Small Cells – Effective Capacity Relief Option for Heterogeneous Networks

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Abstract— **The effectiveness of the small cells for capacity relief in modern heterogeneous networks is analyzed. Based on the real network traffic data, we demonstrate that a few (1 to 3) properly deployed small cells in less than one third of the present macro sectors can often triple the network capacity, due to the non-uniformity of the traffic load. Some practical issues related to planning and deployment of the small cell solutions in the field are also discussed and a few real life examples shown.**

Keywords-small cells, capacity relief, Heterogeneous Networks, capacity planning, RF tools

I. INTRODUCTION

Carriers are preparing their networks to handle an explosive growth in wireless traffic, especially data. The deployment of "typical" (macro) cells, new 4G technologies and acquisition of spectrum in many cases may not satisfy that demand.

Various forms of heterogeneous networks, with small, strategically located cells for capacity offload, are presently considered as a promising complement to typical macrocellular deployments for meeting the forecasted demand.

In this paper, we consider low-height and low-power small cells with the typical radii of around 100-200m. By using real traffic data, we demonstrate that a few properly deployed small cells (1 to 3) in less than one-third of the busiest sectors[1] can usually triple the present network capacity.

We further show how optimum small-cell locations can be planned with an almost surgical precision on top of the present traffic "hotspots" by using software tools that show geo-located traffic.

Once the location planning is done, small cells can be deployed by leveraging public Right-of-Way infrastructure. This allows for the surgical placement of small cells virtually anywhere in addition to providing a backhaul connection, within reasonable and predictable time frames

II. TRAFFIC GROWTH CHALLENGE

While the growth rate of voice traffic in wireless networks is slowing down or declining, the mobile data traffic at various cellular operators exhibited year-over-year growth by factors from 3 to 30 in 2010 ([1], Table 1), often in direct correlation to the proportion of smartphones in any particular network.

Forecasts for the overall wireless industry data traffic volume suggest growth by factors from 20-50 [2] from 2010 through 2015, and recently released growth figures for 2011 show that traffic more than doubled both in the United States [3] and globally [4], actually beating most earlier predictions.

Capacity-related network problems experienced after the introduction of smartphones have caused serious problems for customers (and network engineers) during the last few years. This is well documented even in the mainstream media [5].

To deal with the explosive traffic growth, the wireless industry traditionally relied on building new macro sites to offload capacity, new technologies to improve spectral efficiencies and additional spectrum to expand the capacity.

III. CLASSICAL CAPACITY OFFLOAD APPROACHES

The number of new cell sites in the United States was growing annually by rates of less than 3% in 2010 and 2011 [3]. This is mostly due to a combination of zoning, environmental, economic and even technical constraints. In addition, in many urban cores the present (macro) cell radii are already within a fraction of a mile, making further "cell splitting" solutions even more difficult.

Network upgrades from 3G technologies (HSPA, 1xEV-DO) to 4G (LTE) that are currently underway will improve the network capacity by a factor of two or more, depending on the point of reference and assumptions, but in most cases will not resolve the capacity challenge on their own. And in many cases these gains for some time will be offset by spectrum clearing and subscriber migration problems.

It should be further noted that all modern air interface technologies are already performing quite close to the Shannon limit (in terms of bps/Hz, [6]). Although the question of how big the gap is on real wireless channels is still under investigation [7], future access technology improvements will pro-

[1] In 3GPP nomenclature, "sector" is usually referred to as a "cell".

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vide diminishing returns on very large investments.

Furthermore, some of the theoretical gains in the latest wireless standards could be hard to achieve in practice, especially those coming from MIMO (due to practical constraints on the number of antennas that can be deployed, and in many cases on the richness of the multipath encountered in the field).

As for the additional spectrum, the consensus within the wireless industry is that the capacity challenge will ultimately not be met strictly with new spectral resources. However, spectrum is a scarce and accordingly priced commodity. Further, it is hard to predict if and when spectrum may become available; success in a bidding process is anything but certain. The use of new spectrum also requires significant network and end-user equipment upgrades and often a serious engineering effort, increasing the timeline and cost.

IV. SMALL-CELL CAPACITY RELIEF

Where macro sites are not a viable option, alternate approaches were considered in the past where capacity offload was to be achieved by adding small cells within the existing macrocell network, specifically targeting the traffic hotspots.

Traditionally the high-traffic demand was located at the high customer density areas such as airport terminals, college and business campuses, stadiums, busy shopping malls, etc. These were rather easy to recognize, and in many cases by now have some form of small-cell capacity offload solutions already deployed by the wireless operators.

In recent years, new hotspots are often found in dense urban areas, in and around large office or residential buildings, where high traffic volumes are much harder to predict (and often vary dramatically from one building to the next, in some cases apparently correlated with the presence or absence of the large corporate accounts). Latest data suggests that hotspots are appearing in the classical suburban areas too, where a handful of customers can create huge (data) traffic demands.

Throughout the years small-cell solutions came in a variety of practical implementations and under a number of different names, such as:

- Microcells [8]
- Pico- and femtocells [9]
- Distributed Antenna Systems (DAS) and Remote Radio Heads (RRH, see [10] and references therein)
- Relay Nodes [11]
- Repeaters [12]

From the mobile terminal perspective, there is usually no functional difference between micro-, pico- and femtocells, with the main distinction being their progressively smaller cell sizes, much smaller than traditional macrocells. From the network operations perspective, however, additional auto-configuration functionality is highly desirable for any kind of small cells intended for massive deployments.

These three categories are also expected to be progressively smaller in terms of the enclosure size and price, in part because of the smaller transmit amplifier powers and no need for air conditioning, and often because some of the requirements can be relaxed relative to the macrocell (e.g., maximum number of connected users, total cell or peak user throughput, etc).

DAS and RRH nodes can be viewed as a method to implement small cells where the bulk of the conventional cell electronics can be deployed far away from the transmit antennas. This simplifies the zoning and site-acquisition costs in the outdoors, and the installation issues in the indoor deployments, as further discussed in Section VI.

While the fiber links are by far the most popular choice for connecting the DAS and RRH nodes, relay nodes rely on backhaul over the wireless link from the "donor" cell, most often in the same frequency band as used by the air interface ("out-of-band" relays are also possible). The present trend is to make relay nodes operate like separate entities as seen by the mobile terminals, rather than as just the extension of the donor cell, in which case better performance can be achieved at the expense of a "reasonable amount" of extra complexity.

Repeaters are usually much simpler devices, often not much more than a bidirectional RF amplifier. They can be viewed as providing the "in-band" backhaul, but in the small-cell context the repeaters are considered primarily as a solution for filling coverage holes. The capacity offload is possible with repeaters too, although with more challenges on the RF engineering side. They are also sometimes viewed as "amplify and forward", as opposed to the more complex "decode and forward" relay nodes discussed earlier in this section.

All of these small-cell solutions can be deployed in various overlay/underlay, indoor/outdoor or private/public scenarios.

A femtocell, for instance is most often used to denote a residential indoor cell with access restricted to a "closed subscriber group" (i.e., a "private" cell). Microcell usually refers to outdoor cells with unrestricted access, while picocell sometimes denotes an "enterprise" flavor of a femtocell (i.e., higher capacity indoor) and sometimes an outdoor hotspot cell similar to a microcell. The nomenclature is still far from uniform.

Various forms of "heterogeneous" networks ("HetNet", see [13] and references therein), where any of these forms of small cells are combined with classical macrocells, are attracting lots of attention, as the most promising way to meet the forthcoming capacity demands.

Although the small-cell concept has been around in some shape or form since the mid-90s, actual deployments were limited by:

- lack of economical solutions for electronics and backhaul;
- zoning and site acquisition problems, long lead times and high costs; and

- limited knowledge about the specific location of traffic hotspots.

An additional difficulty is that small-cell deployments require some level of RF optimization work if they share the same spectrum as macrocells, to ensure that the interference to-and-from them is properly managed. Sometimes optimization is also needed to ensure that mobile terminals actually select the small cells in heterogeneous networks.

Due to well contained RF footprint, the interference problems for small-cell deployments can be more easily managed, and newer technology standards provide additional means to deal with both the interference and cell selection issues [14].

V. WHY ARE SMALL CELLS SO EFFECTIVE?

The main objective during the initial deployment of a cellular network is to provide as much coverage as possible at the smallest possible cost. This is normally achieved via large (macro) cells, which follow some type of a grid plan and have quite uniform (and high) transmit power levels.

Normal hexagonal grid patterns lead to high coverage efficiency and performance, but impose constraints on site locations and on antenna azimuth orientations. Due to uniform geometric patterns network designers do not have the flexibility to pinpoint sites to the traffic patterns (which are often not well known in green field deployments anyway, and evolve with new devices, applications, subscribers, etc.). As a consequence, all macrocell ("homogenous") networks usually end up with a very uneven distribution of the traffic among the deployed sectors.

An example of actual traffic distribution from a large, operational CDMA network in the United States is depicted in Figure 1, which shows the cumulative histogram of the sector busy hour traffic values.

Curves like this can be easily made based on per-sector traffic information from the Performance (Service) Measurements available in the networks, or a number of specialized tools.

We see that about 70% of the sectors support less than one-third of their available capacity. Traffic load is not uniformly distributed across sectors in a macrocell network. Thus, our first major result: if only 30% of the busiest sectors can be efficiently offloaded, network capacity could triple.

We note that traffic distributions like the one in Figure 1 are rarely reported in open literature, with a possible exception of the one from an older AMPS/TDMA network [15], which showed quite similar behavior. We expect that in modern non-CDMA macrocellular networks the distributions might be even less uniform than in Figure 1. Conventional wisdom is that CDMA, with its frequency reuse of one, allows for more flexibility with grid layouts than some other technologies.

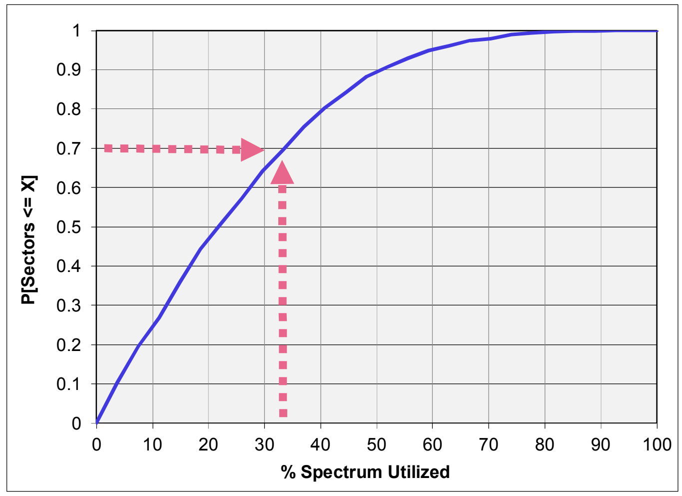

Figure 1: Traffic distribution among sectors
(data from an operational CDMA network in USA)

The second result of our analysis is that traffic within the busy sectors is usually not uniformly distributed either. Apart from maybe a few stadiums or airport terminals, largest traffic loads are generated by "hotspots" around shopping malls, larger offices or residential buildings, busy highways or traffic intersections, all of which typically cover much smaller areas than the busy sectors do.

This is quantified in Figure 2, which is based on the data from the same market as in Figure 1. We see that in a typical sector about ½ of the traffic is generated within ¼ of the sector coverage area.

Given that in metropolitan areas the busiest sectors often have radii of the order of 1km, simple calculation shows that typically around 50% of the sector traffic can be offloaded by one small cell with radius of about 300m. Since the hotspots are sometimes not adjacent, 2 to 4 small cells with slightly larger or smaller radii might be required.

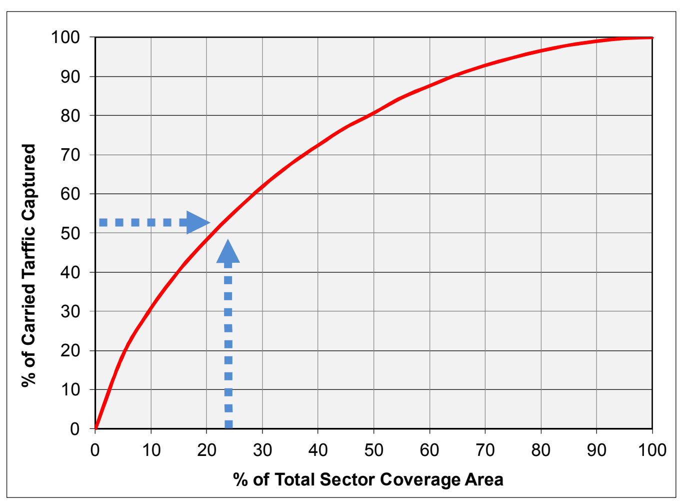

Figure 2: Traffic distribution within sector coverage area
(plot created by using data from TrueCall)

Ultimately, in most markets we find that by deploying 1 to 3 small cells in up to 30% of the network's sectors, the network capacity can be doubled if not tripled without acquiring new spectrum or any technology upgrades.

To create a plot like that in Figure 2, we note that specialized tools are needed, which can geolocate the actual traffic within the coverage area of each cell.

VI. Small-Cell Deployments

Small-cell deployments are able to cover all wireless technologies from 2G to 4G and all frequency bands. They are also able to leverage several available RAN equipment architectures, including fiber DAS, micro-/picocells, and Remote Radio Heads (RRH) or Distributed eNodeB equipment.

Generally they use lower-output power, and are deployed at lower radiation center heights (e.g., on existing utility poles or streetlights). Output power, however, can range between 1 to 4 Watts per MHz of spectrum, up to 40 Watts aggregate per band. Many small cells deployed support multiple bands and even 2x2 MIMO.

Radiation centers are typically from 10 to 15 meters. The lower heights provide for contained coverage footprints, typically within a few hundred meters, which is ideal for capturing traffic hotspots and minimizing interference. Two typical deployment examples are shown in Figure 3.

In the last several years, the deployment of small cells has matured in the United States and has been growing at a rapid pace. As a leading provider of shared wireless infrastructure, and one of the pioneers in small-cell deployment, *Crown Castle* has industrialized the process of deploying small cells and dedicated fiber backhaul for virtually unlimited bandwidth to each cell, and in a manner that complements existing macro infrastructure. They have grown to roughly 10,000 small cells on air or under construction and have thousands of route miles of installed fiber across the United States.

Crown Castle leverages Right-of-Way (ROW) infrastructure to deploy fiber transport as well as small cells. Leveraging ROW infrastructure allows for the surgical placement of small cells virtually anywhere, with a defined building and permitting process. This allows for large-scale capacity offload to be deployed within a one-year planning horizon.

Business case for small cells depends on the type of cells and the intended purpose, but in general they are rather easy to make [16], [17].

VII. Small-cell Planning

Traditionally, network operators manage capacity based on Performance (Service) Measurements collected via their infrastructure.

Performance Measurements are generally provided on per-

Figure 3: Small-cell deployments by *Crown Castle*

sector and per-carrier basis, and – while useful for identifying the busy sectors needing capacity relief – they do not provide any indication as to where in the cell the hotspots are and where the relief is actually needed.

Traffic hotspot locations can be precisely identified by tools that show the geo-located traffic from live networks. One such tool is *TrueCall,* a software product from *Newfield Wireless.*

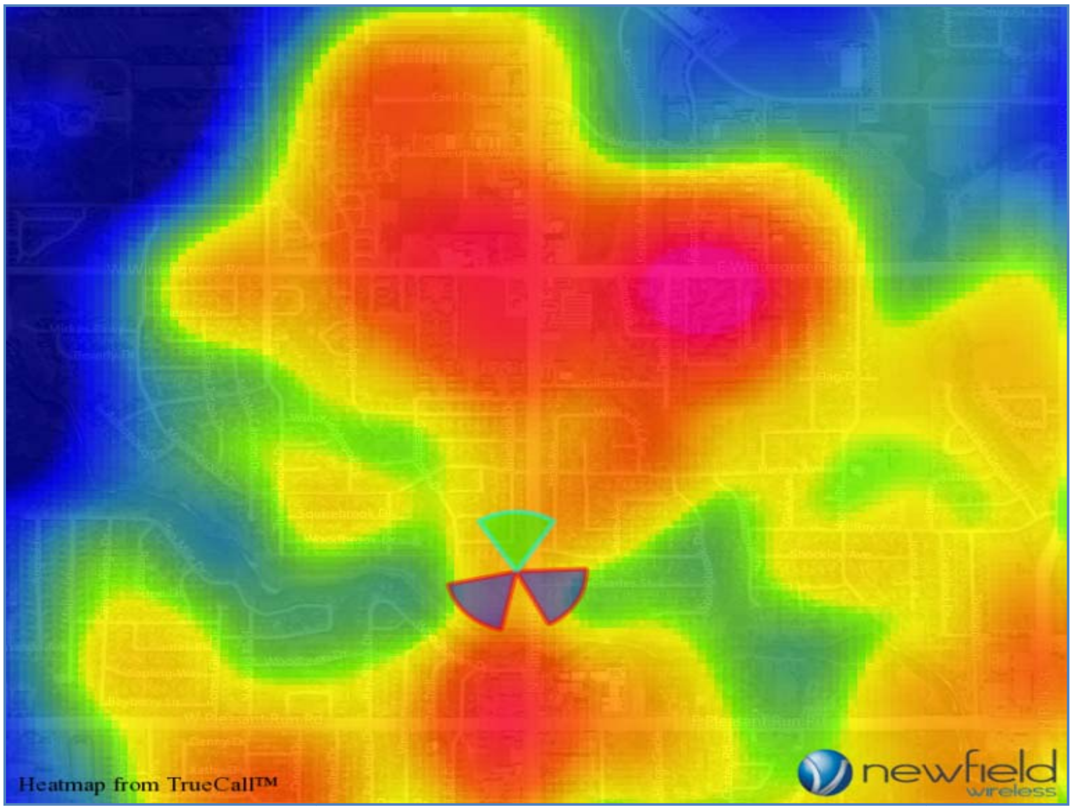

Figure 4: Hotspots within a sector – *TrueCall* snapshot

TrueCall provides traffic maps for various access technologies (CDMA, EVDO, UMTS, LTE), as well as maps showing trouble spots (drops or failed attempts), various RF parameters (measured RSRP, RSRQ, CINR, EcIo, handoff status, etc.).

All maps are based on geolocation of voice and data calls in operational systems, by using information already available in the core network, i.e., without any handset client. The application can also provide a drill-down to the individual call level, or various views per service type, network element, subscriber ID, device model, geographical area, etc. The tool presents this information in real time or based on historical data. Its various features are presently used by RF Performance and Coverage/Capacity Planning Engineers, as well as personnel from Customer Care, Marketing, Regulatory, Finance and Subpoena Compliance departments at several major operators.

In the context of small-cell planning, tools like *TrueCall* provide a means to identify sectors needing capacity relief and to locate traffic hotspots within each of them. A special capacity planning module will be available, to automate this process and accelerate development time. This module can ultimately create a list of proposed search ring centers for deployment of as many small cells as needed to meet the target capacity levels in each of the sector that is to be offloaded.

Economically, small-cell planning tools will pay for themselves with the first surgical placements on top of the *real hotspots*. A reduction in the required number of small cells by only 3-4 will save more than the cost of a tool like *TrueCall.*

VIII. Conclusions

Based on traffic data from real networks, we showed that the small cells are very efficient option for capacity relief. Effectiveness is fundamentally due to the traffic non-uniformity, which in conventional macrocell networks is twofold:

1) Large concentration of traffic in relatively few sectors – offloading about 30% of the busiest sectors can triple network capacity (70% of macro sectors are loaded up to less than one-third of their capacity); and,
2) large concentration of traffic within busy sectors – more than 50% of sector traffic generated in less than 25% of the sector area.

We further discussed the practical design and deployment options for small cells, showing that they can be a very effective solution for capacity relief as part of the overall heterogeneous network architecture.

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