Developing and Integrating a High Performance HET-NET

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EXECUTIVE SUMMARY

With relentless mobile data growth and proliferation of new data hungry devices, mobile operators around the world are considering new and innovative mobile broadband network deployment models. A heterogeneous network (HET-NET) consists of different wireless technologies working together to provide a seamless wireless experience to the end user.

This white paper addresses different aspects HET-NET architecture. This includes challenges arising out of bringing backhaul to the locations where coverage and capacity is needed, along with the associated challenges with radio access and core network.

This paper is structured as follows:

- **Section 1: Background**
  - Provides an overview of the drivers in the industry that lead us towards HET-NET deployment.
  - Architecture discussion and overview of different technologies in HET-NET.
- **Section 2: Problems / Key Challenges**
  - Outlines the challenges in the areas of backhaul, mobility management, and location planning and traffic management.
  - Challenges related to design and deployment of networks, interference, operations, and capacity management are discussed.
  - Security (information and physical) are of concern in HET-NET networks, as backhaul, back office, and integration is more open than in traditional cellular networks.
- **Section 3: Key Enablers in HET-NET**
  - This section is aligned to a large extent with the corresponding problems/challenges sections.
  - The enablers include key functionality and advancements in the industry that address the problems / challenges identified in Section 2.
  - Technical overview of important HET-NET enabling features in both cellular and non-cellular networks is provided.
  - Site solutions that support the working of the complementary networks in a HET-NET are addressed along with the enablers in the OSS/BSS domain to address the operational aspects for the combined network.
- **Section 4: Recommendations**
  - This section is aligned to a large extent with the corresponding problems / challenges sections.
  - Recommendations are geared towards key stakeholders, which include telecom vendors, operators, service providers and other enablers in the industry that will now be working with a converged wireless network.
- **Section 5: Conclusions**
  - Conclusions section summarizes the findings from this white paper.

- **Section 6: Appendix**

    - Appendix section has acronyms and detailed technical material. Details on some of the Key Enablers in Section 3 are addressed here**.**

1 BACKGROUND

1.1 WHAT IS HET-NET?

1.1.1 OVERVIEW

As smartphone and data device penetration increases rapidly, and new data hungry applications become prevalent, the demand for Mobile Broadband (MBB) is growing exponentially. This growth requires significant increases in network capacity, starting with RAN. The choices available to operators to increase network capacity include deployment of advanced technologies like LTE to increase spectral efficiency, additional spectrum, building new cells, splitting cells, and deploying small cells. Acquiring new spectrum and building new macro sites is extremely expensive and cumbersome. Additionally, research shows that the traffic distribution is uneven and 80 percent of the traffic is carried by 20 percent of the cells in hotspots for some carriers. Studies have shown that deploying small cells in hotspots might significantly increase the network capacity as networks become layered and dense. A Heterogeneous Network (HET-NET) is comprised of traditional large macrocells and smaller cells including microcells (<5W), picocells (<1W), and femtocells (200mW). In addition, Wi-Fi can also be used as an acceptable mechanism for traffic offload. This White Paper will discuss the benefits of HET-NET and the challenges associated with building a HET-NET.

For the purpose of this white paper, we will look at both HSPA and LTE HET-NET as some carriers might deploy HET-NET with HSPA technology as well, even though much of the benefits of HET-NET will be realized with LTE and advanced features as defined in the 3GPP Releases 11 and 12. The white paper will explore the building blocks for HET-NET including hardware and software. It will explore the basic challenges of accurately deploying the small cells at hotspots, easy and interference free deployments, handing off between the macro and small cells in a multi-band and Multi-RAT environment, as well as assessing the real impact on overall spectrum efficiency and capacity gains. This white paper also addresses the solutions for backhaul for HET-NET deployment and provides a pros and cons analysis.

Some of the deployment models supporting HET-NET include distributed antenna systems (DAS) and relays. Distributed antenna systems could be active or passive. Active models use Remote radio units providing coverage over a large area connected by fiber to baseband units. These active models may also use relays to provide focused capacity and coverage far from the baseband unit. The Passive DAS models consist of an antenna system driven by one or many radio units.

Figure 1 : HET-NET

1.1.2 VALUE PROPOSITION FOR HET-NET

HET-NET provides two basic benefits to operators:

- Increases capacity in hotspots as traffic is not uniformly distributed.
- Improves coverage in places where macro coverage is not adequate.

Network voice and data traffic is not uniformly distributed. Some studies have shown that 80 percent of the traffic is carried by 20 percent of the sites. There are areas within the network like campuses, malls, and stadiums where people gather and use their voice and data devices to interact and entertain. Deploying lower power small cells is a cost-effective way to provide additional capacity for these bandwidth hungry venues.

Lower power small cells are also a good way to improve coverage in hard to reach areas where macro coverage is not adequate and building additional macrocells is not cost-effective. A good example is femtocells that some operators use for residential coverage and small enterprises.

In addition to this, HET-NETs also allow for efficient capacity management as devices get smarter and select the best access with network support. This allows for efficient use of scarce spectrum and continuity in a converged wireless environment.

1.1.3 KEY BENEFITS

Heterogeneous network architecture enables an operator to meet requirements of coverage and capacity in the most cost-effective fashion. Traditional high power macrocell deployments can provide coverage to large areas, fulfilling needs for ubiquitous connectivity. The resulting capacity density is low and insufficient to meet growing capacity requirements in hotspots within each sector. This may be addressed by additional spectrum or expensive cell splits to increase spectrum reuse. Selective deployments of small cells could provide a means to scale and deploy additional capacity at a lower cost.

Several factors listed below can enable lower deployment and OPEX cost for small cells relative to macro base-station cell splits.

- Smaller form factors enabled by tight radio integration to baseband and SoC availability
- Support for flexible installation options (pole, strand, etc.)
- Ability to re-use existing transport
- Ease and lower cost of install and site build-out
- Lower cost of radio equipment

3GPP CELLULAR

The addition of small cells to existing network infrastructure could mitigate or delay the need for additional spectrum and capacity for operators who do not have enough spectrum to meet the growth. Spectrum is the key ingredient with much more needed throughout the Americas region, but solutions to increase capacity can improve network performance.

Figure 2 below provides a view of relative gain in spectral density for different deployment choices, with increasing spectral density achieved using lower power pico and indoor femtocells deployed over smaller coverage areas. A combination of macrocells and small cells provides an operator tools to engineer a network to deliver ubiquitous coverage and targeted capacity in hotspots creating demand.

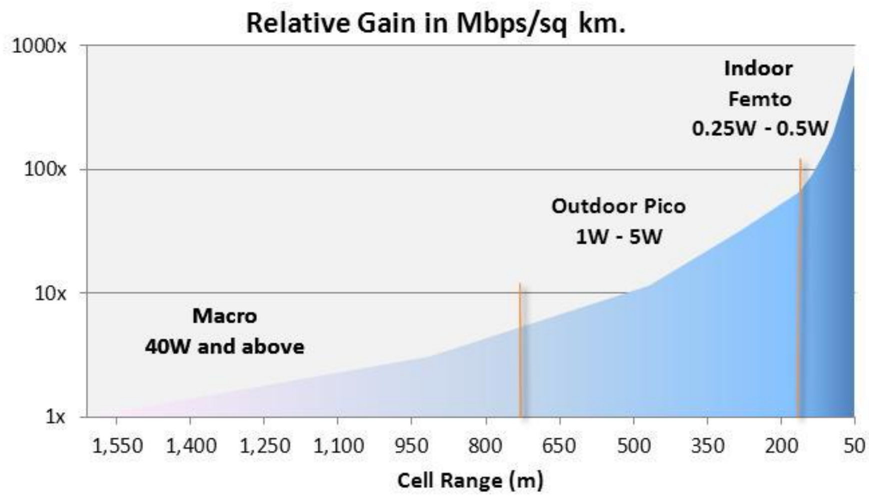


Figure 2: Relative gain based on topology

Simulations of HET-NET deployment scenarios (4 picocells in each macro sector per 3GPP 36.814) show capacity gains over 10x. Users connected to the macrocell benefit from offloading gains due to additional resource availability on the macrocell. Users connecting to small cells experience signal quality improvement (especially in in-building deployments) in addition to the spectral reuse gains resulting in high capacity availability in the small cell coverage area. The additional capacity available to the macrocell and small cell can be dedicated to improved service quality or to accommodate additional users. In addition to capacity gains, HET-NET's enabled UEs reduce transmit power and promote much improved battery life. The factor of reduction in transmit power can be significant, especially in indoor deployments. This is another key benefit that improves overall user experience beyond enhancement to the quality of services offered and capacity.

WIFI

The strong success of Wi-Fi in enterprise deployments has contributed to increasing interest from the carriers in the WLAN technology using ample unlicensed spectrum. Wi-Fi is viewed today as another tool in the carrier arsenal to provide the much-needed capacity for satisfying the rapidly growing demand for mobile data. Offloading traffic from cellular to Wi-Fi can be a cost-effective strategy to relieve the capacity crunch experienced today in mobile broadband networks.

Carrier grade Wi-Fi can be deployed using stand-alone Wi-Fi AP's and/or integrated small cells with both HSPA and LTE. This depends on the coverage-capacity model sought. End users usually expect continuous or blanket coverage in indoor public space, e.g., mall, stadium, and hotels. On the other hand in outdoor scenarios coverage is provided where people congregate (hotspots). Given the disparate footprint of cellular and mobile broadband technologies, when deploying integrated small cells indoors it would be cost prohibitive to deploy integrated small cells based on the smaller coverage. Instead, the heterogeneous network will consist of integrated small cells as well as Wi-Fi AP's to provide the continuous coverage. Also, in certain places where high traffic is expected (conference rooms, stadiums); only Wi-Fi AP's will typically be added to the network.

Most carrier/enterprise grade Wi-Fi AP's have dual radio dual band (2.4 and 5 GHz) with at least 2x2 MIMO. Such an AP can provide peak aggregate throughput of over 200Mbps to augment the capacity delivered by a cellular small cell. This enhanced capacity depends on the distribution of end user devices (laptops, tablets, and smartphones) each having different wireless capabilities. In the future, the usage of the 5 GHz band will further increase leveraging over 300 MHz of unlicensed spectrum promoting dense deployment of AP's to further scale capacity density as needed. Ultimately, the synergies of using both WiFi and cellular will result in improved cost-performance.

1.2 HET-NET ARCHITECTURE

1.2.1 CELLULAR TECHNOLOGIES

In traditional cellular systems a network of single layer macrocells is deployed with similar characteristics such as transmit powers and antenna patterns. Network capacity may be increased deploying more macrocells, but site acquisition costs and high interference between cells makes this option less attractive. Cellular HET-NET's rely on deploying additional layers of lower power base stations with a lower antenna height to overcome these limitations.

Cellular HET-NETs are not really new in the operators' network deployments. For example, it has been common in 2G multi-frequency networks, using technologies like GSM, to place micro base stations to provide capacity in hot spots. In this case the key point for having made possible the deployment of HET-NET's was the availability of many frequencies, which could be used to isolate the macro layer from the micro layer, and efficiently divert traffic from one layer to other.

Unfortunately HSPA and LTE networks do not enjoy such multi-frequency advantage. Being basically technologies for single frequency network deployments, the macrocell layer and the small cell layers will compete for the same radio resources, and this will have an impact of the HET-NET architecture if these limitations are to be overcome.

The LTE approach for optimum spectrum usage has been to move the radio resources assignment to the base station, the eNB, in order to minimize the delays and provide the currently available resources to a UE, thereby leveraging on direct communication between eNB's (the X2 interface) for coordination between base stations. This has led to a so-called flat architecture, where all the radio protocols are managed by the eNB's without any central control from the core network which must be used, or perhaps adapted, for a multi-layer heterogeneous network.

In such a network, the operator will face some challenges that are not fully solved in the current standards. One example is the balance of the traffic load between different layers in the HET-NET. In LTE the handover between base stations is autonomously decided in the eNB, taking into account radio link measurements. It is difficult to enforce load diverting policies between layers, as policies should ideally be UE specific and dynamically changed by the operator. Another example is the inter-layer coordination for efficient radio resources assignment, which is now based on the X2 interface and non-standardized assignment algorithms in the eNB's. This can be problematic in a deployment scenario where different layers of base stations are provided by different suppliers. These limitations for an efficient HET-NET operation could require some future updating of the current LTE network architecture.

1.2.2 WIFI

Wi-Fi technology is considered by the mobile operators as a possible way to reduce the traffic load supported by their networks operating in licensed spectrum. Currently, most of this traffic is offloaded by means of the access points located at the customers' premises, where the operator has little control of the offloading performance, or by means of public access points located in high traffic locations. Therefore, it is still an independent network with much reduced coordination with the mobile network, limiting the benefits of a true mobile HET-NET.

There are two parallel but not still convergent initiatives to achieve an interworking HET-NET that fully includes Hot Spot 2.0 and I-WLAN. Hot Spot 2.0, promoted by Wi-Fi Alliance, is quite advanced and expected to start its certification program by the end of 2012. Its current focus is on simple network discovery and authentication and roaming between networks, but its full interworking with 3GPP networks does not meet mobile operators' requirements yet. On the other hand, I-WLAN, promoted by 3GPP, integrates a Wi-Fi network as another radio access that can be connected to the mobile core network and managed as a single HET-NET, applying operator's policies for which radio network must provide a given service to a specific user. However, I-WLAN development is not currently fully compatible with Hot Spot 2.0 and delayed with respect to this Wi-Fi Alliance initiative.

The outcome of these two parallel developments is still unclear, but in the long term the most effective, integrating HET-NET, would allow a seamless integration of Wi-Fi as another radio technology, and the application of operator's policies (e.g. ANDSF solutions) as it is promoted by 3GPP, including Hot Spot 2.0's network discovery, authentication and roaming features as an integral part of it.

One of the main drawbacks of I-WLAN when integrating Wi-Fi to the EPC is requiring IPSec tunnel from the mobile to the PDN gateway (P-GW) because it is treated as an **untrusted** network. This results in a large number of IPSec tunnels making this approach not scalable as it puts a significant load on the P-GW. With operators owning the AP's (or integrated LTE- small cells), and with the enhanced security measures when using Hotspot2.0 (strictly using WPA2-AES server mode), it is treated as a **trusted** network. Taking this into account, the 3GPP added a new feature in Release 10 known as S2a based mobility over GTP (SaMOG). In this architecture, the secure IPSec tunnels are established between the AP and the P-GW, reducing the number of tunnels and the load on the gateway. The air link between the mobile and the AP is secured through 802.1x EAP-SIM/AKA authentication and AES128 encryption. The small cell is serving as the authenticator and connected directly to the EPC AAA server over STa interface. The S2a interface facilitates a Proxy Mobile IP (PMIP) tunnel allowing network managed offload anchored at the P-GW with service continuity transparent to the user. The network managed offload is of great importance to the service provider as it controls the offload process and maintains visibility with the subscriber rather than letting him wander to a random AP and lose services opportunities (e.g., location based services). With the emerging model of Wi-Fi as a trusted network on the 3GPP network, it is expected that operators will prefer the SaMOG method over I-WLAN.

1.2.3 FEMTO CELLS

Femto cells are already positioned as a technology for providing indoor coverage, usually at home locations. Even though they are part of the operator's mobile network, their coordination with the macro layer, including aspects like interference mitigation and mobility management, is not fully achieved in current deployments and they cannot be considered to be part of a unified HET-NET.

On the other hand, femtocells are expected to be positioned as a new small cell alternative to the micro and picocells. New generation higher capacity femtocells are designed to be deployed in outdoor high traffic locations and enterprise environments, blurring the boundaries of what is defined as a femtocell. They face similar challenges to other small cells alternatives, like automatic configuration, interference management, and interworking with the macro layer or load balancing between layers. From this point of view, femtocells for public service are synonymous of small cells, perhaps involving a somehow lower power or capacity than other implementations of that concept.

Given their low-power and low-capacity characteristics, femtocells for outdoors can provide service in a limited area and therefore they should be deployed in large numbers, requiring a low cost per installed femtocell. There are obvious similarities between this kind of deployment and that based on technology (e.g. low cost and moderate capacity per access point). This is leading to foreseen combined femtocell / deployments in order to share costs like site rental and backhauling in what could be a true interworking mobile and Wi-Fi HET-NET.

1.2.4 HETEROGENEOUS NETWORKS

A heterogeneous network aims to bring together these disparate wireless networks and technologies to provide a seamless experience. This can occur in multiple ways. To realize this requires functionality to handover within/between technologies in devices, networks. Initially, there is also a need for end user awareness to manually select the best access for maximizing the mobile broadband experience.

A HET-NET may be implemented with a combination of approaches like:

- Device Driven
- End user driven
- Core Network driven

Details are in the subsections below.

DEVICE DRIVEN:

This is the status quo today where device intelligence and priority drives selection and reselection of networks. This leads to loss of operator control in ensuring a consistent network controlled experience. This behavior is usually transparent to the end user. Some of the mechanisms to implement a HET-NET are End-User Driven and Core network Driven and:

END USER DRIVEN:

The end user makes a conscious choice to move between networks. This usually happens when the different networks in the HET-NET are disparate. In this example, offload is driven by the device based on RF conditions. The user may suffer interruption in real time services if the IP address changes between the core networks serving the heterogeneous wireless accesses.

CORE NETWORK DRIVEN:

In this case, the network monitors and triggers the device to move between the component networks of the HET-NET. The different wireless accesses maybe served by a common core that anchors the IP address, and allows continuity in real time services between wireless access technologies. This allows for a seamless offload.

1.2.5 TOPOLOGIES

Evolution can occur from single technology networks of today to multi-cellular technology, evolving further to multi-technology networks. Topologies for a HET-NET may be of the following types:

- Multiple frequencies of the same cellular technology e.g. HSPA working together.
- Multiple cellular technologies like HSPA and LTE working together.
- Different technologies like cellular (HSPA, LTE) and working together.
- Active technologies like cellular and interacting seamlessly with passive DAS type technologies.

MULTIPLE FREQUENCIES OF SAME CELLULAR TECHNOLOGY

Topology considerations could be viewed as a starting point towards HET-NET. It is aligned with existing multi-frequency cellular network topologies. The HET-NET aspect lies in aligning devices with the larger spread of frequencies involved in the newer cellular technologies like LTE. As spectrum re-farming occurs in the networks between cellular technologies, the resulting effect on device support of frequency technology provides challenges.

MULTIPLE CELLULAR TECHNOLOGIES LIKE HSPA AND LTE WORKING TOGETHER

This is an initial step towards the target topology of cellular technologies working together with each other. The topology requires evolution of network infrastructure to address the variance in RF and packet core technology between HSPA and LTE.

Major impacts in this topology lie in more complexity in cellular technology and spectrum support in devices, the core network, subscriber, and authentication databases.

DIFFERENT TECHNOLOGIES - CELLULAR (HSPA, LTE) WORKING TOGETHER

This topology involves mechanisms by which the device and user accessing multiple technologies is recognized, authenticated, and served seamlessly by both cellular and other accesses. This would use common authentication mechanisms, with common elements in the packet core to provide continuity of IP address and user experience across accesses.

Major impacts in this topology lie in the device, the core network, and subscriber and authentication databases and back end provisioning.

ACTIVE TECHNOLOGIES INTERACTING SEAMLESSLY WITH PASSIVE DAS TYPE TECHNOLOGIES

This topology involves mechanisms by which the combined (active) technologies in the topologies above are extended into passive infrastructures like DAS to further extend their reach. This is a true HET-NET as multiple topologies mesh with one another to provide a continuous user experience across technologies.

This topology may involve some discontinuity in user experience depending on the degree to which the networks are integrated with one another. This integration places requirements on devices and back end infrastructure.

2 PROBLEMS/KEY CHALLENGES

2.1 BACKHAUL CHALLENGES

One of the challenges of providing backhaul to small cells is that they are typically placed in locations that will not have backhaul facilities. Running a fiber optic cable to a lamp post can be extremely expensive even if the distance is only a few hundred feet. There are two basic scenarios that will be used for providing backhaul for small cells:

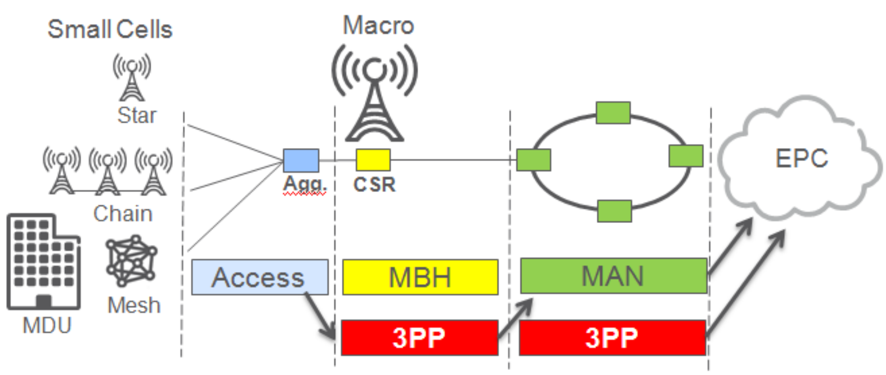
- Macro Subtended: The small cell is connected back to the nearest macro site and uses the macro backhaul facility to get to the core network.

- 3PP Transport: The small cell backhaul is provided by a leased facility from a third party provider, or, if applicable, via the wireline network.

The above could be one of the following (non-exhaustive list):

- Ethernet
- Line of sight microwave
- Non-line of sight microwave
- Fiber

Simple reference architecture would look like this:



This architecture introduces a new concept in HET-NET backhaul network which we can call small cell access. The type of facility used for small cell access can be fixed or wireless. In the case of fixed, a fiber optic cable is preferred, but is the most expensive option. Other fixed options include outside plant bonded copper or VDSL2 or CAT5 cable for in-building deployments like MDU's or large venues. Wireless backhaul options for small cells include, line of sight (LOS) or non line of sight (NLOS), radio, or mesh.

The requirements on the small cell access part of the backhaul are somewhat different to the requirements for macro backhaul (MBH). This access network needs to have:

- Low installation cost
- Low or no MRC (monthly recurring costs)
- An aggregation point for 4 to 16 small cells.
- Hardened outdoor components (e.g. for lamp post deployment)
- Low power consumption

- Small form factor
- High security (e.g. tamper proof, encrypted user plane)

The Quality of Experience for the end user needs to be maintained but the Quality of Service of the individual backhaul facility can be relaxed somewhat compared to a macro site. This is because small cells typically serve one of two purposes: either they enhance voice coverage in poorly covered areas, or they enhance capacity in areas with high data demand. In either of these cases, a short interruption of service is not nearly as catastrophic as an interruption of a macro backhaul facility, since the macro layer can take over a certain amount of the traffic during the interruption. For this reason it is unlikely that redundancy in a small cell backhaul facility is cost justified. Latency and throughput requirements vary depending on the use case of the small cell and whether or not tight co-ordination with the macro layer is required.

The backhaul facility will need to transport S1, X2, Iub, and/or Iuh, and sync interfaces. If access is included in the small cell then IPSEC is usually required. The small cell aggregation gateway can be used to terminate IPSEC tunnels when handing off to a secure backhaul network. Throughput of 50 to 100 Mbps is typically required to handle all of this data, and priority queues are required to make sure priority data gets precedence.

2.2 MOBILITY MANAGEMENT CHALLENGES

While mobility issues in general are essentially the same in a HET-NET as in macro-only networks, namely managing inter-cell handovers and idle-mode mobility, the presence of small cell layer and small cell-sizes creates a new perspective and brings about additional challenges.

- First is the question of idle-UE mobility between small cell and macro layer. Camping strategy is a vital part of idle-mode reselection parameters as it affects the way UE's reselect and camp-on macro- versus the small cells. This essentially determines the idle-mode UE distribution between macro- and small cell layers and affects relative loading between the two layers. The loading and traffic management aspect will be addressed in the capacity management subsection. The camping strategy also has a potential impact on UE battery-life as well as frequency of handovers.

- Increased handovers due to small cell-sizes creates a potential source of DCR (Dropped Call Rate) increase, even when handover success rate remains unchanged (please refer to section 3.2.x for details). To make matters worse (as mentioned a few paragraphs later), a higher failure rate has been observed for outbound mobility from a small cell for high-speed UE's. This can be mitigated by keeping higher-speed UE's sequestered on the macrocell layer, but achieving this requires speed-based traffic steering which is a challenge especially for LTE networks.

- Note: For HSPA Net-Nets, HCS (Hierarchical Cell Structures) framework can be harnessed to achieve speed-based UE segregation to macro layer for idle-mode UE's. No such mechanism is available for LTE.

- Lastly, in a limited number of scenarios (depending upon camping strategy, operator preference, etc.), connected-state UEs' in macro-layer may need to be handed-in to a small cell. In such cases, if small cell is on a different carrier, efficient small cell discovery that minimizes impact on UE battery-life is also necessary.

One of the challenges that was observed during 3GPP Release 11 heterogeneous mobility studies [3GPP TR 36.839] (that is in progress as of writing this 4G Americas white paper) is that among the various possibilities for mobility in a heterogeneous network the outbound mobility from a small cell has a relatively higher failure rate than other types of heterogeneous network mobility. In particular the failure rate is high for fast moving (60 mph or more) devices. While decisions regarding need for enhancements and possible solutions are still under investigation, this is one scenario where a fast moving device has the need to be steered away from the small cell layer to improve the robustness of heterogeneous network mobility. So in heterogeneous networks there is a need to have speed based mechanisms to improve mobility robustness. This requires investigation to see whether the current mobility state estimation function needs further improvements to obtain a more accurate classification of mobility or speed states.

2.3 LOCATION PLANNING / TRAFFIC MAPPING CHALLENGES

Traffic mapping, and in particular the precise determination of the high traffic locations or hot spots, is one of the major challenges that a network operator faces when deploying a HET-NET. Due to its low power in comparison with the macrocells, the small cells are only able to capture a significant traffic if they are placed within a few tens of meters of the source of the traffic. However, traffic location with such precision is not an easy task, and can follow two different approaches, either network assisted or handset-based.

- Network -Assisted Approaches

  Network -assisted solutions are based on platforms for analysis and optimization of networks. Hot spot location is usually only one application of these tools. Call traces are the data source used for the geo location. The main challenges of network-assisted approaches are:

  - Dependency on RNC's vendors tracing tools.
  - Massive volume of data to be processed, requiring high capacity data bases and powerful processing servers running proprietary algorithms, which usually leads to high cost.

- Handset-based Approaches

  Handset-based solutions rely on location information gathered locally by the UE. These solutions are cheap but currently face many challenges:

  - They require a SW application running in the UE, either as a downloaded App (dependency on the user willing to download it) or installed from the beginning in the UE's OS.
  - Geo location is based in GPS measurements (not available indoors, and usually disabled by the user to prevent battery drainage), Access Points detection (spotty location availability, and usually dependency on third parties' data bases), or base stations Cell ID and received power detection for location inference (which usually provide poor location accuracy).

2.4 CHALLENGES IN INTERFERENCE MITIGATION & RADIO PLANNING

2.4.1 CHALLENGES IN INTERFERENCE MITIGATION

Inter-cell interference is already one of the limiting factors in today's mobile communications systems, especially in dense, urban deployments. The problem is even worse in the context of multi-layer heterogeneous networks. If small cells are deployed using the same carrier as the macrocell (so-called co-channel deployment), the following interference problems can occur:

- In the downlink, a terminal assigned to the macro base station may see strong interference coming from a small cell (e.g. femtocell), leading to a macro layer coverage-gap. This problem is particularly pronounced if the smaller cell serves a closed subscriber group (CSG) and the terminal (i.e. the subscriber) is not a member of that group. In this case a terminal may be very close to a small cell but not allowed to connect to it. On the other hand, a terminal served by a small cell (e.g. picocell) at the cell edge area may see strong interference from a macrocell.
- In the uplink, a terminal assigned to the macrocell but close to the cell-edge will typically create strong interference to the small cell. However, a more problematic aspect is the uplink interference that a potentially large number of small cell terminals may generate towards the macrocell.

2.4.2 RADIO PLANNING

One of the basic issues with heterogeneous networks is how to determine the spectrum to employ in each cell layer. To attain the highest possible data rates, it is necessary to use at least as much bandwidth as the UE is capable of handling in each layer. UE capability in terms of frequency bands influences spectrum possibilities: if capacity (high traffic volume) is the driver or spectrum is scarce, then macro-cellular carrier frequencies should be reused. However, such an approach requires good cell planning and radio resource management schemes to control interference between cell layers. In particular, mobility and control plane quality might be affected.

By definition, a low power node has significantly lower transmission power than its surrounding macro base stations. As cell selection is based on downlink transmission power and channel conditions, the low power node cells are generally small. By increasing transmission power, the cell size of low power nodes can be increased. However, doing so affects the cost and size of the node, which in turn limits site availability.

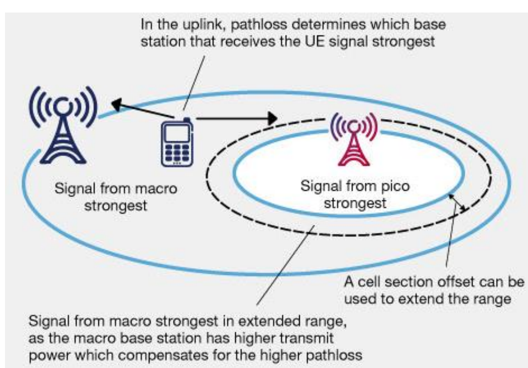


Figure 3: Cell Selection in a Heterogeneous Network

2.5 DEPLOYMENT CHALLENGES

The processes needed to deploy small cells economically can vary notably from the processes used in existing macro networks. The fundamental skills and experience are the same, but the methods used are streamlined. For example, to minimize the number of resources deployed to site, field employees need to be trained in multiple disciplines - like small cells, OAM configuration, and transport.

The other challenge operators' face when rolling out small cell networks is accommodating the increased scale of small cell deployments. Doing this effectively depends on three variables: speed, quality and cost. Regardless of the project, these are the three variables that operators care greatly about. Each of these variables becomes much, much more challenging when you add enormous scale to a project.

Another challenge when deploying small cells is to figure out where to deploy. Due to limited range of lower power small cells, operators need to know *exactly* where traffic is generated. Moreover, operators need to know not only where traffic is currently generated, but also anticipate where it will be generated in the future.

Associated with the location of the small cell, transport is another challenge. With a macrocell, transport is deployed to the macrocell. But with a small cell, you might have to take the small cell to some available transport. Small cells must support flexible transport solutions. In one city with one backhaul, one solution might turn out to be an optimum solution, but if you change scenarios with other backhauls another solution can turn out to be an optimum solution.

Regardless of whether the deployment is indoor or outdoor, new kinds of site leases will be required. Obviously, using the same asset types as often as possible and signing Master Lease Agreements (MLAs) will greatly streamline both the design and site acquisition processes.

2.6 OPERATIONAL CHALLENGES

The deployment and operation of a heterogeneous network is a major challenge for a network operator. This is because current procedures, which rely heavily on a human intervention, will not be able to cope with an order of magnitude increase in the number of base stations that could be expected in the small cell layer.

The deployment of the small cell layer will enable:

- Reduced expertise/knowledge required by staff for new deployments
- Minimizing the installation time
- A plug & play approach for new nodes integration in the already existing network

These are high level requirements that could be solved, to some extent, by means of SON procedures. For this purpose, SON should be aware of the network status and capable to react accordingly, implementing functionalities like:

- Self-awareness of the network topology, neighbor nodes configuration, and available connectivity with them
- Radio channel characteristics
- Current Radio Resources usage in neighbor nodes
- Traffic load location and operator's load balancing criteria.

These SON procedures and functionalities face an implementation or architecture challenge, because fast adaptation to local conditions favor distributed SON algorithms, but the operator of the network will probably need some kind of control of the SON procedures, indicating general policies or performance goals, that could require a centralized SON entity.

2.7 CAPACITY MANAGEMENT CHALLENGES

2.7.1 INTRODUCTION

Capacity Management in a HET-NET depends upon its configuration. In case of HET-NET consisting of multiple RAT technologies the first challenge is how to optimally distribute traffic load among different RAT's. The same problem also occurs in multi-RAT macro-only networks. Management of capacity in the presence of WiFi has additional complexity and is addressed separately in the following sub-section.

In case of multiple 3GPP based RAT's in a HET-NET, the camping/load distribution has two components. UE during its camping decision needs to choose the RAT and also choose between macro- and small cell layers. This process needs to be optimally controlled / influenced to achieve optimal load distribution and increase capacity.

Within a particular RAT, for instance LTE, appropriate camping strategy is needed to achieve an initial load-distribution between macro and small cells in accordance with operator preferences.

In addition to it, load-balancing capability between macro and small cells is a must to avoid overload conditions at a particular layer. Furthermore, traffic steering for connected UEs is also needed to dynamically adjust the relative loading between macro and small cells to optimize HET-NET capacity and performance.

2.7.2 OFFLOAD CONSIDERATIONS

Many of the challenges in dealing with offload are related to defining the thresholds that trigger the offload between Wi-Fi and cellular technology. Some of these thresholds that challenge network design are:

- RF thresholds for efficient movement between technologies without ping pong effect
- Application thresholds that prevent use cases that stress capacity in cellular networks e.g. certain downloads are allowed only over Wi-Fi,
- Choice of the appropriate network for hotspots. Capacity and coverage needs at hotspots could drive different network and technology choices at hotspots.
- RF design methods for cellular and networks can be based on different principles.

Requirements on networks and devices to drive the criteria defined for moving traffic between technologies.

2.8 SECURITY CHALLENGES

While small cells present several benefits from network performance point of view, they also create new challenges from a security perspective. The main challenges fall into two main categories: physical security and information/network security.

2.8.1 PHYSICAL SECURITY

While macrocell sites have strong physical security in the form of locked doors, alarms, and strict access control, small cells due to their small form factor are usually deployed in public areas with open access, e.g., utility poles, shopping malls, etc. Therefore, they can be easily tampered with and potentially compromised by unauthorized people. This can pose a serious security vulnerability as small cells are connected to the operator core network. The small cells units can be stolen, vandalized, replaced by rogues, etc. Strong authentication mechanisms are required to prevent misuse of the units.

2.8.2 INFORMATION/NETWORK SECURITY

Unlike macrocells that were originally relying on secure TDM protocols most small cells will be installed in IP mobile network environment that by definition has greater security vulnerability. Also, because small cells support fewer numbers of users they will need to leverage existing fixed access networks for backhaul and thus the mobile user traffic will be exposed to untrusted open Internet environment (e.g., when using DSL or Cable). This is in contrast to macro traffic that is managed end-to-end across the operator dedicated and trusted network.

In addition, in LTE, encryption terminates in eNodeB (only air interface is secured) with no native encryption mandated between eNodeB and the core network. This is in contrast to HSPA networks where encryption exists between the air interface and the BSC/RNC. This means that in LTE small cells there is no 3GPP-mandated encryption from the small cell to the core network - something that needs to be addressed due to passing through untrusted networks (Internet). Therefore, the operator will need to encrypt the small cell backhaul to secure it effectively.

More specific security challenges for HSPA/LTE small cells and for carrier grade Wi-Fi deployments include:

- HSPA/LTE small cells – when using wireless backhaul (usually a separate device from the small cell) traffic can be intercepted in the wired/wireless along the backhaul path. In addition, when using the X2 interface between LTE small cells, an attacker could potentially leverage the X2 interface to gain access to adjacent cells.

- Carrier grade Wi-Fi Deployed – potential security vulnerabilities exist on the air interface (various known attacks). For example, networks with weak security mechanism (WEP) can be broken into, or networks with pre shared security key (PSK) may be compromised if the key is somehow leaked. Therefore, only a server-based authentication (WPA2/enterprise) is recommended (this will be addressed by Hotspot2.0). Similarly, the backhaul needs to be secured using a secure IP tunnel between the AP and the core network.

3 KEY ENABLERS FOR HET-NET

3.1 BACKHAUL SCENARIOS

Backhaul for small cells typically involves spanning the last 1,000 feet between the small cell and a location where a fixed transport facility is available. As stated earlier, 20 percent of macrocells handle 80 percent of traffic. These heavily loaded macro sites would typically be in densely populated urban areas and may be in locations where getting permits for another macro site would be very difficult.

- One approach for small cell deployment is to subtend the small cells from a macro site and utilize the already installed macro backhaul facility to carry the small cell traffic back to the mobile core. From a performance perspective the best option for connecting small cells back to a macro site would be fiber, but this is often prohibitively expensive, especially in built up urban areas where aerial and rooftop fiber routes would be needed. An alternative solution in this scenario is non line of sight radio (NLOS).
- NLOS: Non line of sight (NLOS) or near line of sight (nLOS) radio is defined as a radio transmission path where the Fresnel zone is either partially or completely blocked. NLOS technology uses a wider beam angle than traditional line of sight (LOS) microwave, and relies on reflection and refraction to get the signal around obstacles. As a consequence of this, the remote radio must be designed to cope with multiple reflections of the same signal arriving at the antenna. Because of the interference created by multiple transmission paths, NLOS radios typically need deep error correction mechanisms, and are optimized to handle multiple retransmissions. NLOS technology can be used in either PtP (point to point) or PtMP (point to multi-point) mode. PtMP mode is particularly useful for macro subtended small cells, since a single NLOS hub with a wide antenna propagation pattern can serve several remotes simultaneously.
- Several NLOS PtMP products are now coming to market in the sub 6 GHz unlicensed spectrum where there are no restrictions on the location of the hubs and remotes. One exception in the sub 6 GHz being the 2.3 GHz band which is licensed.
- Ethernet: One of the drivers for small cells and non-macro based HET-NET is to use available non-dedicated backhaul. It is expected that small cells and hotspot based HET-NET solutions will connect to available gigabit Ethernet connections.

3.2 MOBILITY MANAGEMENT PROCEDURES IN HET-NET

Mobility management is performed to support mobility of user equipment (UEs). It involves informing the network of UEs’ present locations at the cell-ID level, providing the network with UE identities, and maintaining physical channels.

In LTE Evolved UTRAN (E-UTRAN), mobility management is classified into two states based on corresponding Radio Resource Control (RRC) states.

- Idle Mode Mobility management
- Connected Mode Mobility management

For each of the states, the following procedures can be performed based on the difference of frequencies/RAT.

- Intra Frequency Mobility Procedures
- Inter Frequency Mobility Procedures
- Inter Radio Access Technology (RAT) Mobility Procedures

In the connected mode mobility management, the mobile network ensures continuity of physical channels and provides uninterrupted communications service for UEs in connected mode through handover when the UEs are moving in the network. Handover is a procedure where the serving cell of a UE in connected mode is changed. In LTE, the handover decisions are performed by the eNodeBs without involving the MME or serving gateway which is used as anchor nodes only. That is, the E-UTRAN NodeB (eNodeB) delivers the associated configuration through signaling on the control plane, and UEs perform measurements accordingly and complete the handover procedures under the control of the eNodeB.

A UE that is powered on but does not have a RRC connection to the radio network is defined as being in the idle mode. In this mode, UEs report their locations to the network and the eNodeB broadcasts system information, which can be used by UEs to select suitable cells to camp on.

3.2.1 IDLE-MODE MOBILITY MANAGEMENT IN 3GPP HET-NET

DEPLOYMENT ASSUMPTIONS/BACKGROUND

Small cells can be introduced over an existing LTE macro network either by sharing the same carrier or using a dedicated carrier.

If existing macro-carrier is re-used by small cells, interference management techniques must be used to avoid performance impact due to mutual interference. A notable exception to this rule is when the same carrier small cell is deployed to cover an existing macro-coverage gap. In this case the two cells will be sufficiently isolated from RF perspective.

If small cells are deployed on a dedicated LTE carrier, neighbor-relationship(s) must be established with the existing LTE macrocells (by advertising small cell-frequency in SIB5) to enable UE's in the macro-system to search for the small cells. Multiple options exist for establishing the neighbor relationship with the macro-carriers.

- All macro-carriers implement small cell-carrier as neighbor in SIB5.
- Only cells from a subset of macro-carriers implement small cell-carrier as neighbor in SIB5. For cells on the remaining carriers, inter-macro carrier load-balancing techniques can be used to re-distribute the load.

The option chosen impacts the camping and load-balancing between the small cell and macro carriers. First option provides immediate offloading to all macro-carriers in small cell-coverage area, but the risk of small cell getting overloaded increases. The second option only provides immediate capacity relief to "neighbor" macro.

CELL SELECTION

During the cell selection procedure, the UE will determine which is the best cell that can be used to establish an RRC connection. Conventionally, the UE will select a cell based on the Received Signal Reference Power (RSRP) that is determined based on measurements it performs on the Cell Reference Signal (CRS) broadcasted by the cell with a nominal transmit power.

$$CellID_{serving} = \arg\max_{\{i\}} \{RSRP_i\}$$

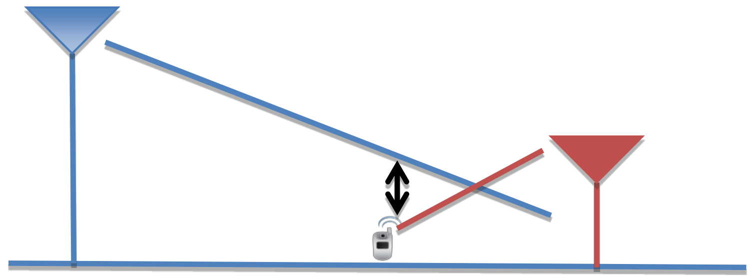


Figure 4: RSRP slopes in the UE association procedure

In Figure 4, the RSRP slopes of the macro and metro are shown simplistically. Because of the substantially higher power emitted by the macro, the two slopes will crossover at a very small distance from the metro. This shrinks the DL coverage of the metro. In addition, it can create asymmetry in the UL coverage that is unaffected by the transmit power differences of the cells. R8 specifications allow the bias of the cell selection with the UE determining the serving cell based on the relationship,

$$CellID_{serving} = \arg\max_{\{i\}} \{RSRP_i + bias_i\}$$

The cell selection bias can range from 0 to 20 dB and can be communicated to the UE via higher layer signaling or be cell-specific, which in this case is broadcasted as part of a system information block (SIB). The effect of the bias is to extend the DL metro coverage as the UE artificially increases the measured RSRP from the metro by the bias value. At the same time, the DL Signal to Interference and Noise Ratio (SINR) when an RRC connection establishment is attempted is degraded. In cases where the metro cell is sufficiently far from the macrocell, the range of the metro is adequate without bias, especially if the transmit power of the metro is increased to 5W. In the case of the latter, increase of the transmit power is to some extent another method to increase the range of picos.

3.2.2 CONNECTED MODE MOBILITY STRATEGY IN 3GPP

For UE's in connected-state that are moving out of cell coverage, handovers are required to move their Radio-link from one cell to another. It is preferable to keep a UE in the same layer (small cell or macro) as it performs handovers, unless there is a necessity to move from one layer to the other.

Same layer handovers use the normal coverage-based intra-frequency handover framework used in macrocell network.

3.2.2.1 HANDOVER PROCEDURES IN 3GPP HET-NET

The handover procedure in LTE has been covered adequately in the existing literature and the interested reader can consult the 3GPP Radio Resource Control (RRC) standards specification TS 36.331 [1].

In summary, the UE initiates a handover procedure, based on signal and time thresholds defined and transmitted to it by the serving cell. These are the HO hysteresis, Time to Trigger (TTT) and the parameter cell Individual Offset (O_c). The latter is a *vector* quantity sent by the serving cell that contains the offsets of the serving (O_c(s)) and neighbor cells (O_c(n)) that all UEs in this cell must apply in determining whether the measured RSRP satisfy the conditions of the so called "event A3", that results in the UE sending a measurement report (MR) that triggers the handover. O_c values can be positive or negative. The measured RSRPs are filtered and O_c values are added to determine the cell id {k} according to the relationship.

$$CellID_k = \arg\max_{\{i\}} \{RSRP_i + O_c\}(i)$$

The challenge is to optimally configure the cells with these parameters such that the HO KPIs, namely the HO success rate and the dropped call rate, need to be kept close to their targets. This is especially difficult in urban areas where UE mobility regime mingle such as in the "traffic-light" problem. In the later problem, UEs stopping in intersections may handover to a nearby picos for the duration of the red signal (few tens of seconds) and then handover again to the macro layer. Traffic steering dependent amongst other factors on the UE average mobility condition, potentially estimated from MME layer events, is usually applied to disable en mass ping-pong effects between cell layers.

Inter-layer (macro-small cell) handovers are covered in this section.

COVERAGE-BASED:

As an active UE moves out of coverage of the layer (small cell or macro) to which it is connected, it must be handed over to the other for service continuity.

Most prevalent scenario is small cell-to-macro handover. UE's that are connected to small cells may continue performing handover's to other small cell's until they arrive into a boundary small cell. If a UE continues to move further it will need to be handed over to a macrocell that provides coverage in the same area.

In the converse scenario of the macro-to-small cell handover, the situation described is also possible but not always needed.

As a UE that is connected to a macrocell moves, it can maintain its connection by performing handovers to other macrocells. It does not need to handover to small cells in areas where small cell coverage is also available. Given that the UE's connection can be maintained without handing-in to small cell, it is better to not perform macro-to-small cell hand-ins in order to minimize Handovers (because every UE Handed-in to small cell is a candidate for Handing-out later). The following are two exceptions where macro-to-small cell handovers are needed/desirable:

MACRO-COVERAGE GAP:

If macro-layer has a coverage gap that is covered by a small cell, the macro-connected UE must be handed-in to the small cell when it enters that area otherwise call-drop would occur.

CELL-EDGE/WEAK MACROCELL COVERAGE:

In areas where the small cell signal is significantly stronger than the macro cell signal (e.g. cell-edge etc.), it usually makes sense to hand-in macro-connected UEs to the small cell. Note: To reduce the number of handovers, it is desirable to make an exception for high-mobility UEs and not hand-in them to small cells. Please refer to the related Speed Consideration section below.

LOAD-BASED:

The following discussion applies to small cells only. Macrocells already support load-based handover mechanisms.

When a micro-cell is overloaded, handing-over some UEs to the macro-layer can provide relief. Small cells can be configured to perform LB handover to macrocells. This is applicable only for hotspot small cells. UEs should never be offloaded from small cells deployed over a coverage-gap.

3.2.2.2 HANDOVER TYPES

Whether coverage triggered or load-based, the following are various types of handovers that are supported and may be needed for inter-layer handovers.

INTRA-FREQUENCY HANDOVER:

Intra-frequency handover is needed when macro and small cell layer use the same frequency. No new inter-frequency measurements/reporting are needed. However, engineering-wise it is more complicated to implement same-layer preference for Handover targets: CIO must be configured in such a way to give appropriate preference to macro- or small cell- target cells.

INTER-FREQUENCY HANDOVER:

Inter-frequency handover is needed when macro and small cell layer are on different frequencies. Inter-frequency measurements and reporting needs to be configured for target frequencies. Same-layer preference logic is much simplified.

UE SPEED CONSIDERATIONS:

It is preferable to prevent high-speed UE's from handing-in to a small cell from macro-layer, except where dictated by lack of macro-coverage, as the same UE would likely have to hand-out from the small cell-coverage in a short while. Generally, there is no downside in retaining such a UE on the macro-layer.

One straightforward way to discourage high mobility UE's from initiating handover to small cells is by using a higher Time-to-Trigger value in their HO Measurement configuration. High mobility UEs can be identified by various means, e.g. keeping track of handover history (number of handovers over time duration).

Identified high mobility UEs can also be explicitly prevented from handing-in to the small cell.

3.2.3 MOBILITY MANAGEMENT

A HET-NET may consist of both Cellular and Wi-Fi technologies. Mobility management within cellular is addressed extensively in the standardization for IRAT between GSM/HSPA/LTE and CDMA/EVDO.

Wi-Fi handover is composed of four main phases:

- Detecting the possible set of next APs the handover could be aimed at (also called probing phase)
- Choosing the destination AP
- Associating with that AP
- (Re-) authenticating the STA to the network.

Standards related to Hotspot 2.0 address roaming between Cellular and Wi-Fi technologies. This is mainly built around device and network changes in the following areas[1]:

- Network discovery and selection: Mobile devices will discover and automatically select and connect to Wi-Fi networks based upon user preferences and network optimization.
- Streamlined network access: Mobile devices will automatically be granted access to the network based upon credentials such as SIM cards, which are widely used in cellular devices today. No user intervention will be required.
- Security: Over-the-air transmissions will be encrypted using the latest-generation security technology (Wi-Fi Certified WPA2-Enterprise).

The key elements of the Wi-Fi Certified Phase 2 Pass point certification program are as follows:

- Immediate account provisioning: The process of establishing a new user account at the point of access will be simplified, eliminating many user steps and driving a common provisioning methodology across vendors.
- Provisioning of operator policy for network selection is an important issue: A mobile device's connection manager uses this policy to select the best Wi-Fi network to join when multiple networks are available.

[1] http://www.cisco.com/en/US/solutions/collateral/ns341/ns524/ns673/white_paper_c11-649337.html

3.2.4 TYPICAL USE-CASES IN HET-NET

MICRO-TO-MACRO HANDOVERS:

- Can be coverage-based, i.e. UE moving out of micro-coverage.
- Can also be triggered due to small cell overload (load-balancing).
- Needed in both same-frequency as well as dedicated frequency small cell deployment.

MACRO-TO-SMALL CELL HANDOVERS:

- Can be coverage-based – UE moving into a macro coverage-gap or weak macro-coverage.
- Preferable to avoid handing-in high-mobility UE's to small cell – unless call-drop is feared (due to coverage gap).

Speed detection is applicable for same-frequency small cells deployment as well as in different-frequency scenarios.

3.2.4.1 SPEED DETECTION – MEASUREMENTS, INTER-FREQS HANDOVER MEASUREMENTS

To address the challenge of failures in outbound mobility of high-speed devices from small cells the best defense is to avoid having high-speed devices being served by a small cell. This requires efficient traffic steering mechanisms to steer high-speed devices from small cells. Hence, one of the traffic steering criteria can be the device speed, i.e. depending on the speed of the device, the device and thus traffic can be steered to a specific layer of the heterogeneous network. Therefore, speed detection of a device is one important aspect for traffic steering in a heterogeneous network.

3GPP LTE standards already provide a mechanism to be able to do this, but this is not meant to detect the accurate actual speed of the device. Rather it is used to classify the device into one of three possible mobility states of normal, medium, or high. This is currently a device function, which is able to do this by counting the number of handover or cell reselections, depending on the connection state of the device, during an evaluation time window and comparing it to pre-configured speed state thresholds. This has been accepted as sufficient to estimate the mobility state of the device moving around in a macro-only network. The main application of such an evaluated mobility state is tailoring certain mobility parameters that allow expediting the mobility for fast moving devices from one macrocell to another to avoid dropping the call. In 3GPP LTE Release 11 one of the topics being studied is whether the existing mobility state estimation function needs any enhancement for use in heterogeneous networks. At present, there is also the possibility for the network to estimate the speed of the device using information available to the network. On the network side, history information about device movement is collected that includes the time the device stayed in previous cells, the corresponding cell type, and cell size, etc. Thus, it is possible for network to take both the number of past cell changes and the corresponding cell size into account for estimating the device speed at the network.

3.2.4.2 HANDOVER KPI METRICS AND TARGET

Metric	Description	Target Range
Dropped Call Rate	The number of drops over a time interval [e.g. 100 sec], rather than as the percentage of handovers that fail.	[1%] for BE traffic [< 1%] for VoIP*
HO Failure Rate	The number of handover failures over a time interval.	[< 1% in general]

* This objective is more stringent than for best effort traffic as re-establishment attempts to correct for handover failures can significantly degrade VoIP QoE.

There are important statistical correlations between the HO failure and call drop rates that are not trivial to extract from KPI measurement data and outside the scope of this white paper. For example, to maintain a call drop rate of 1 percent in a region with average handovers rates of 20 handovers in a 100sec period, an ideally homogeneous network would be required to be designed with a handover failure rate of 0.05 percent. Compare this to the case with average handover rates of one handover per 100 sec period where a design target of 1 percent handover failure would suffice. Algorithm or parameter changes may increase the handover rate in HTN but may not decrease the handover failure rate affecting negatively the drop call rate.

3.3 LOCATION PLANNING / TRAFFIC MAPPING

3.3.1 INTRODUCTION:

A cellular system can be *homogeneous*, where full size (“macrocells”) base stations are deployed in certain known geographical locations according to network planning and availability of resources by the network operators. In areas where capacity requirements are higher or coverage enhancement is necessary, additional macrocells can be deployed; alternatively, the operator can deploy low power nodes (small cells), creating a *heterogeneous* network (HET-NET). Full realization of HET-NET benefits requires an optimal deployment that is tuned to local conditions. These include both traffic microstructure and coverage microstructure; i.e., traffic and coverage conditions within the area of a typical macrocell.

Evaluation of coverage and traffic microstructure presents varying degrees of difficulty. Network coverage conditions are more easily evaluated based on call performance; for example, localizing call access failure or call drop will characterize a weak coverage area or coverage gaps. In contrast, non-uniform traffic variations across the (covered) area of a macrocell are less easily determined. This phenomenon, identified through traffic density studies and macrocell/network resource utilization, is key to optimal, cost-effective small cell deployment. Knowledge of such high-resolution traffic density (traffic microstructure) is not easily gained, since mobiles do not routinely determine nor report their exact location.

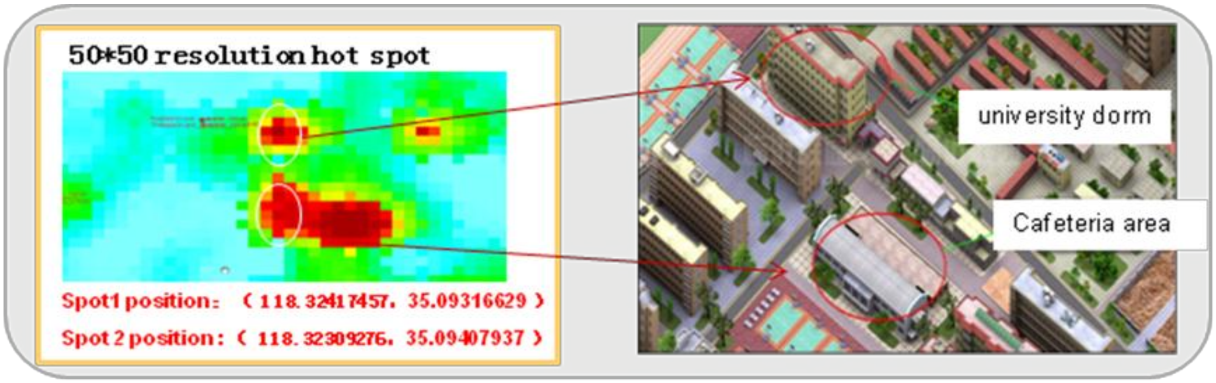


Figure 5: A hotspot detection example based MR location

With growing demand for data services, it is increasingly becoming important to determine traffic density to identify locations where the traffic density or demand is relatively higher (hotspots; see Figure 5). Small cells by design possess a small radius; accordingly, for capacity relief it becomes important to place them centrally or proximally to hotspots. In addition, more specific knowledge of the hotspots is required in order to provide a cost-effective capacity relief; e.g., to be able to place small cells only in hotspots of appropriate size and intensity as not to violate a point of diminishing returns. High-resolution traffic structure also enables computations for appropriate assignment (or bias) of bandwidth usage for hotspots, load balancing between small cell and macrocell layer, and parameter (e.g., forward power) settings to achieve specific but possibly competing performance objectives such as improved local user experience and macrocell offload.

The traffic density estimation does not necessarily require traffic accuracy requirements necessary for ‘hard’ locate decisions such as those for location-based services (e.g., 911); rather, traffic density estimation only need be sufficient to localize the area to volume and user density in addition to hardware requirements for a small cell deployment. Accordingly, the required accuracy can be market-dependent. Appropriate estimations can be folded into a ‘traffic map’ where the high concentration of traffic originations is identified in a GIS.

In the following, we overview the various methods available for obtaining the requisite traffic density, and then expand upon its use in planning small cell deployments. Much of our discussion will focus on the former where — as in 911 localization — they are methods for obtaining traffic density. These can be roughly divided into categories of ‘network-based’ and ‘handset (device)-based’ (or network-assisted and device-assisted). Generally speaking, ‘network-based’ requires no special additional functionality at the handset and is therefore widely applicable regardless of device distribution; in contrast, ‘handset-based’ requires added features at the receiver. For example, localization based on network observation of the difference in arrival time between two base stations receiving routine signals from the handset would be network-based. In contrast, localization via GPS at the handset would be device-based, since it would only work for the subset of devices within the subscriber population that had a full GPS receiver.

Our discussion mirrors proposals submitted by standards bodies for traffic mapping. Currently the following two methodologies are being pursued by the industries:

- Network assisted RF and RTT finger printing
- Device assisted MDT based location data

Note that we deliberately exclude GPS-based (GPS or AGPS) solutions from the above categories since they do not in principle provide a robust solution for estimation of traffic density (vs. ‘hard’ locate decisions). In this context, difficulties with a GPS-based solution include:

- Not all handsets have GPS or AGPS capability.
- GPS –based solutions do not work well in buildings.
- GPS reports from all devices in the field are not part of current signaling. Accordingly, transmission of GPS information would place a significant additional signaling load on the network.

The last point might be overcome by various mechanisms; however, the first two present the very practical difficulty that the subset of subscribers that either have no phone GPS capability and/or are inside buildings would be excluded from any traffic density estimates. This subset can vary by market but can be particularly significant in urban areas where many wireless users routinely operate from inside buildings. GPS/AGPS is therefore viewed as an ancillary or opportunistic method for obtaining traffic density (e.g., it may increase the location accuracy of known outside users) rather than a core approach.

3.3.2 NETWORK-ASSISTED APPROACHES

Network assisted approaches can be broadly categorized into 'fingerprinting' and time delay/angle of arrival approaches. In the latter, time delay information associated with the path between device and base station(s) is used to estimate aspects (e.g., range, azimuth) of individual device locations. In the former, previous detailed spatial knowledge of the radio environment (e.g., identity and strength of overhead signals at a dense set of locations) is used to map routine reports (MRs) of overhead signal information from the device into a likely location. Ideally, the spatial knowledge can be viewed as a radio 'fingerprint' that is unique to each location, enabling the network to accurately associate any MR with a precise location. In practice, the accuracy of this process is compromised by several factors, including non-uniqueness of the fingerprints, incomplete spatial knowledge of the radio environment, and inaccuracy of device MR measurements.

In both cases (time delay/fingerprinting) the information available from individual location decisions can be aggregated into a traffic density estimate. The aggregation process is not standards-based and can be significant; for example, optimal aggregation can smooth out or reduce the sources of error described above. We discuss each approach in more detail below.

3.3.2.1 NETWORK ASSISTED FINGER PRINTING:

Finger printing techniques can be classified into two broad categories. (i) RF signal strength measurements (ii) Round trip signal delay measurements.

In the RF fingerprinting, a polygon area is chosen as area of interest from KPI and cell resource utilization measurements. The area is driven and RF measurements are collected, and a feature database is generated based on RF characteristics of the locations. Periodically MRs from handsets are collected at the RNC, where each MR report has signal strengths records experience by the handsets. The traffic map solution locates MRs by mapping the data in the feature database. In certain cases, it is needed to preprocess or filter the MR data. The mapping method is as follows: Searching the feature database for the location whose features are closest to the MR. The feature database contains the features about every known location. Currently, features refer to the information about the signal strength between a location and each cell. The feature database can also be generated or updated based on the drive test data, auto drive test data, and AGPS data. This ensures the consistency between the data both in the feature database and on the live network. This improves the accuracy of MR locating. The accuracy of the data in the feature database is the basis of accurate feature mapping.

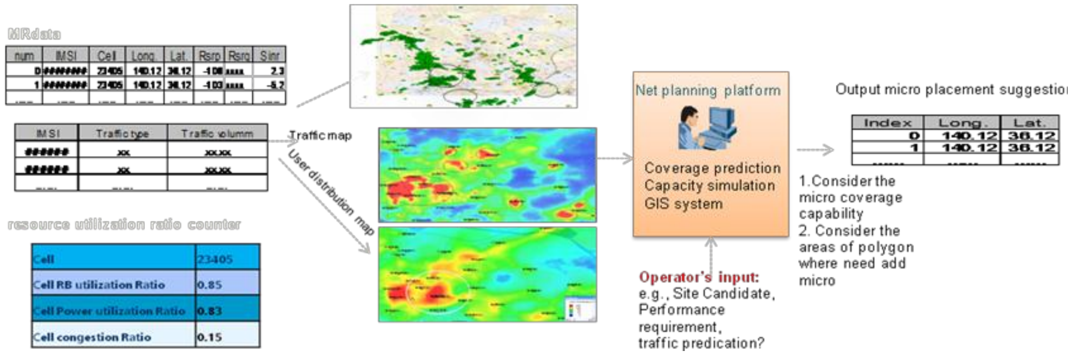


Figure 6: RF finger printing technique

3.3.2.2 TIME DELAY/ANGLE OF ARRIVAL

In addition to RF fingerprinting, much attention has been focused on signal time delay and angle of arrival. Generally, approaches based on time-of-arrival (TOA) or time difference-of-arrival (TDOA) and angle-of-arrival (AOA) measurement can greatly improve the accuracy of position determination. Unfortunately, the main shortcoming of these methods is that they require line of sight (LOS) propagation for accurate location estimates. However, non line of sight (NLOS) error is the dominant error in location estimation in urban or suburban areas where people are more interested in the mobile user's (MU) location. When direct signal paths between handset and base stations are mostly obstructed by buildings and other structures, alternate, reflected paths dominate. These paths are longer, affecting TDOA and TOA methods, and arrive from a different direction, affecting AOA. TDOA and TOA NLOS errors are always positive, i.e. the path is longer, but range from a small number to thousands of meters. To mitigate position estimates from NLOS error corruption, different approaches have been proposed. The finger printing technique using TDOA is widely successful since using TDOA does not require the signal transmission time from the handset, so there is no need to synchronize handset with the BTSs very accurately. Very similar to RF finger printing techniques, LMU is integrated into eNBs to take advantage of the existing GPS and the calibrated RX Path.

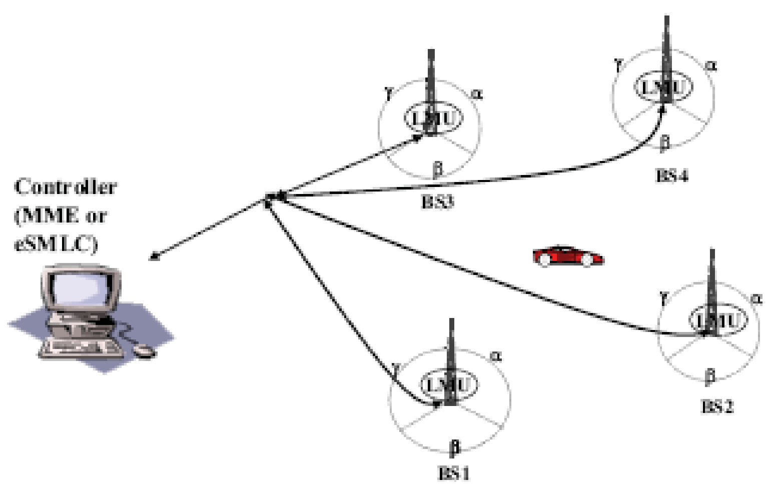


Figure 7: LMU integrated eNB to take advantage of GPS and calibrated RX path

The Uplink Time Delay of Arrival (UTDOA) measurements are collected and a time delay based feature database is generated. This database takes into account NLOS errors as well.

The database method is based on the spatial correlation, and utilizing interpolation technique to generate the NLOS error correction map. Once the reference map is generated, SRS received from devices are mapped to the feature database and a traffic map is created.

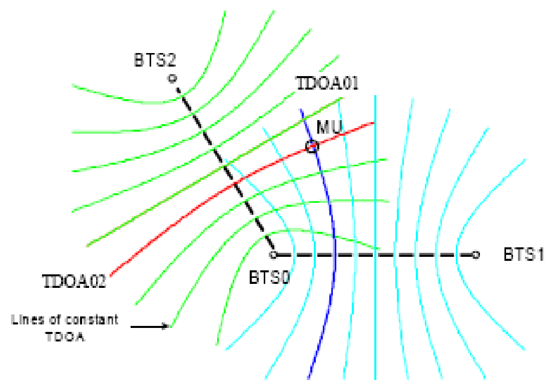


Figure 8: Time measurements for UE location identification

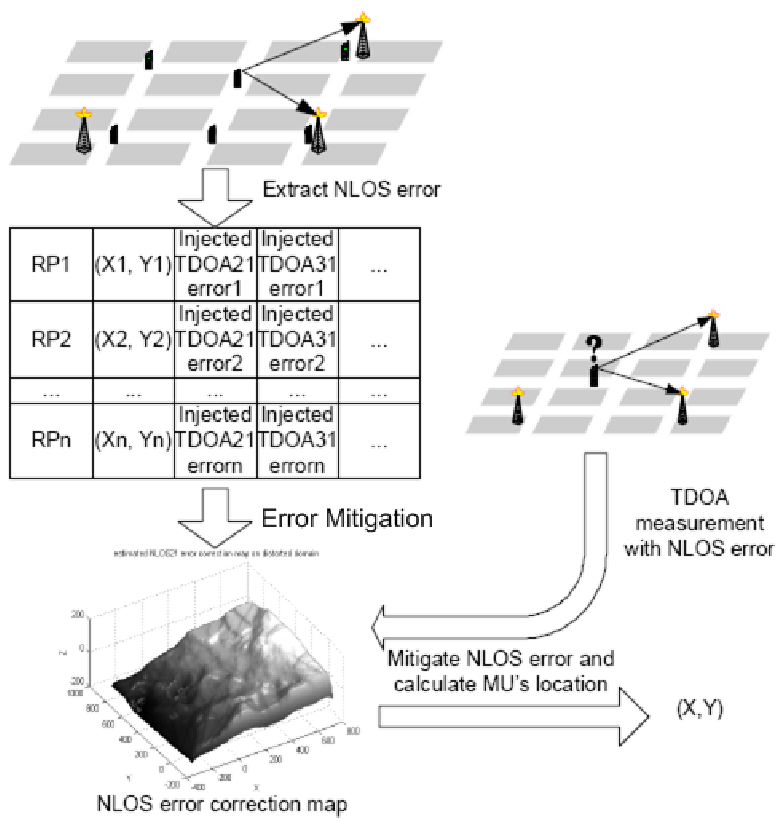


Figure 9: RTT fingerprinting process

3.3.3 HANDSET-BASED APPROACHES

Device Assisted MDT Technique

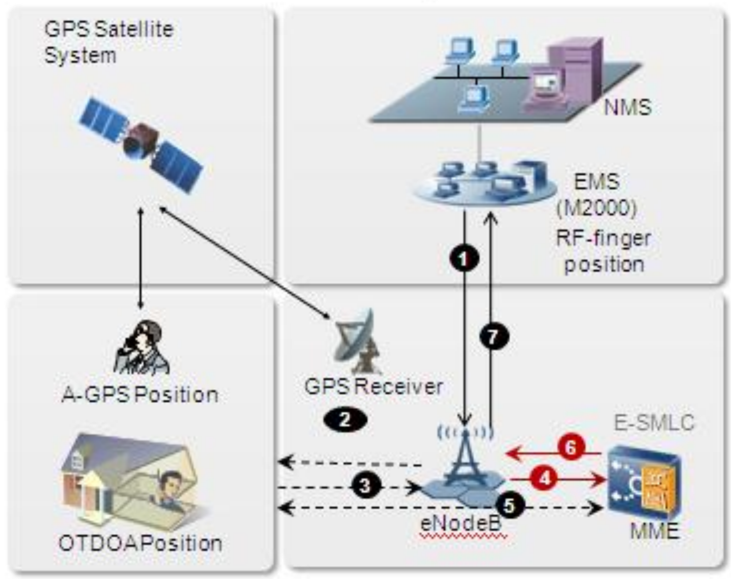


Figure 10: Device Assisted MDT Technique

Widely used in coverage, interference and handover analysis. Minimize Drive Test (MDT) based approach relies on UE capability to support GPS information and provide location to network. The procedure works as follows:

- OSS send MDT Activation to eNB
- UE selection based on device capability and UE measurement configuration
- UE MDT Report
- Location requirement to ESMLC
- LPPa, LPP procedure
- Location response from ESMLC
- eNB send the MDT data to OSS

Risk associated with MDT technique is handset capability and user desire to enable GPS information. Without the GPS information, eNB will not able to process location information.

3.3.4 USE OF TRAFFIC DENSITY IN DEPLOYMENT

The deployment of small cells to fill coverage gaps is guided primarily by the gap location. The amount of traffic demand inherent to the gap (if known) is a secondary consideration. Even if very little traffic is present, the gains of establishing seamless coverage (no drops) through deploying a small cell usually outweighs any question of how much traffic the small cell would absorb. In contrast, the deployment of small cells for capacity gain ("capacity-driven deployment") within an already-covered area is strongly guided by anticipation of the local capacity relief the small cell will provide. Our discussion below focuses on the use of traffic density in guiding capacity-driven deployment.

A planned small cell deployment based on traffic density knowledge can reap significant capacity and performance gains. For reference, these are often compared with the gains obtained from random placement. The most suitable immediate candidates for small cell placement are locations where traffic density shows high concentrations of traffic (hotspots). Once the traffic area is indentified, the number of necessary small cells is determined by the call volume (hotspot intensity), area (hotspot coverage), and performance objectives (e.g., a minimum average user throughput for users that join the small cell, a threshold for offloading macrocells, average cell throughput, etc). Additional considerations include conditions such as user distribution, traffic type, cell RB/Power resource utilization, expected traffic increase, availability of logistics, use of dedicated or shared carrier, and mutual interference considerations between the macrocell layer and small cell layer. Best capacity gains are usually available in areas with a highly non-uniform traffic distribution with identified peak traffic spots, as long as the small cell(s) can be placed in sufficient proximity to the peaks to absorb a large fraction of its traffic. In contrast, minimal capacity gains are available for a uniform density of traffic, although small cell placement may still help optimize a given location and improve call performance metrics.

3.3.5 KPI'S FOR TRAFFIC ANALYSIS:

KPI's provide in-depth understanding of network resources utilization. KPI's can be a used to identify highly loaded cells or poorly optimized cells as a first measure to identify and filter areas where small cells are needed. For example, evaluating the power utilization and average cell throughput in addition to call performance KPI's give a good high level view of the problem areas. To localize the problem areas to a specific location we need to get a good traffic map.

3.4 TECHNOLOGIES/FEATURES PLANNED FOR HET-NET

3.4.1 INTERFERENCE MITIGATION

Downlink and uplink inter-cell interference mitigation can be achieved using several variants of time and frequency domain co-ordination or interference cancellation techniques. Interference rejection combining and MMSE-SIC based receivers have been leveraged in HSPA technologies and are important tools that improve HET-NET performance.

Interference mitigation in 3GPP Release 8 is achieved by using static or dynamic frequency domain co-ordination between cells. Each cell can use a subset of resource blocks at higher transmit power whilst reducing power (or completely muting) other resource blocks to mitigate inter-cell interference to neighbors as illustrated in Figure 11 below.

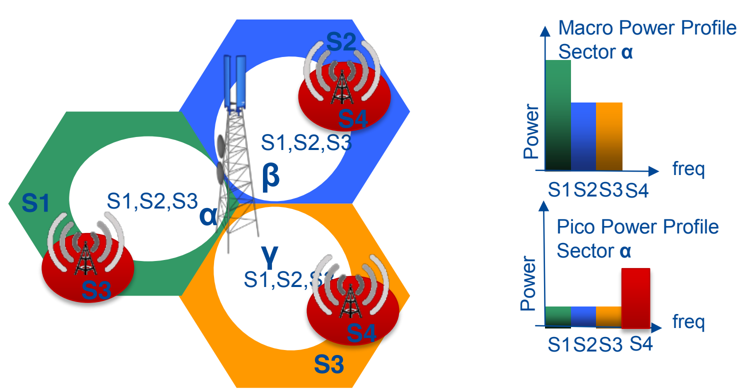


Figure 11: Mitigating Intercell Interference

Cell edge users can be scheduled in the high power resource blocks resulting in an improvement in cell edge SINR. 3GPP Release 8 supports exchange of DL power bitmap information (RNTP) and uplink interference indicators (OI, HII) between cells over the X2 interface to enable dynamic distributed interference co-ordination and adjustments. Dynamic co-ordination may also be achieved using a central SON server or hybrid approaches. Such dynamic co-ordination is very useful in HET-NET scenarios since there can be significant variance in interference conditions based on location of small cell relative to macrocell. Interference mitigation can be achieved using such techniques for downlink and uplink shared channels and uplink control channel. However, downlink control channel interference from macro to small cell is not completely mitigated. Interference can be reduced by increasing the number of symbols provisioned for DL control channel and by reducing CCH utilization. Robustness to interference can be increased by using higher degree of control channel aggregation and power boosting. Such techniques in addition to appropriate radio planning and limited usage of range extension enable HET-NET deployments using 3GPP Release 8.

The downlink interference problems in heterogeneous networks with a macro layer and a small cell layer (layer with e.g. pico and/or femtocells) can be mitigated using a time domain enhanced inter-cell interference coordination (TDM eICIC) technique introduced in 3GPP Release 10. TDM eICIC employs coordinated resource partitioning in the time domain. In TDM eICIC the aggressor cell, that is the interference source, almost stops radio transmission at certain time durations (one or more subframe duration in the radio frame timing) to minimize interference to the affected cells or victim cells. Such muted or blanked subframe is called an Almost Blank Subframe (ABS). During an ABS some necessary transmissions for backward compatibility reasons to support legacy terminals that do not support TDM eICIC are still done. This technique requires strict time synchronization between base stations in the heterogeneous network and victim cell's knowledge as to which subframes of the aggressor cell are ABS subframes. Figure 12 below illustrates the concept of TDM eICIC and ABS.

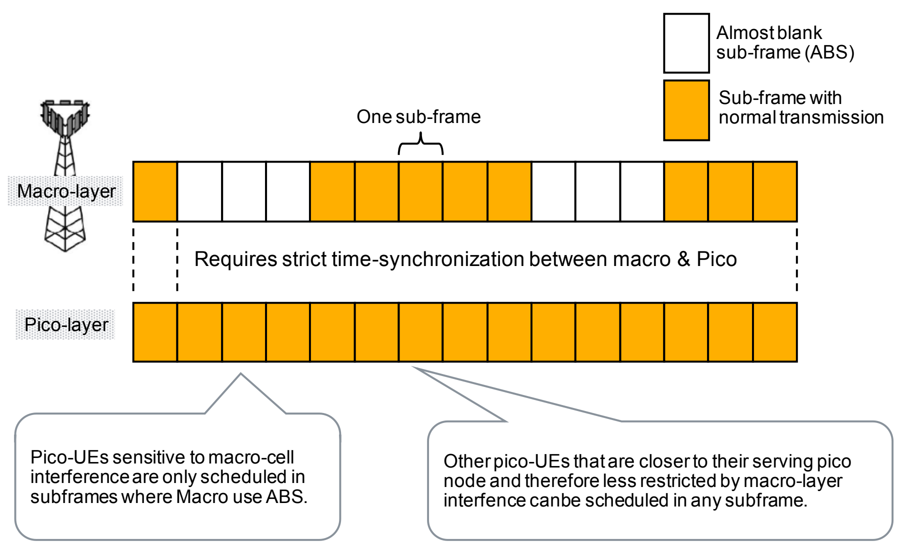


Figure 12: TDM eICIC and ABS

In 3GPP LTE Release 10 TDM eICIC, with aid of ABS to control interference from an overlay macrocell along with the use of liberal offset to the radio signal measurements from a device served by the picocell, effectively allows extending the range of the picocell coverage for devices served by the picocell. This is called pico Cell Range Extension (CRE).

There are multiple ways to address uplink interference problems in LTE heterogeneous networks. The methods range from limiting the location of the small cells according to vendor RF engineering guidelines to adjustment of the power control policy applied. Furthermore, a carrier based inter-cell interference coordination (CB-ICIC) technique is under discussion in 3GPP Release 11 at the time of writing this white paper (September 2012). CB-ICIC is a frequency domain inter-carrier inter-cell interference coordination mechanism that allows frequency domain resource partitioning on a carrier resolution. Unlike TDM eICIC, CB-ICIC does not require synchronization. 3GPP Release 11 standardization is also exploring other techniques like CRS interference cancellation at UE, CRS puncturing at the UE, or CRS muting at the eNB to further reduce interference due to transmission of RS. In addition, enhancements to PDCCH are also being considered to enable frequency domain ICIC for DL control channel in order to improve control channel performance.

3.4.2 COMP (COORDINATED MULT-POINT TRANSMISSION/RECEPTION)

Coordinated multi-point transmission/reception (CoMP) is considered by 3GPP as a tool to improve coverage, cell-edge throughput, and/or system efficiency. 3GPP is in the process of standardizing CoMP.

3.4.2.1 PRINCIPLE

The main idea of CoMP is as follows. When an UE is in the cell-edge region, it may be able to receive signal from multiple cell sites and the UE's transmission may be received at multiple cell sites. Given that, if we coordinate the signaling transmitted from the multiple cell sites, the DL performance can be increased significantly. This coordination can be simple, as in the techniques that focus on interference avoidance, or more complex, as in the case where the same data is transmitted from multiple cell sites. For the UL, since the signal can be received by multiple cell sites, (if the scheduling is from the different cell sites), the system can take advantage of this multiple reception to significantly improve the link performance. In what follows, the COMP architecture will first be discussed followed by the different schemes proposed for CoMP.

3.4.2.2 COMP ARCHITECTURE

CoMP communications can occur with intra-site or inter-site CoMP as shown in Figure 13. With intra-site CoMP, the coordination is within a cell site. The characteristics of each type of CoMP architecture are summarized in Table 1: *Summary of the characteristics of each type of CoMP architecture*

An advantage of intra-site CoMP is that a significant amount of exchange of information is possible since this communication is within a site and does not involve a backhaul (connection between base stations). Inter-site CoMP involves the coordination of multiple sites for CoMP transmission. Consequently, the exchange of information will involve a backhaul. This type of CoMP may put additional burden and requirement upon the backhaul design.

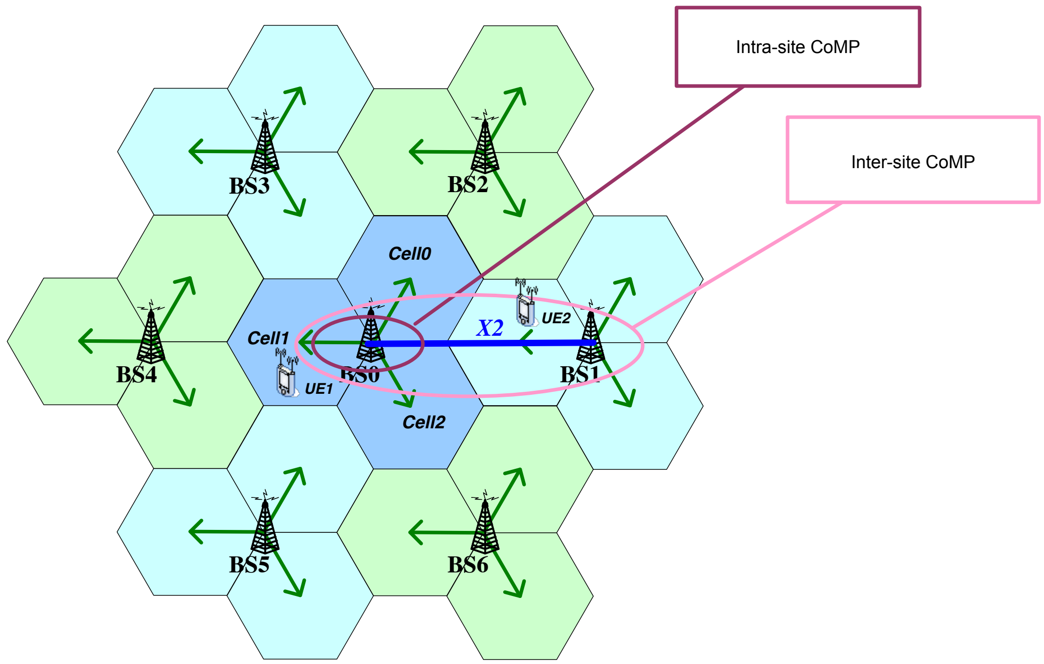


Figure 13: An illustration of the inter-site and intra-site CoMP.

Table 1: Summary of the characteristics of each type of CoMP architecture

	Intra-eNB Intra-site	Intra-eNB Inter-site	Inter-eNB Inter-site (1)	Inter-eNB Inter-site (2)
Information shared between sites	Vendor Internal Interface	CSI/CQI, Scheduling info	CSI/CQI, Scheduling Info	Traffic + CSI/CQI, Scheduling Info
CoMP Algorithms	Coordinated Scheduling, Coordinated Beamforming, JP	Coordinated Scheduling, Coordinated Beamforming, JP	Coordinated Scheduling, Coordinated Beamforming	Coordinated Scheduling (CS), Coordinated Beamforming, JP
Backhaul Properties	Baseband Interface over small distances provides very small latencies and ample bandwidth	Fiber-connected RRH provides small latencies and ample bandwidth	Requires small latencies only.	Requires small latencies. Bandwidth dominated by traffic.

An interesting CoMP architecture is the one associated with a distributed eNB depicted in Figure 14**Error! Reference source not found.**. In this particular illustration, the radio remote units (RRU) of an eNB are located at different locations in space. With this architecture, although the CoMP coordination is within a single eNB, the CoMP transmission can behave like inter-site CoMP instead.

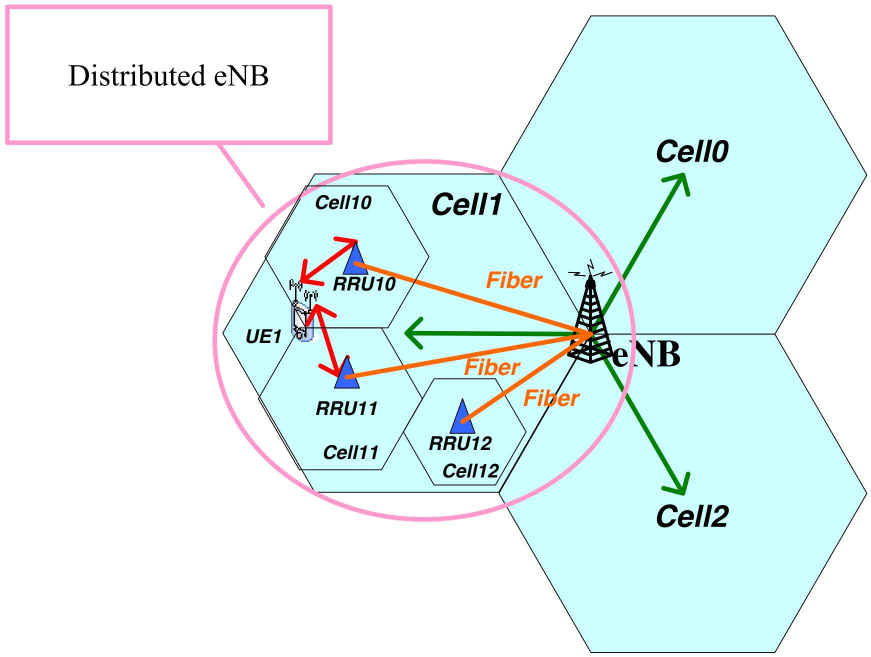


Figure 14: an illustration of intra eNB CoMP with a distributed eNB.

3.4.2.3 DL COMP

In terms of downlink CoMP, two different approaches are under consideration: *Coordinated scheduling and/or beamforming*, and *joint processing/transmission*. In the first category, the transmission to a single UE is transmitted from the serving cell, exactly as in the case of non-CoMP transmission. However, the scheduling, including any beam-forming functionality, is dynamically coordinated between the cells in order to control/reduce the interference between different transmissions. In principle, the best serving set of users will be selected so that the transmitter beams are constructed to reduce the interference to other neighboring users, while increasing the served users' signal strength.

For joint processing/transmission, the transmission to a single UE is simultaneously transmitted from multiple transmission points in practice cell sites. The multi-point transmissions will be coordinated as a single transmitter with antennas that are geographically separated. This scheme has the potential for higher performance, compared to coordination in the scheduling only, but comes at the expense of more stringent requirement on backhaul communication.

Depending on the geographical separation of the antennas, and the coordinated multi-point processing method (e.g. coherent or noncoherent), the coordinated zone definition (e.g. cell-centric or user-centric), network MIMO and collaborative MIMO have been proposed for the evolution of LTE. Depending on if the same data to a UE is shared at different cell sites, collaborative MIMO includes single-cell antenna processing with multi-cell coordination or multi-cell antenna processing. The first technique can be implemented via precoding with interference nulling by exploiting the additional degrees of spatial freedom at a cell site. The latter technique includes collaborative precoding and CL macro diversity. In collaborative precoding, each cell site performs multi-user precoding towards multiple UEs, and each UE receives multiple streams from multiple cell sites. In CL macro diversity, each cell site performs precoding independently, and multiple cell sites jointly serve the same UE.

3.4.2.4 UL COMP

Uplink coordinated multi-point reception implies reception of the transmitted signal at multiple geographically separated points. Scheduling decisions can be coordinated among cells to control interference. It should be noted that in different instances, the cooperating units can be separate eNB's remote radio units, relays, etc. Moreover, since UL CoMP mainly impacts the scheduler and receiver, it is primarily an implementation issue. The evolution of LTE consequently will likely just define the signaling needed to facilitate multi-point reception.

3.4.3 SITE SOLUTIONS

HET-NET small cell deployments will require equipment that is small, flexible, can be installed easily and rapidly without costly civil engineering and site preparation, and is cost-effective to operate. Small cells can be installed in virtually any location—from lamp posts to walls and cell towers, and from rural areas to enterprise locations and indoor locations. The only requirements to operate them are power and backhaul.

Zero-footprint configuration for small cells is highly desirable. This configuration can support up to 3 sectors, can be mounted on poles or walls, and combines the base station, RF, antenna, Ethernet switching, power supply, battery backup, and backhaul modules in one enclosure. This configuration limits the power loss due to the coaxial cable used to connect the equipment to the antennas, and substantially reduces the power requirement of the entire small cell. Additionally, the configuration should provide passive cooling.

The physical dimensions and appearance of the enclosure should conform to the size, weight, and aesthetic requirements mandated by zoning officials, allowing the units to blend into the environment.

These compact enclosures for small cells will allow the operators to rapidly deploy the small cells and reduce the cost of building and operating the wireless network, thus reducing the overall CAPEX and OPEX.

3.5 DEPLOYMENT SCENARIOS

3.5.1 DESIGN CONSIDERATION FOR HETEROGENEOUS NETWORKS

Several aspects govern effective design of heterogeneous networks. From a demand perspective, parameters such as target traffic volumes, traffic location, and target data rates are important. From a supply perspective the important aspects include radio environment, macro-cellular coverage, site availability, backhaul transmission, spectrum, and integration with the existing macro network. Table 2 summarizes guidelines for some of the key design choices.

Table 2: Rules of Thumb for Low Power Load Deployment

Design Choice	Decision Criteria
Access Open access	**Deployment conditions** Operator deployed
Closed subscriber group (CSG)	User deployed
Deployment	**Hotspot spread and position**
Indoor deployment	Large indoor hotspot
Outdoor deployment	Outdoor hotspot or many smaller indoor hotspots
Type of low power node	**Backhaul availability**
RRU	Fiber
Conventional pico	Copper / fiber / microwave
Relay	Backhaul over the Uu interface in the same or different carrier / frequency band.
Frequency reuse	**Capacity need and access**
Reuse macro spectrum	Capacity is driver
Separate spectrum	Closed subscriber group (CSG)
Power and cell selection	**Hotspot area**
Power	Cover the hotspot*
Biased cell selection	Cover the hotspot*
	*value varies significantly

3.5.2 UNCOORDINATED SOLUTIONS

The simplest deployment configurations are when the macro layer is mostly uncoordinated with the Pico, Femto, and Micro layers. Configurations such as that are shown in Figure 15 below.

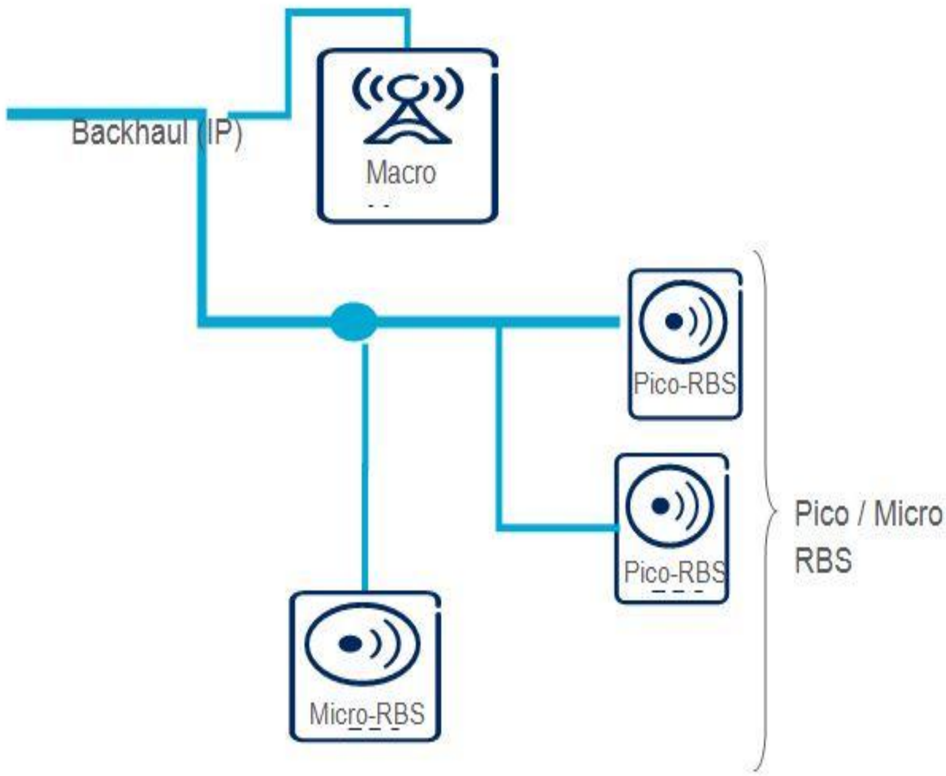


Figure 15: Uncoordinated Solutions

While these configurations maybe easiest initially to deploy, they can lack in many key areas such as OA&M integration, Mobility Performance, and interference mitigation schemes.

Un-coordinated solutions may be necessary in most cases where multi-vendor solutions are applied.

3.5.3 CENTRALIZED ENB (COORDINATED SOLUTIONS)

Coordinated eNB solutions allow for improved performance and functionality between multiple layers and nodes in the network. Macro, micro, femto, and pico nodes can all coordinate with each other. Both all-in-one RBSs (i.e. Micro-RBS, Pico-RBS and macro-RBS) and distributed (main and remote) nodes can all coordinate with each other as shown in Figure 16 below.

The coordination schemes selected will be based on the interconnect quality and whether it is high or low latency interconnect.

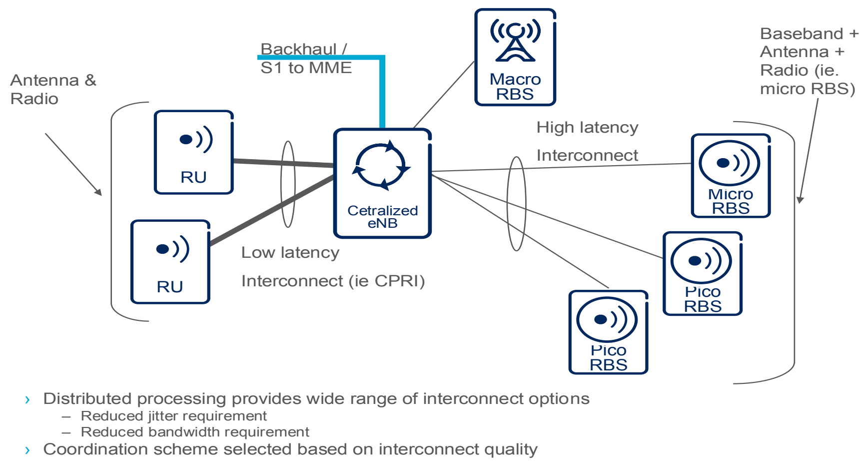


Figure 16: Coordinated Solutions

There are many examples where coordinated networks offer improvements over uncoordinated networks:

- Shared Cell Approach
- Carrier Aggregation based e-ICIC
- Power Balancing and Range Expansion
- Almost Blank Subframes (ABS)
- Mobility Improvements
- OAM integration

3.5.4 DEVICE IMPACTS

HET-NET brings convergence in wireless access to allow the end user to be agnostic of the actual technology that is providing mobile broadband. To enable this, the device has to be capable of some of the following, depending on the operator's definition of service continuity:

- Ability to register on multiple wireless access domains (HSPA, LTE, non-3GPP accesses).
- Portability/reuse of authentication credentials across registered networks.
- Ability to measure, and trigger handovers to the best access, subject to operator configuration.
- Ability to act on triggers from the network to reselect or move the ongoing session to a different wireless access on the HET-NET.
- Ability to work with the operator's network deployment from a device capabilities perspective. This will enable leveraging of HET-NET specific common functionality across wireless technologies and accesses.

3.6 OPERATIONAL ENABLERS

3.6.1 O&M, BACK OFFICE SYSTEMS

There are major challenges in accommodating HTN in today's network management stacks. We expect to see "touch points" in every function of the OSS and BSS systems show in Figure 17.

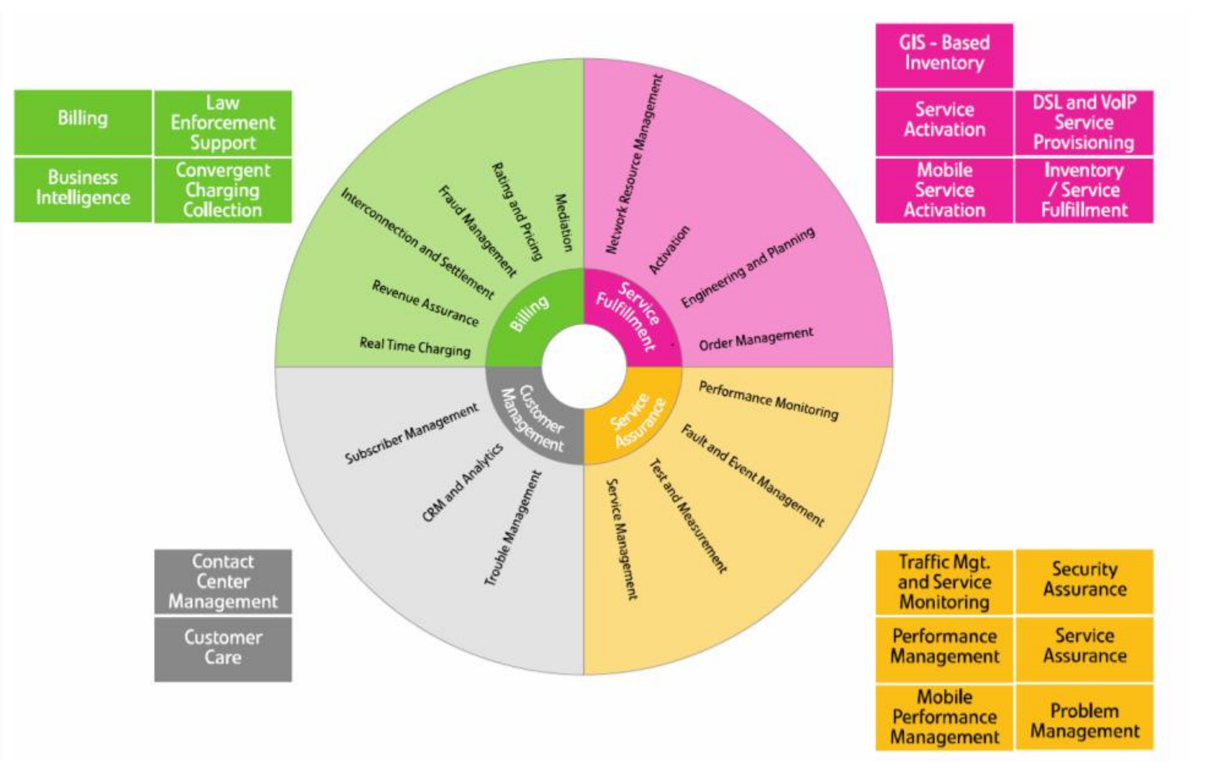


Figure 17: OSS/BSS Functions

In terms of Billing, multiple tariffs may need to be defined and pricing may have to be dynamically adjusted depending on the cell id, the roaming category of the small cell (OSG, CSG), and other factors outside the scope of this white paper.

Service Fulfillment and notably Engineering and Planning are affected in major ways as has been covered already in previous sections of this report. Apart from the UU interface challenges, the sheer numbers of small cells that create ripple effects in the way radio network planners engineer the HTN networks makes planning automation a requirement rather than an option. Service Assurance is a vast area and Configuration Management (CM), Fault Management (FM), and Performance Management (PM) areas requiring special handling. Platforms that handle such messaging must be scalable due to the number of small cells involved. CM and FM are largely standardized, but PM isn't and this has implications in the ability of operators to establish multivendor sourcing strategies. This was manageable up to now with vendors' assigned geographically different markets. With HTN however, such assignments may not be either feasible or attainable economically.

In Customer Management, we expect no implications other than existing accommodations of femto nodes where many operators and vendors enable self-install of such nodes.

3.6.2 SON CONSIDERATIONS

There are basically two possible strategies for HET-NET deployments that will deal with the required increase of area spectral efficiency. Those strategies are:

- Radio planned deployment: in which the Mobile Operator (MO) selects sites, characteristics, and connectivity of the deployed access points and maintains them. That is the case in a pico base stations layer, deployed under the coverage area of a macro base stations layer, for capacity improvement. However, it must be taken into account that the operator will not be free to select the optimum locations and probably will be tied to existing sites or limited by the availability of locations for small cells (e.g. light poles).
- Unplanned and veering deployment: in which sites, characteristics, and connectivity of the access points are, up to some degree, ruled by stakeholders out of the mobile operator control, such as corporations, stores, or residential customers. This is the case in a femto base stations deployment, in which final customers deploy and maintain equipments in their own facilities for capacity improvement.

In both cases there will be an increased complexity in optimizing the radio resource usage and configuration parameters due to the raised number of user equipment on cell borders and the cells coverage areas overlapping.

Therefore, advanced Self Organizing Networks (SON) solutions are key enablers to keep a resilient response to the actual network conditions and the radio behaviour in a changing environment. SON technologies have been included in 3GPP since Rel-8, currently still including enhancements in Rel-11.

Current SON functionalities being developed on 3GPP working items, which will enable an enhanced and simpler network configuration, are:

- Inter-RAT failure issues related to deployment of LTE over GSM/UMTS-HSPA coverage areas.
- Connection failure resolution support for HET-NET deployments in case of the following scenarios:
    - After HO preparation from a macrocell to a pico and due to high speed mobility UE.
    - Differences on macro to picocells HO criteria due to cell range extension technology.
- Inter-RAT ping-pong resolution.

However, new and further enhanced SON techniques will be specifically needed to address the challenges raised by the foreseen massive deployment of access points that are a result of HET-NET.

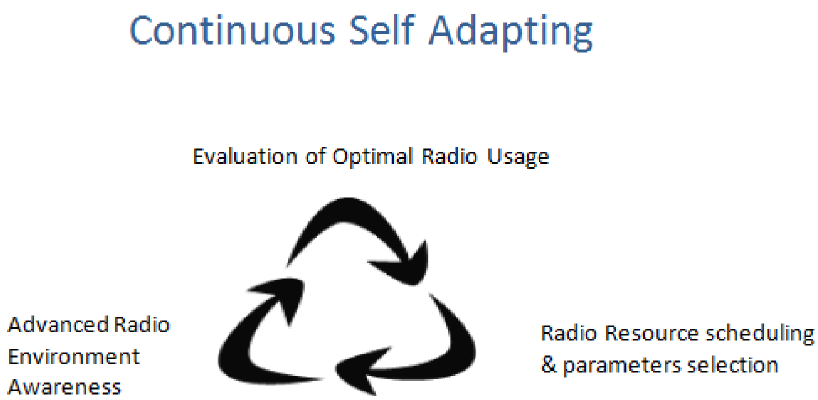


Figure 18: Radio Resource Usage with SON techniques

Furthermore, if HET-NETs are owned by MOs, as indicated in the first deployment scenario, the number of equipments operated and maintained by MOs could increase dramatically and therefore increase mobile network Total Cost of Ownership (TCO). This rise will be mainly due to higher OPEX, but also to the initial deployment cost itself.

Therefore, a key enabler need for the deployment of HET-NET, keeping TCO under reasonable values, is to implement advanced SON technologies, not only allowing base stations to self adapt to the changing radio environment, but also providing self healing and self configuration, following a zero touch deployment approach.

It should be noted that one of the MOs main assets is its assigned bandwidths, and optimization of users' throughputs within a given bandwidth will have a high impact on the overall network efficiency. In this sense, bandwidth usage flexibility among different RATS and among different layers on a single RAT is also a key factor for future network efficiency improvement.

3.6.3 CM, FM AND PM IN MULTIVENDOR HTN NETWORKS

It is worth looking at the northbound interfaces, as well as east-west interfaces, that connect Element Management Systems (EMSs) to network management stacks and to each other. There are clearly two trends that are being formed in the current markets. The first is that vendors place SON functions in the network elements (NE) themselves. The second is that vendors place SON functions in the EMS or above layers. Both approaches necessitate proprietary messaging. In fact, with distributed SON algorithms at the NE element, such messaging is sometimes over X2 interfaces that lack today Interoperability Testing (IOT). This further complicates or incapacitates the deployment of such nodes in multivendor networks. The second approach is where EMS plays a central role in hosting the SON intelligence, East-West (E-W) interfaces are used sometimes, to enable multivendor deployments. Unfortunately E-W interfaces are not as open as the northbound interfaces and not always deployable.

In addition, PM inherits the current status of macro networks, which are not even completely defined, usually left in vendor specific “data silos” to implement.

SON must on one hand expose at the very least the same level of “controls” to the OA&M layers that today's macro networks expose. Given that SON is a requirement for small cells; it must satisfy monitoring, execution and reconfiguration requirements (e.g. latency) that are use case dependent. To provide a concrete example, eICIC requires reconfiguration via X2 or CM of ABS in the macros, reconfiguration of cell selection bias in the small cells, synchronization of such reconfigurations, strict load monitoring latencies at the cell level that track the expected load fluctuations, and design for the IOT limitations of the X2 interface etc. In other words there is quite a lot of "plumbing" to get it right, on top of assignment algorithms, and to be able to function with macros and small cells from different vendors.

3.7 HET-NET CAPACITY MANAGEMENT ENABLERS

Small cells are expected to provide additional capacity in their area of deployment. But additional capacity can only be beneficial if it is utilized in an optimal manner, i.e. overall capacity is increased. One or more of the following techniques can be used for the management of load distribution between the small cell and macro layers in order to optimize the available system capacity.

3.7.1 3GPP HOTSPOT ENABLERS

IDLE-MODE CAMPING STRATEGY

- Idle-mode carrier and cell selection/re-selection related parameters dictate the camping strategy. Section 6.2. (See Appendix) gives more details on the various options that are available.
- Camping strategy impacts the distribution of idle-mode UE's between small cell and macro layers. Choosing the appropriate camping option can help manage the capacity demand between the two layers.
- Idle-mode Load-balancing via Range Extension: Idle-mode UE distribution can be adjusted by dynamically adjusting the Range-Extension parameters. Essentially, the idle-mode reselection parameters are adjusted in response to changes in relative loading between small cell(s) and macro. This impacts the idle-mode UE distribution accordingly. Such adjustments can be made on a dynamic or semi-static basis.

TRAFFIC STEERING

- Camping strategy (and any related idle-mode load-balancing) affects the idle-state UE distribution, which ultimately does have bearing on actual load distribution on the two types of cells.
- Active-state traffic steering capability provides greater control on load distribution. For example, not only network can steer a particular UE (hence its load) to a particular type of cell. It can take other aspects like service-type, data volume, and/or UE's speed into account to fine-tune the traffic steering decision.
- An extreme example would be a HET-NET system that does not allow any UE to directly camp on small cells. Rather only UE's that meet particular small cell eligibility criteria (e.g. low-speed, service or QoS type etc.) are selectively re-directed to small cells.
- Other criteria can also be used apart from factors like UE-speed, service, and data-volume. For example, UE location information, when available, can also be utilized to introduce greater efficiency in the traffic-steering process. Only UE's under or near a small cell are considered for traffic steering.
- Traffic Steering can be used to re-distribute active state-load between small and macrocells in such a way that maximizes user and system throughput as well as enhances QoE for the users.

Active-state traffic steering can be summarized in the following steps:

- Identification of a set of potentially steerable UE's based on operator selection criteria.
- Determination of whether steering action results in more optimal UE distribution.
- Initiating a Handover to Macro. Please refer to section 3.2.2 for addition information related to Handovers.

LOAD-BASED HANDOVERS

HET-NET Load-based handovers can be considered a coarser form of traffic-steering where the goal is to avoid overload conditions from developing on a small cell or macrocell.

This type of handover is needed to avoid overload conditions arising out of uneven load-distribution between small and macrocells. Its needs can be reduced by selecting a good set of camping and traffic steering framework that complement each other in optimizing the load-distribution.

Nevertheless, when asymmetric loading conditions suddenly arise, tending towards overload conditions, load-based handover must be used to balance the traffic. Please refer to section 3.2.2 for additional discussion for small cell to macro LB handover.

For LB handover from macrocell to small cells: UE Location information, if available, can be utilized to narrow-down the set of UE's considered for LB-handover.

In all cases, Load-balancing HO for HET-NET needs to be refined so the UE selection for the HO is according to operator-set criteria (regarding service, mobility etc.). But in case of overload avoidance scenario, if no UE meeting the selection criteria is found, then HO may be performed using any eligible UE.

3.7.2 WI-FI HOTSPOT ENABLERS

- **Hotspot 2.0**

The Wi-Fi Alliance (WFA) has taken an active role in enabling wider adoption of WiFi through Hotspot 2.0, an industry-wide initiative aimed at facilitating and automating secure and trusted connection with the ability to use a variety of user/device-based credentials.

Given the explosion of data traffic on cellular networks and the desire of operators to offload this traffic to networks, Hotspot 2.0 is widely viewed as a critical component to accelerating the adoption as a complementary technology to high-mobility broadband cellular networks.

Hotspot 2.0 is built around a set of a few IEEE specifications:

• **IEEE 802.11u** (new standard approved in 2011): network discovery and selection

802.11u was developed to effectively automate how devices connect to available Wi-Fi networks, a process that up till now has been manual and cumbersome. 802.11u enables Wi-Fi hotspots to advertise their capabilities and then allows devices to connect to them automatically rather than requiring the end user to manually select an SSID.

• **IEEE 802.11i:** encryption (using WPA2-enterprise)

In Hotspot 2.0 only server-based authentication is allowed, a notable change from ‘Open’ and ‘Pre Shared Key’ (PSK) methods supported today. AES 128 bit is used for encryption of the air link.

• **IEEE 802.1x:** authentication (using SIM/USIM device credentials with new EAP additions)

Four EAP types are supported in the specifications: EAP-SIM, EAP-AKA, EAP-TLS, and EAP-TTLS. The cellular convergence comes in with the new additions of EAP-SIM and EAP-AKA. It will now be possible to authenticate a mobile device with the operator AAA server through a Wi-Fi AP using the SIM/USIM card in the device.

The following steps are performed to discover and select the appropriate network:

- AP beacons/advertises Hotspot 2.0 support.
- User device probes with Hotspot 2.0 support.
- Device selects AP and request information to determine what providers are supported, services, capabilities of the AP, etc.
- AP responds to device query with requested information.
- Device compares provisioned profile information against Hotspot 2.0 data from AP’s and associate with the best SSID.

Note that both the device and the AP have to support 802.11u for Hotspot 2.0 to work.

In summary, Hotspot 2.0 promises to automate network discovery, registration, provisioning, and network connectivity, which are manual steps today when a user connects to a given Wi-Fi hotspot. It also helps the wireless operator in facilitating unified security architecture using the AAA server in the EPC to authenticate users connected via Wi-Fi and/or LTE. Ultimately, 802.11u and Hotspot 2.0 promise to make connecting to services as easy, seamless, and secure as today's cellular experience.

3.7.3 HET-NET BETWEEN WIFI AND 3GPP HOTSPOTS

For efficient capacity management between the WiFi and cellular domains, functionality will be implemented on both networks and devices.

A common core network serving Wi-Fi and cellular, where the Wi-Fi is considered a trusted network in 3GPP (see Section 1.1.3), will enable operators to build traffic steering functionality between cellular and networks.

On the device side, devices will report network performance indicators to both Wi-Fi and cellular controllers to allow for network initiated actions that will include capacity management between network technologies.
With the advent of traffic steering based on traffic type or policy, operators will be in a position to steer traffic based on expected capacity loads from the application being activated by the subscriber.

3.8 SECURITY ENABLERS

Most of the security challenges outlined in Section 2.8 can be addressed by the operator using existing known authentication and encryption mechanisms. In addition to securing the air interface between the mobile device and the small cell (3G/LTE/), all assets at the edge of the network that rely on untrusted network transport (Internet) must be connected to the core network via secure IP tunnels (GRE, IPSec). It would be advantageous to the operator to leverage the same IPSec security architecture for all of its small cell deployments (femtocells, picocells, carrier-).

Integration to the operator core network and the use of wireless backhaul are relatively new additions to the network architecture (in addition to femtocells that are already wired to the core via untrusted public networks),

- **Integration to the Core**

Parallel to the development of the 3GPP approved I-WLAN standard of the use of IEEE's 802.1x authentication combined with GRE/IPSec tunneling from the small cell to the core is probably the preferred way for securing end-to-end traffic from the mobile to the operator core. As mentioned earlier I-WLAN requires an IPSec tunnel from the mobile device to the core network and may have limited scalability supporting millions of devices. Instead, authenticating the user using 802.1x and encrypting the air interface using 802.11i will result in a more scalable solution as tunneling is required only from the small cell (and not from the mobile device) to the core. These provisions are addressed in Hotspot2.0 in Section 2.7.1.

- **Wireless Backhaul**

Wireless backhaul is anticipated to play an important role in small cells for ease of deployment and because of limited access to fiber, GE on lighting poles, etc. Many microwave and other radio-based backhaul solutions support robust encryption. The disadvantage to the operator in relying on this as an alternative to IPSec is that IPSec provides a uniform approach for both authentication and encryption across all its insecure cells.

4 RECOMMENDATIONS

4.1 BACKHAUL

Key Challenges in the industry in the area of backhaul have been discussed in Section 2.1. Key Enablers in a HET-NET enabled network to address backhaul have been addressed in Section 3.1. Based on these sections, the following needs to be considered in the selection of backhaul for HET-NET enabled networks:

- Low installation cost
- Low or no MRC (monthly recurring costs)
- An aggregation point for 4 to 16 small cells
- Hardened outdoor components (e.g. for lamp post deployment)
    - Low power consumption
    - Small form factor
    - High security (e.g. tamper proof, encrypted user plane)

4.2 MOBILITY MANAGEMENT

3GPP is already on the right path studying the need for enhancements to ensure robust mobility in heterogeneous networks without adversely impacting device power consumption and user experience. It is recommended that such a study be continued and appropriate enhancements be made to account for different cell sizes. Addressing issues like efficient discovery of small cells and ensuring a more stable mobility state estimation of a device in heterogeneous networks, traffic steering based on device speed, and cell sizes involved in the mobility management are important.

4.3 LOCATION PLANNING

Accurate location planning for small cells maximizes capacity. The best traffic location results are currently provided by network-based solutions. For the purpose of installing a new site for additional capacity, they are the only ones accurate enough to determine the UE position within a few tens of meters. In order to reduce the costs of these tools to identify the best location for a small cell in a multi-vendor HET-NET environment, it is critical for the industry to align on traces description, network interfaces to be inspected, and other information that needs to be gathered.

Minimization of Drive Test (MDT) servers can also be a useful source of information for the optimal placement of small cells. Unifying vendor-specific schemas open APIs and orchestrating the data collection across MDT vendor boundaries is necessary.

4.4 TECHNOLOGIES / FEATURES PLANNED

Several technologies and features planned to facilitate and improve Het-Net performance have been detailed in Section 3.2. Innovative equipment design in support of small form factors with flexible deployment options will enable cost-effective deployment and operations. Interference mitigation techniques are already supported in existing standards and additional enhancements are being identified in forthcoming releases. Multiple strategies inclusive of network based co-ordination for ICIC, CoMP methodologies, and UE based receiver enhancements in combination should be considered for design of a high performance Het-Net.

SON implementations, which automate network operation and help in the planning and deployment process, are key HET-NET features for CAPEX/OPEX reduction and performance optimization. However, SON procedures are usually vendor proprietary and some of them run in a distributed way at the RAN level. In a multi-vendor HET-NET, whether a single-vendor per geographical area HET-NET or single-vendor per layer HET-NET, it will be recommendable to keep a higher level control of all the SON procedures by means of a higher level SON running in the operator's OSS and a set of direct communications with every vendor's domain Element Manager in order to provide general operator's policies to every lower level SON such as:

- HET-NET performance monitoring, based on enhanced MDT techniques
- Location Planning / Traffic Mapping

As has been discussed in the previous sections, the biggest challenge in SON HTN implementations is the interactions between SON features. Some of them can cause anything from capacity loss to instabilities in the overall network if not explicitly controlled. It is recommended that the OSS level SON functions have the ultimate centralized control irrespective if the individual SON functions are distributed in the network elements or centralized in or above the Element Management Systems (EMS). State persistency of the overall network is a key characteristic / recommendation that will allow backtracking of parameter configurations, overriding of processes, and redirection of SON workflows to correct troubling feature interactions that are only exacerbated in multivendor environments.

4.5 DEPLOYMENT

Handling deployment challenges and enablers from a deployment standpoint requires that some of the following is addressed by the industry:

- Network planners in Wireless networks:
  - Network planners are required to understand how wireless works across technology (GSM/UMTS-HSPA/LTE) boundaries.
  - Devices are capable of either providing continuity across heterogeneous networks, or gracefully terminate sessions at technology boundaries.
  - Network planning tools need also to evolve to capture the scale of the HTN networks. In a major metropolitan area, with 3000 macro sites, we would expect to see up to 10x (30,000) public small cells in addition to many tens of thousands of CSG cells. This makes the planning exercise a major computational task even at the starting point of determining the best locations and initial configuration of 30,000 cells.
- Multidisciplinary awareness in wireless deployment:

- Tight integration of RF and transport planning requires that networks may need to be built around sources of transport.
- Quality of service across these disciplines is imperative to facilitate intelligent handling of traffic across technologies and components of the HET-NET.

- Tighter integration of multiple RF technologies into the packet core to ensure continuity across HET-NET:
  - Real time services will drive consistency, continuity in IP address for a single session. This places an important requirement and recommendation on heterogeneous network design across technologies.
  - Cooperation between traditionally wireline/broadband packet cores and wireless cores are required.
- Charging and provisioning infrastructure across HET-NET:
  - Partnerships and interfaces between individual technology networks to build a common charging and provisioning interface across the HET-NET.
- Roaming traffic:
  - Enabling of roaming and authorization interfaces within and across HET-NET technologies.

4.6 OPERATIONAL CONSIDERATIONS

A dynamic and smart traffic steering between HET-NET layers, frequencies, and RAT's for load balancing is a major requirement for the operation of the network. Current load balancing SON procedures are typically vendor-proprietary and work properly within its domain. Therefore, in order to improve load balancing in a multi-vendor scenario, 3GPP standards must be evolved to simplify the interoperability tests through the X2 interface, and some OSS-centralized high level SON for load balancing should be implemented. Furthermore, it must be taken into account that in many HET-NET deployments the same carrier frequency will be shared between the macro and the small cell layer, thus limiting the freedom to load balancing between layers due to interference. In this scenario, 3GPP Release 10 and beyond interference mitigation and cell edge performance improvement techniques will be mandatory for performing load balancing between layers.

4.7 CAPACITY MANAGEMENT CONSIDERATIONS

Capacity Management across the heterogeneous network requires a strong understanding of the traffic profiles and relative distribution in the use of these technologies at a particular hotspot. The following recommendations apply:

- Network operators need to drive stronger partnerships between industry segments like Wi-Fi, wireline broadband, wireless broadband. This will enable efficient planning of capacity management and offloading between technologies that comprise the HET-NET.
- Judicious use of technology based on service requires that QoS based management of capacity is adopted by the industry to ensure that the most capable technology is prioritized for the service.
- RF design techniques that mesh the diffused capacity/high coverage approach from cellular wireless, with the focused capacity/small coverage approach from Femto / approach.

4.8 SECURITY RECOMMENDATIONS

Small cells form factor and installation in open public areas expose them to security threats (physical security as well as network security). To mitigate the security risks involved with small cells, from theft to network hacking attacks, some measures are recommended. Both IPSec and Hotspot2.0 (for Wi-Fi) are important mechanisms to secure end-to-end traffic from the mobile device to the core network. IPSec should be used to secure network infrastructure at the edge (femtocells, picocells, and carrier grade Wi-Fi), and Hotspot2.0 will take care of securing the air interface of devices. Specific recommendations include:

- Small cells have to be authenticated to the core network using pre-shared credentials (e.g., certificates).
- Use of IPSec security architecture as a unified approach to all insecure cells. This includes authentication and encryption from the small cells to the core network.
- Wi-Fi access should be limited to WPA2-enterprise, that is, all users are authenticated to an AAA server (e.g., using 802.1x with EAP-AKA, EAP-SIM, etc.). This will be facilitated by Hotspot 2.0.
- Small cells should be tamper-proof, i.e. unauthorized access to the unit should generate alarms. In addition, moving or displacing the device should also generate an alarm or notification.
- Traffic between small cells and the core network should be transported via a secure tunnel (IPSec) when traversing untrusted medium (Internet).
- Traffic between mobile devices and small cells should be protected through air link encryption (e.g., AES 128 bit).

In summary, both users and small cells have to be authenticated and traffic should be secured on the air link as well as between the small cells and the core network. In addition, any physical movement of the small cell or unauthorized attempt to open it should generate an alarm.

5 CONCLUSIONS

Multi-RAT, multi-layer heterogeneous networks will be instrumental in meeting the coverage and capacity needs of increasingly data centric networks of the future in a cost and operationally efficient fashion. This white paper analyzed the industry challenges in the areas of converged wireless networks using cellular, Wi-Fi, and other wireless accesses. Challenges are identified on an end to end perspective including radio, core, operational, mobility, and security aspects. Potential solutions to the challenges are discussed and presented.

Heterogeneous Network deployment encompassing multi-RAT, multi-layer, and multi-band networks will be a challenge and opportunity for network designers. Some of the key challenges include provisioning of cost-efficient backhaul that can deliver the performance expected by the end user. Mobility Management in HET-NET is a key consideration in HET-NET deployments and further studies related to enhancements need to be conducted to ensure robust mobility and superior quality of experience for the end user. Placement of small cells near the traffic is another key challenge that needs to be addressed. Proper placement of small cells will ensure that traffic is optimally served in the small cells while reducing the interference leading to significant gains for operators in serving their subscribers. Interference cancellation / coordination could play a very significant role in HET-NET deployments and mitigation techniques will be needed for shared carrier deployment of macro and small cells. Management of a large number of additional cells will pose a huge operational challenge, so new SON features will play a key role in the deployment and management of HET-NET.

HET-NET will continue to evolve in the 3GPP standards bodies for both HSPA and LTE technologies as networks are deployed, and the need for new features arise to meet the deployment and operational challenges of these networks.

6 APPENDICES

6.1 ACRONYMS

ANR	Automatic Neighbor Relation
CCO	Coverage and Capacity Optimization
CM	Configuration Management
COC	Cell Outage Compensation
CQI	Channel Quality Indicator
CSG	Closed Subscriber Group
DAS	Distributed Antenna Systems
EMS	Element Management System
eNB	Enhanced Node Base station
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FM	Fault Management
GCI	Global Cell Identifier
HO	Hand Over
HSPA	High Speed Packet Access
ICIC	Inter-Cell Interference Coordination
IRAT	Inter-Radio Access Technology
IRP	Integration Reference Point
KPI	Key Performance Indicator
LTE	Long Term Evolution
MDT	Minimization of Drive Test
MLB	Mobility Load Balancing
MRO	Mobility Robustness Optimizations
NB	Node Base station
NGMN	Next Generation Mobile Networks
NM	Network Management
OAM	Operations Administration and Maintenance
OPEX	Operational Expenditure
PCI	Physical Cell Identifier
PM	Performance Management
PRB	Physical Resource Blocks
QCI	QoS Class Identifier
QoE	Quality of Experience
QoS	Quality of Service
RACH	Random Access Channel
RF	Radio Frequency
RLF	Radio Link Failure
RRC	Radio Resource Connection
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SDU	Service Data Unit
SINR	Signal to Interference and Noise Ratio
SON	Self-Organizing Networks
TAC	Tracking Area Code
TTT	Time To Trigger
UE	User Equipment

6.2 CAMPING STRATEGY

Idle-mode cell selection/reselection mechanism governs the camping of the UE's. For small cell deployment, any of the following camping strategies may be used to control how UE's make a decision to camp between available macro and small cell cells. If a chosen camping strategy results in small cell overload due to too many UEs being offloaded onto it, a Load-based Handover mechanism may be invoked to reduce small cell loading. Target for Load-based Handover should preferably be a "non-neighbor" macrocell/carrier to prevent the UE from bouncing back to the small cell immediately after connection release. Appropriate configuration ensures that a handed-out call is not immediately handed back to a small cell. Load-based handover should not be configured for small cells deployed for coverage reasons. Other load alleviation techniques may be used instead.

6.2.1 FREE CAMPING:

By default (in the absence of any explicit carrier prioritization and/or Cell or Frequency specific offsets), UE's always select the best serving cell to camp on. This is termed as free camping. Free camping can be used for intra-frequency as well as inter-frequency neighbors. No special configuration is required except that any inter-frequency carrier must be listed in SIB5 to enable UE's to search for it.

With free camping, UE's always camp on the best carrier/cell, which is optimal from RF performance point of view. But best carrier does not assure optimal throughput under high and uneven loading among carriers/cells, and it is possible that actual user-level throughput may get reduced due to higher resource contention on the best cell. Under such conditions, a UE may be better-off selecting the second strongest cell. Free camping can be applied to shared-carrier as well as dedicated-carrier small cells, but free-camping has limited applicability. Since small cells have lower transmit power than macro, free camping only works for small cells deployed where macro-signal has sufficiently weakened, e.g. inside building, cell-edge, coverage-gap etc. This makes free-camping most suitable for same frequency small cell deployed over a coverage gap.

IDLE-MODE MOBILITY UNDER FREE CAMPING – (MAINLY MACRO)

A macrocell UE remains tuned to it until it finds a stronger signal whether another macrocell or small cell.

A macrocell UE remains tuned to the macrocell/carrier until it finds small cell signal stronger than macrocell.

A high-mobility UE can be discouraged from tuning to small cell by use of a higher *Treselection* parameter. This works best in case of isolated small cells. Use of this technique is more appropriate for different-frequency small cells, as a frequency-specific *Treselection* can be specified for this purpose without affecting normal *Treselection* value used in macrocell reselections.

A small cell UE remains tuned to it until it finds a stronger signal whether another small cell or macrocell. If UE is moving out of small cell coverage, macrocell signal usually becomes stronger much before UE loses small cell coverage.

6.2.2 PREFERRED CAMPING – (OFTEN SMALL CELLS)

In this scheme, *Qoffset* parameter is used to bias reselection in favor of small cells. Small cell is selected for camping even if it is not the strongest, as long as its strength is within *Qoffset* (db) of the strongest macrocell signal and meets the minimum signal level requirement.

This method can be applied to same-carrier as well as dedicated-carrier small cells. But there are some limitations when used for same-carrier small cells:

- For small cells on the same carrier as macro (serving), *Qoffset* has to be specified for each small cell using the Intra-Frequency Neighbor-Cell list parameter in SIB4.
- Only a limited bias can be practicably used in favor of small cell. Otherwise interference from the much stronger same-frequency macro would cause performance issues.

This coupled with the small cell's low transmit power limits where same-carrier small cell preferred camping can be used to areas where macro-signal has become comparable to the small cell's signal e.g. inside buildings and near cell-edge. This is very similar to free-camping limitation, but expands the small cell feasible area around it (small cell free-camping area).

Small cells-preferred camping is much simpler for dedicated-carrier small cells, as a frequency-wide *Qoffset* can be specified in SIB5 for the small cell carrier. The amount of bias applied to small cells can also be relatively higher as macro-layer is not a direct interferer (though adjacent-carrier interference considerations still apply). Given this freedom, dedicated-carrier small cells can be deployed almost anywhere within the macro network (except where precluded due to adjacent channel interference considerations) and UE's made to camp on small cells-layer irrespective of the macrocell signal strength there (by using sufficiently high bias).

In small cells-preferred Camping, even though a UE is not camping on the optimal carrier (RF-wise), improved throughput is possible if it results in better load-distribution and lower resource contention. This method provides an opportunity to exploit this further. *Qoffset* bias between small cell and macrocell can be adjusted to dynamically balance loading on small cell- and macro-layers for optimal throughput Idle-mode Mobility under small cell-preferred camping.

UE reselects to the cell with the highest offsetted signal-strength (i.e. measured strength plus *Qoffset* value).

Thus a UE on macro-layer continues to reselect to the strongest macrocells until it finds small cell signal(s) within *Qoffset* db of the strongest signal. It then reselects to the small cell (with the highest offsetted signal-strength, if more than one). A UE on small cell-layer switches to macrocell only when a macro's measured signal strength exceeds the small cell's by at least *Qoffset* db, or the small cell's signal strength falls below acceptable level.

A high-mobility macro-layer UE can be discouraged from tuning to small cell by use of a higher *Treselection* parameter. This works best in case of isolated small cells. Use of this technique is more appropriate for different-frequency small cells, as a frequency-specific *Treselection* can be specified for this purpose without affecting normal *Treselection* value used in macrocell reselections.

6.2.3 PRIORITY CAMPING (SMALL CELL)

This scheme can only be used for different-carrier small cells. Small cell-priority camping is implemented by giving small cell frequency higher priority via Inter-Frequency Carrier-List Cell-Reselection-Priority parameter in SIB5.

This makes UE’s always prefer small cell for camping as long as its signal-strength is not below minimum acceptable level. Thus all UEs falling in the coverage-area of the small cell end-up camping on it (unless they are tuned to a “non-neighbor” macrocell that does not broadcast small cell carrier information in SIB5). This has a potential to lead to overload conditions on the small cells, and may need Load-based HO to offload users as described earlier.

As long as this camping scheme leads to reduced loading on macrocell (without overloading the small cell), lower resource contention results in improved throughput. Assigning absolute higher priority to small cell carrier does have potential disadvantages however. Due to absolute prioritization, a UE will stick with a small cell as long as it receives acceptable signal from it no matter how weak it is compared to macrocell. This would result in reducing the maximum realizable throughput for that UE. Careful tuning of *thresholdServingLow, threshX-Low* and *threshX-High* is required to mitigate this problem. Idle-mode Mobility under small cell-priority camping:

UE reselects to strongest cell from the high priority cells (small cells) as long as it meets minimum signal requirements noted below. UE reselects to low priority carrier (macro) under the following conditions:

- Strongest high-priority signal strength is below minimum signal level requirement, or
- Strongest high-priority signal strength is below *thresholdServingLow* while a low-priority signal strength is better than *threshX-Low.*

Thus UE’s on small cell continue to reselect to same or other small cells unless forced to reselect macrocell due to either of the conditions described above. Once on macro-layer, UE’s only remain on it as long as it doesn’t find a small cell signal meeting *threshX-High level.*

High-mobility macro-layer UE can still be discouraged from tuning to small cell by use of a higher *Treselection* parameter. This works best in the case of isolated small cells.

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