells increases. But in reality, the distribution of users is not uniform as they tend to concentrate in certain "traffic hotspots." In this case, a small cell in a traffic hotspot is expected to provide lower throughput than a small cell in a uniform user distribution area. In the meantime, a user on the macrocell will experience a more pronounced increase in throughput because a higher proportion of users are offloaded from the macro cell. As even more small cells are added, interference will increase leading to successively diminishing marginal increase in throughput.

This last note is an important one: small cells are beneficial up to a point. The user experience will be affected by the density of small cells with a diminishing marginal return followed by actual degradation of service as the number of small cells exceeds a certain threshold. When this threshold is reached depends on a number of factors that include the type of technology, morphology, and cell density and distribution. Inter-small cell interference is one factor that limits small cell performance. Another factor is that as we add more small cells, we create more 'cell-edge' regions within the coverage area of macrocells that can also limit performance as I will expand upon below.

The throughput performance will depend on the location of the small cells and their proximity to macrocells. A small cells close to a macrocell is more likely to be affected by interference than one located at the cell-edge resulting in lower throughput performance. Correspondingly, the performance will depend on the size of the macrocell, or rather, the macrocell density. Small cells deployed close to the cell edge of a large macrocell will provide better performance than those deployed in high-density macrocell area where the average radius is relatively small.

Throughput performance will also depend on the output power of the small cell. Simulations show that for a certain macrocell radius, higher power small cells provide better throughput performance than lower power ones given the same small cell base station density.

Nevertheless, the key take away here is this: it pays to find out where the traffic hot spots are as otherwise, the gain achieved from small cells will be small. Small cell deployment would have to be 'surgical' in select areas to achieve the maximum return on investment.

Interference and Coverage Performance: While small cells improve performance in general, there are certain situations where they cause interference or even a coverage hole. One decisive factor is the large power imbalance between the small cell and the macrocell. The power imbalance is larger than simply the rated transmit power because macrocells implement high-gain sectored antennas (13-16 dBi) while small cells typically implement a much lower gain omni-directional antenna (3-6 dBi). The power imbalance results in asymmetric downlink and uplink coverage areas. Because the macrocell has much higher power than the small cell, the downlink coverage area of the small cell would be smaller than the uplink coverage area. This shifts the handover boundary closer to the small cell increasing the possibility of uplink interference to the small cell with which the interfering mobile might have a line-of-sight path. This type of interference is potentially very damaging since it affects all the users in a cell and forces the mobile units served by the small cell to transmit at higher power. The power imbalance also increases the risk of downlink interference although this type of interference is more limited because it affects a single user. The uplink-downlink imbalance is a leading reason why LTE Release 8 small cell gain is limited because cell selection is decided by downlink signal strength and the options for interference mitigation are limited.

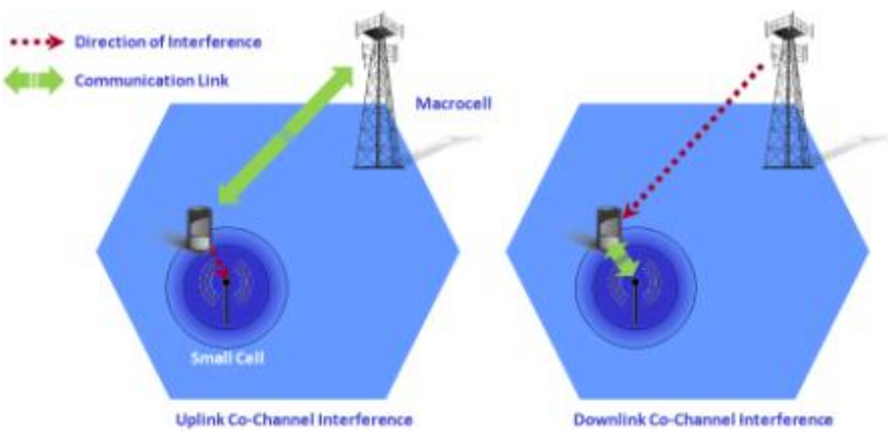

Figure 2 Co-channel interference scenarios in small cell deployments.

To address the uplink-downlink coverage imbalance, the coverage area of the small cell base station is extended to allow the small cell to capture more traffic. This is accomplished by adding a bias to the small cell received signal during the cell selection process. But extending the small cell coverage also increases the chances of downlink interference to a mobile subscriber operating at the edge of the small cell.

Aside from co-channel interference, there's also a risk of adjacent channel interference in multicarrier networks where macrocells implement two or more frequency carriers. Consider for example a mobile attached to a macrocell on frequency A while it is very close to a small cell operating on adjacent frequency B. The mobile is susceptible to adjacent channel interference from the small cell which would likely have a line-of-sight path to the mobile in contrast to a non-line-of-sight connection with the macrocell. Another example is that for the uplink: a mobile attached to a macrocell and operating from the edge of a small cell on an adjacent frequency could cause interference to the small cell.

There are other potential interference scenarios in addition to those described here. But the basic fact is that the actual performance and benefit of small cells will vary, and will do so more widely in the absence of interference mitigation/performance enhancing techniques. This is one reason why some requirements for small cell deployments have been hotly debated, without a firm resolution. For example, a basic requirement is that of small cell backhaul capacity: what should it be? Should the backhaul link be designed to handle the peak throughput rate, which is a function technology, or the average throughput rate which is much harder to ascertain and put a value on because it depends on many factors related to the deployment scenario?

Based on the above description, we know that throughput of small cells will depend largely on the load. The more clustered the subscribers, the lower the overall small cell throughput. On the other hand, if there's a light load (few users), then the capacity will be high. If you are an operator, you sure would need to think carefully about the required backhaul capacity! And while we're on the backhaul topic, let's not forget that we also need to make sure that backhaul on the macrocell is dimensioned properly to support higher traffic load which will certainly come as more small cells are deployed.

In this post, I went through some aspects of small cell performance. These problems are well recognized and certain techniques are being developed and integrated into the standards to address them. This raises other important questions to the operator's strategic network planning process, such as: what interference management and performance enhancement features should be considered? And, what is the technology roadmap for these features? I will expand more on some of these techniques in a future blog post.

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