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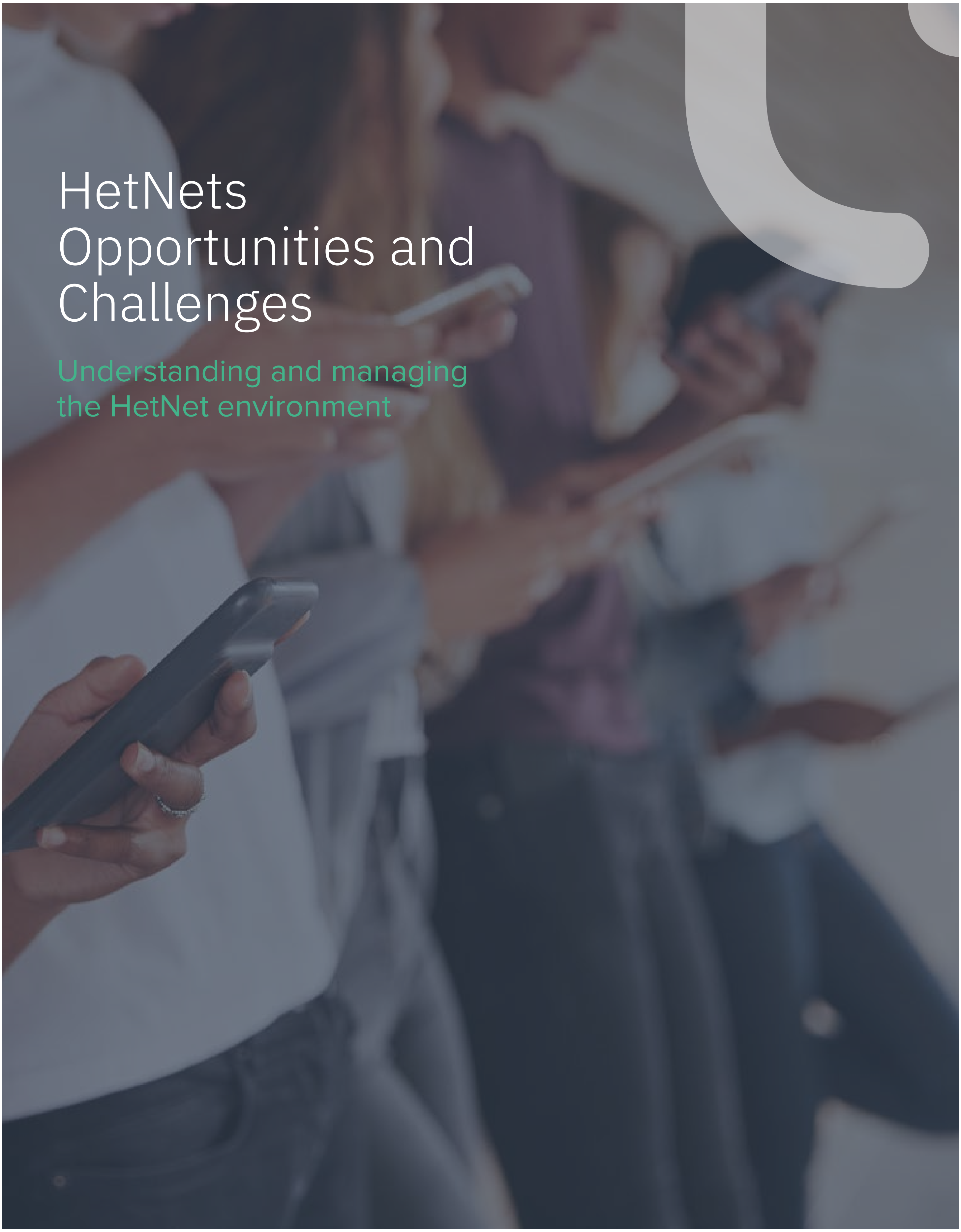


HetNets Opportunities and Challenges

Understanding and managing the HetNet environment

Content

Why HetNets?

The impact of Voice over Wi-Fi

With the explosion of mobile data services expected, operators around the globe are seeking ways to expand capacity in their networks. This capacity need is driven by the deployment of smartphones that are data centric and based on new data services – mostly video – that are hungrily consuming bandwidth and capacity in the networks. The industry is predicting that growth in users of smart devices will increase four- to five-fold by the end of 2014, and that the resulting data traffic will grow 30 to 40 times in volume. Mobile video is predicted to be the major driver of traffic in the network with estimates forecasting that it will drive 70 to 75 percent of the mobile traffic growth over the next few years.

The demand for higher bit rates and capacity also needs to be tempered by the cost of the expansion of the operators' networks, and here many of the requirements will be handled by the deployment of LTE networks. Today LTE is the fastest developing system in the history of mobile communications and is the basis for many of the prognoses that point to about 50 billion wirelessly connected devices operating by 2020. However, the rate of mobile data growth generated by users far exceeds the speed of network deployment or expansion at the moment, and this will sooner or later force the industry to find new ways of expanding the capacity of the networks. These new solutions need to add capacity in a cost efficient way and minimize the deployment and operational cost.

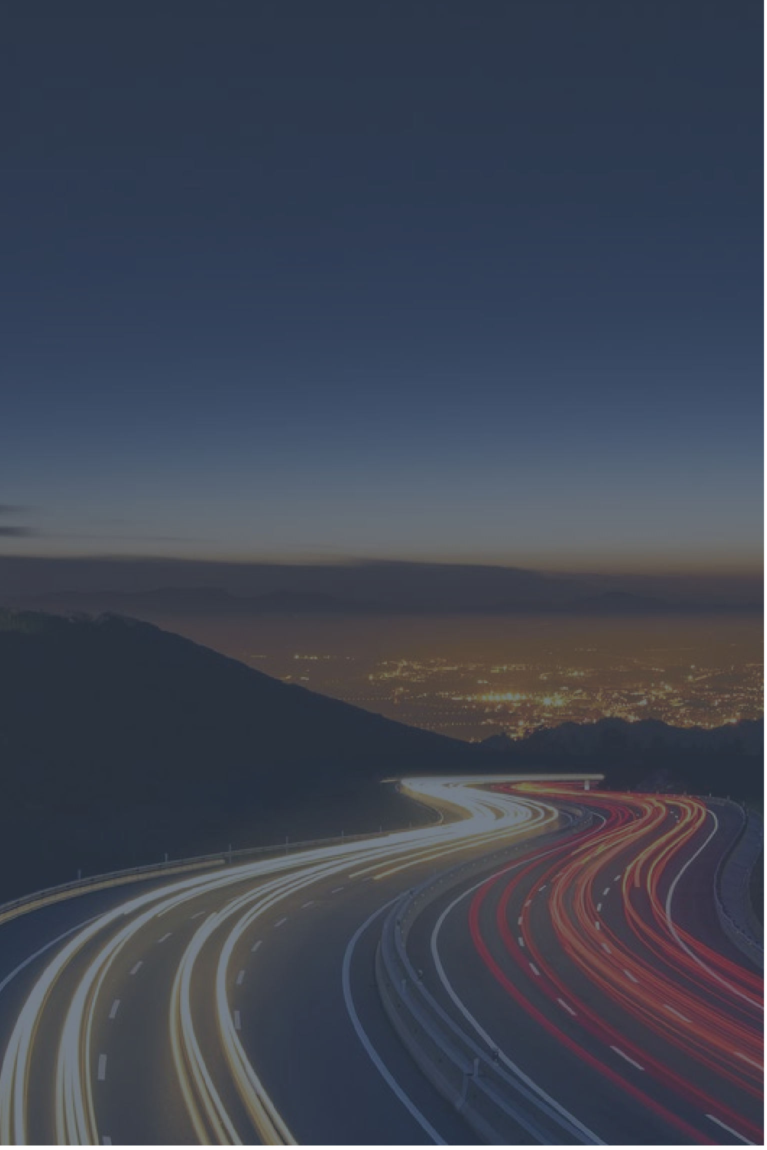
Surveys of operator management shows that 98 percent of responding operators say that they think small cells will be essential to address capacity constraints in a cost effective way in their networks. Other surveys predict that 90 percent of all base stations by 2016 will be small cells – a total of more than 90 million small cells – and will handle up to 80 percent of the capacity needs but with only 20 percent of the investment in total radio access network (RAN) cost. Already today (August 2013), the number of small cells exceeds the total number of traditional base stations in the world.

Hyper-dense deployment of small cells will increase the capacity of the network, and coverage will be expanded, and not only indoors. We will also see that the small cells will grow the capacity for outdoor coverage by moving macro cell coverage outside of residential buildings that have deployed small cells. Initial tests show that outdoor coverage is already increased when there is household use of small cells (called femto cells) at a penetration rate of about 10 percent in an area. With a femto cell penetration of about 20 percent, roughly 90 percent of the data traffic in a given neighborhood can be routed via these small cells instead of the traditional macro network. An ever-growing demand for mobile wireless capacity makes small cells a valuable cornerstone in the future strategy for network expansion.

A heterogeneous network, dubbed "HetNet" by the industry, is a tiered RAN cell topology that uses macro, and various types of smaller (micro, pico and femto) cells and several technologies together to offer wireless services. HetNets are already here today, and the majority of the Tier-1 wireless operators have already deployed some type of HetNet solutions in their networks. HetNet technology does not distinguish between radio bearers but rather focuses on the deployment and configuration of the network. This means that we see HetNets that are a combination of radio access technologies, where both traditional mobile networks with UMTS/CDMA and LTE will work together with Wi-Fi networks to form the multilayered heterogeneous networks.

Historically, mobile networks were built out of base stations where the location of each base station was carefully planned, and the network's topology was configured for maximum service signal coverage. Growing the capacity in these types of homogeneous networks – networks that only use traditional macro cells – can be achieved by cell splitting, or by adding carriers to the existing network. With a greater number of denser networks, site acquisition has become much more difficult. Growing this type of network topology will not cost effectively meet the need for increased capacity and coverage. Therefore, new approaches to the network's entire cell-based architecture are needed, and this is why "heterogeneous networks (i.e., HetNets)" are so important to the future of the mobile wireless industry. One aspect of these HetNets are small base stations that can easily be deployed inside an existing macro network, forming small coverage areas using low power – from 100 milliwatts to 2 watts.

With small cell deployments, two typical use cases present themselves: either indoor/outdoor commercial areas covered by operators, or residential areas that use small cells deployed by subscribers themselves. To keep the deployment costs of these small cells very low



it is important that the small cell units are more or less self-configurable. Small cells typically are deployed in indoor/outdoor commercial areas requiring high capacity that cannot normally be met using only the macro network. These small cell installations most often use leased backhaul connections that are already part of the deployment in the commercial facility being covered.

In residential areas, one of the main reasons for using small cells is to extend the coverage of the macro network. By adding small cells at end user's location in their homes, it is possible to use broadband access from homes as backhaul, and in this way reduce the need for expensive infrastructure build-outs. For the residential installations, the deployment process must be kept as a plug-and-play scenario where customers can plug in the unit and just power it up. The configuration of the residential small cell should then be automated based on the location and the surrounding environment.

Three main types of HetNet deployments can be identified: 1) Mobile – Wi-Fi; 2) Mobile – Mobile + Wi-Fi; and 3) Mobile – Mobile.

Mobile – Wi-Fi offers two main advantages. First, Wi-Fi offloading can afford the user potentially higher data rates over the radio interface. However, the Wi-Fi backhaul may not always support such rates, thereby essentially limiting the end to-end throughput. Second, not using the licensed spectrum of macro or femto cells reduces the overall interference to the macro-cellular network and can potentially improve the overall cell performance. This has to be balanced, however, against the greater control of handover and interference within a cellular network. In addition, the Mobile – Wi-Fi scenario requires manual user intervention to switch the device between the two carriers.

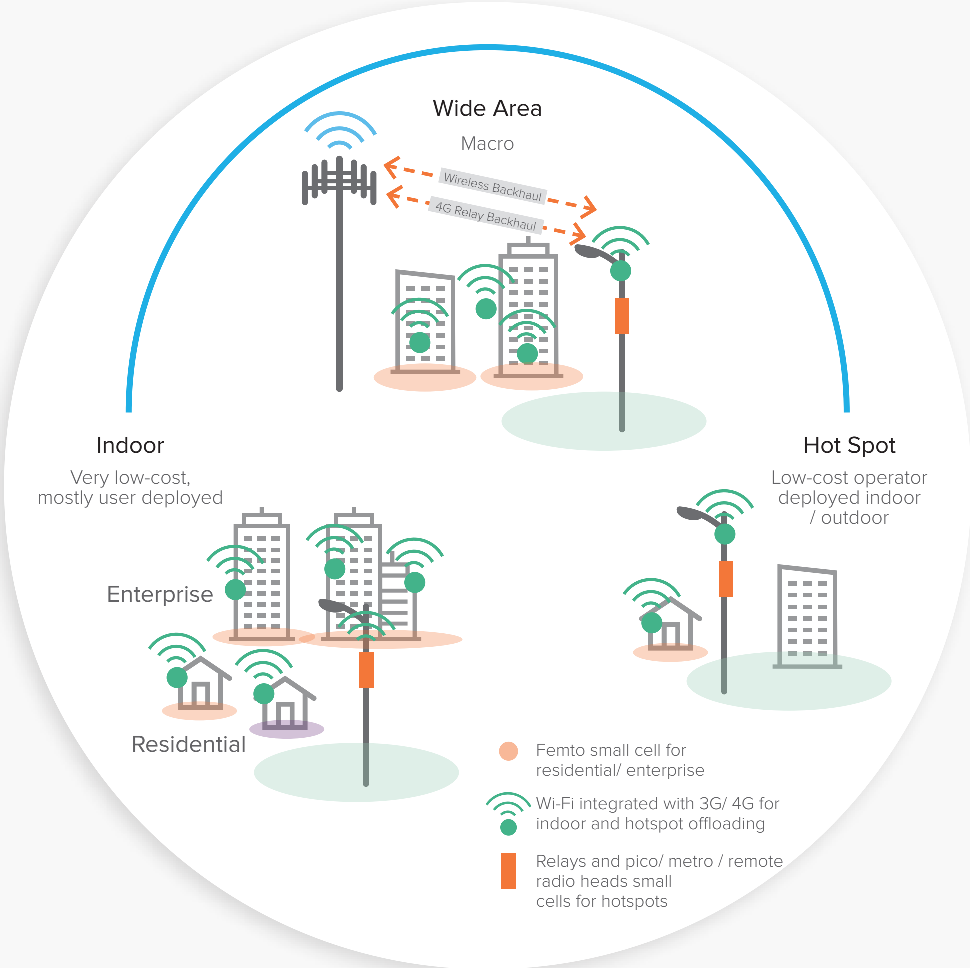
Mobile – Mobile + Wi-Fi and/or Small Cells require seamless interworking in devices that is transparent to the user. More advanced implementations allow both small cell cellular and Wi-Fi to be used simultaneously for different traffic flows, or to create a single large pipe for HD media, or to create a highly resilient connection.

The Small Cell Forum [7] and Wireless Broadband Alliance (WBA) [8] recently announced that they will work together to intelligently integrate small cells and Wi-Fi to improve quality of service, lower costs and simplify deployment. In addition, Cisco announced it will start building small cells for the first time and that these will ultimately support 3G, LTE and integrated carrier Wi-Fi.

Mobile - Mobile solutions are already defined by 3GPP [1], making use of the cell range expansion (CRE) (section 2.1.) concept to integrate the small cell layer within the existing macro layer.

Operators are working on new approaches to make more efficient use of the spectrum over the air, but there is an associated demand to have increased capacity in the backhaul network. By using external bandwidth from end users' broadband connection, to hooking up to existing commercial IP networks, operators are gaining new, and in some cases free, capacity without the need to build out their own networks. However, this also adds new challenges. Operators need to ensure the end-to-end quality for services they are delivering to customers, and they need to make sure that service quality is not affected by the configuration of the network, even if parts of the network are not controlled by the operator. These are some of the issues that need to be addressed in these types of new networks, and we describe the challenges arising from the deployment of HetNets in this paper.

Figure 1. Currently available HetNet solutions



Challenges with HetNets

Managing the potential for interference

The 3GPP solution to the exponential growth of mobile data traffic is LTE and LTE-A (Rel. 11 and onwards), where the standards are designed to ensure the realization of cellular grids dotted with dynamic cellular bubbles, creating HetNets.

The coexistence of macro cells and small cells (different types identified in Table 1), such as micro cells for outdoor applications, pico cells for indoor applications (generally enterprise), and femto cells for residential indoor applications, are seen as the most promising solutions to provide a major performance leap for increased spectrum efficiency and spatial reuse. In other words, packing more cell sites into a given area enables mobile appliances to intelligently reuse the available spectrum.

Equipped with smart software, these small cells are designed to sense their neighbors and even expand their power to meet changing capacity needs. However, the HetNets' potential for increased coverage and capacity, while seamlessly integrating with the macro cells and with one another, comes at the price of interdependent technical challenges – an increase in the potential for interference. The interference between the small cells as well as with the overlying macro cell layer is the major challenge which also directly affects the mobility management within the HetNet. 3GPP adopted solutions to cope with these challenges (see reference [1], [3], and [4]) rely on timing and synchronization between small cells themselves, as well as with the macro layers, and/or on backhaul available bandwidth.

The performance of the interference and mobility management solutions depends on the advent of more powerful UEs with much more advanced processing compared with the UEs served in traditional macro cellular networks. This is required due to the fact that UEs - under potentially severe interference conditions characteristic of HetNets - need to configure resource-specific channel measurements and feedback as well as run interference cancellation algorithms. Without these, the gains from 3GPP-specified interference management solutions will be lost.

The main key performance indicators (KPIs) that describe a given HetNet's performance are 1) overall network throughput, 2) cell fringe and in-building performance, and 3) seamless mobility. Maximum quality of service gain would be achieved if it could be possible to adequately adjust a UE's association with various cells, and dynamically manage radio resources and interference accordingly. This means that operators must carefully benchmark the UEs' capabilities for HetNet operation to ensure the selected UEs fully exploit the advantages that HetNet deployments and advanced interference cancellation techniques can offer for both interference, as well as mobility management.

In allowing substantial increases in data capacity by offloading traffic from the macro cell, small cell performance is also highly dependent on backhaul scalability and provisioning. In addition, network security poses serious challenges for scenarios using Wi-Fi hot spots and/or third-party small cell solutions.

This section discusses aspects related to these challenges, how to cope with these challenges, and what the testing implications are in ensuring the delivery of high quality of service.

Cell Range Expansion and Synchronization Role

Due to the difference in the transmission power of the small cells and the macro cells, the terminals do not necessarily connect to the cell showing the lowest path loss (small cell), but rather to the strongest downlink signal strength (macro cell). Therefore, the cell selection strategy for achieving high data rates on the uplink is based on the cell range expansion (CRE) feature [1].

This CRE feature ensures an additional offset to the received downlink signal strength from the low powered cells during the cell selection process. It is desired to have higher offsets - generally more than 9dB - for a larger CRE zone and, therefore, high efficiency of the small cells due to increased overlapping coverage area with the macro cells. However, high offsets pose interference problems which can be controlled by restricting macro cell transmissions from using the same time and frequency resources as the low powered cells. This can be achieved by either implementing cell resource partitioning in time or frequency domain, or by using the soft cell concept. **Figure 2** describes all three scenarios. For time or frequency partitioning (**Figure 2a**), the macro and small cell act as independent cells (**Figure 2b**). The soft cell scenario (**Figure 2c**) relies on the LTE capability of splitting the base station functionalities into a baseband unit (BBU) and a remote radio head (RRH); therefore the small cell becomes part of the macro cell, owing and sharing all their control and data channels (**Figure 2d**), as explained in more detail in section 2.2.2.

Table 1. The coexistence of Macro Cells and Small Cells

Cell	Cell/ Cell Radius	Tx pw
Macro (outdoor)	>300m	46dBm
Micro (outdoor)	100-300m	40dBm
Pico (outdoor/ indoor)	<200m	>24dBm
Femto (indoor)	10-25m	<20dBm

The cell resource partitioning in the frequency domain is specified in Rel. 10, and generally used by adopters of carrier aggregation. It relies on time synchronized small cells with the overlaying macro layer when placing downlink control signaling from the two layers on separate carriers in the range expansion zone (**Figure 2a**). The time-based resource partitioning relies on the Almost Blank Sub frames (ABS) feature which reduces the macro transmission activity in certain frames in order to protect the small cells' downlink control-signaling (**Figure 2a**). Therefore, time-based partitioning performance is determined by the accurate synchronization of the two layers for identifying and using the macro layers' freed radio blocks, and made available to the small cells layer. Unlike the time and frequency partitioning, in which macro and small cells are separate (**Figure 2b**), the soft cell concept implies that the small cell is part of the macro cell (**Figure 2c and Figure 2d**). This is possible based on the accurate time alignment of the macro and small cells' frames, which ensure the coordination of the control and data channels originated from different transmission points (section 2.2.2).

Therefore, timing and synchronization play an important role in the integration of the small cells with the overlaid macro cell layer, and it logically follows that careful testing of device-based timing measurements is crucial in optimizing a HetNet's performance.

Interference Coordination and the Role of UEs

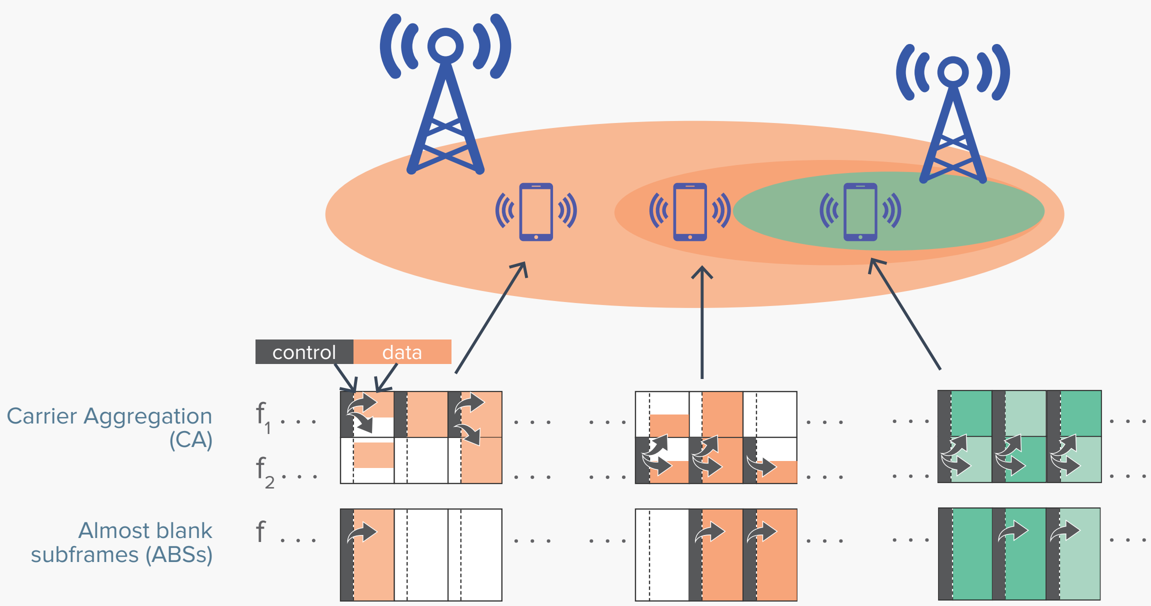
In theory, the deployment of small cells can either be on the same frequencies with the macro layer or on different frequencies. Until separate dedicated frequencies are widely used, however, it is crucial for HetNet deployments to intelligently share frequencies with the overlapping macro base stations.

Large capacity gains can be achieved only by implementing complex interference coordination techniques. This is because in HetNets it is more likely for the UE to experience severe interference, especially from neighboring cells covering the same area as the serving cell of the UE.

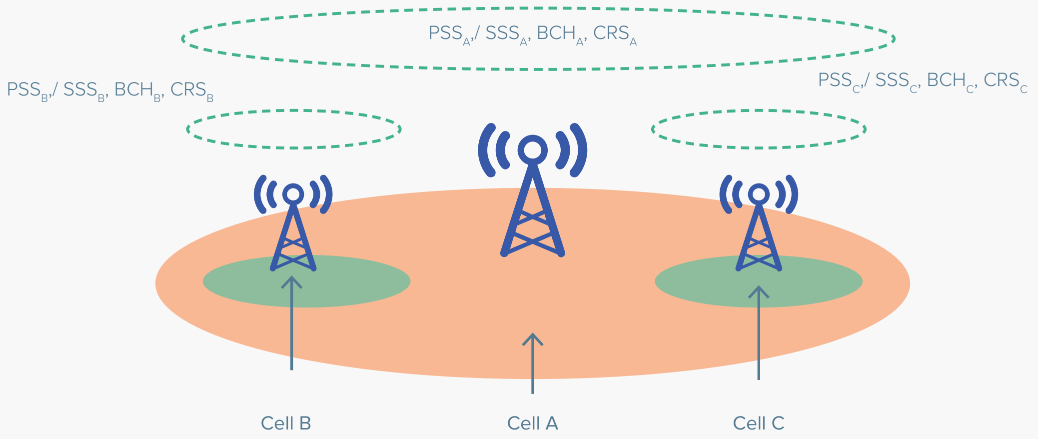
In addition, simple deployment of low-powered nodes can lead to underutilization of air interface resources due to the relatively small footprint of the small cells and/or service outage in the case of femto cells with access restricted to only the Closed Subscriber Group (CSG) which is the network provision [2] to allow only a limited number of UEs to access a particular femto cell.

For these reasons, the cell range expansion techniques mentioned in section 2.1 are commonly used to direct traffic to underutilized cells, which, if not well controlled, could increase the interference risk problem.

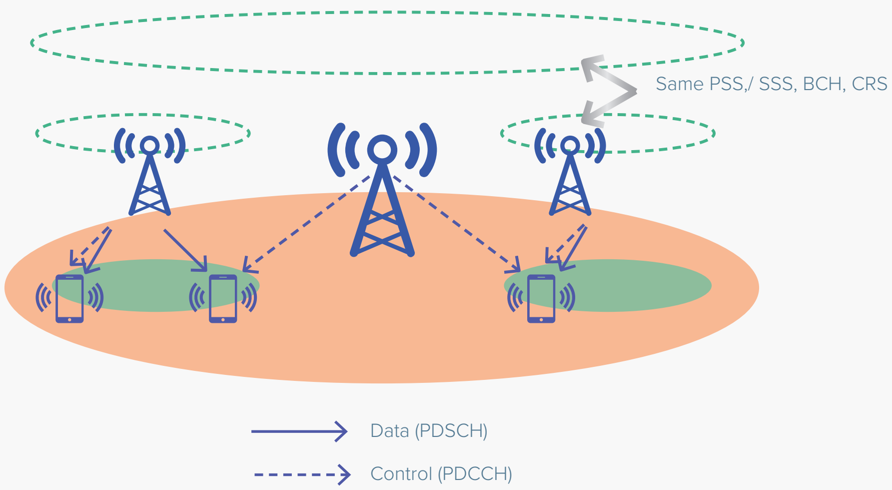
Figure 2. HetNet deployment scenarios



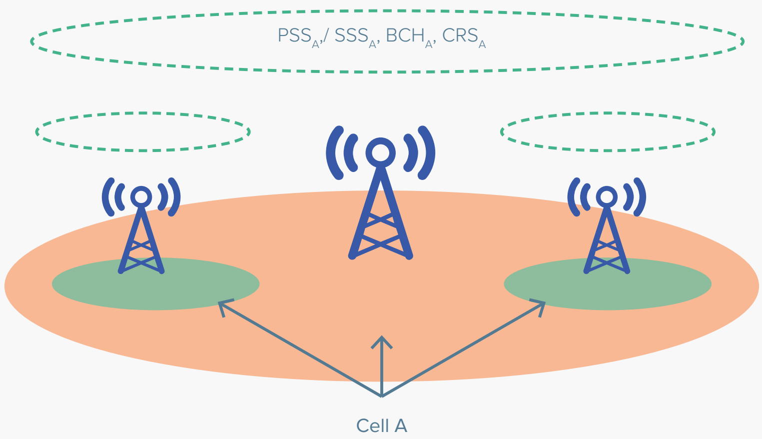
a) Frequency and time domain partitioning



b) Independent calls in case a



c) Heterogeneous deployment using a soft cell scheme



d) Small cell as part of a macro cell in case c

The interference risk from HetNets affects both downlink and uplink. In the downlink, a UE assigned to a macro cell may experience strong interference coming from a small cell, leading to a macro layer coverage hole. This coverage hole becomes more acute if the small cell serves a CSG, in which case a UE 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 may experience strong interference from a macro cell, especially if cell range expansion is in place to enforce traffic offloading. In the uplink, a UE assigned to a macro cell, but located close to the cell fringe, will generally create strong interference to the small cell. This small cell's performance degradation is generally considered acceptable due to the fact that each UE connected to a small cell typically accesses a much larger share of the small cell's radio resources. However, a more significant uplink interference scenario is caused when a large number of small cells' UEs migrate toward one macro cell.

Enhanced Inter Cell Interference Coordination (eICIC)

To address interference challenges, Rel. 10 introduces time domain enhanced inter cell interference coordination (eICIC) techniques to effectively coordinate interference from the dominant interfering cells. These techniques enable the configuration of sub frames with almost no transmission (Almost Blank Sub frames). The information is passed over the X2 interface or an OAM interface, and UEs under harsh interference conditions can be served in the ABS by their respective serving cells. With this, an "interference free" tunnel is established between the serving cell and the UE, enabling CRE of weak cells. However, configuration of ABS does not provide an interference coordination mechanism for all potential cases of interference.

Interference coordination in HetNets is a complex topic that still requires significant improvement and expansion to other aspects that need to be considered. One important aspect is that the interference coordination messages exhibit delays that depend on the backhaul technologies.

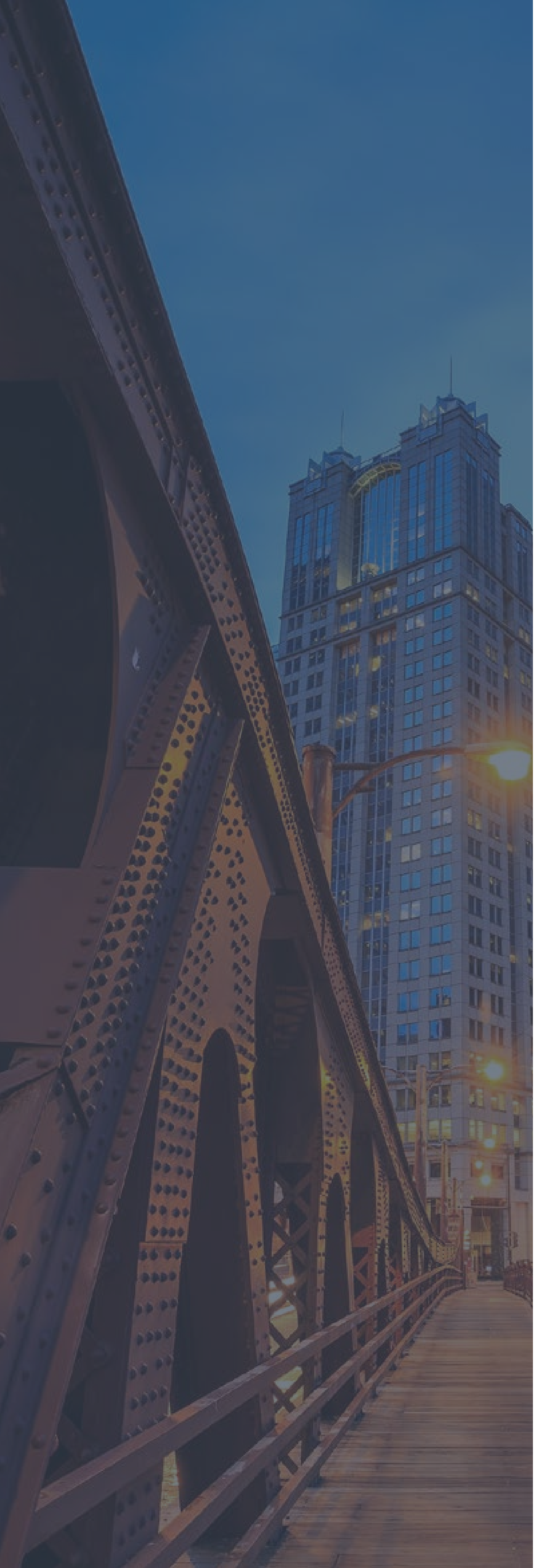
In addition, the generally high powered cell acquisition signals and reference signals for channel quality measurement known as Common Reference Signals (CRS), which must be sent on a fixed schedule, cause additional interference stress to the UE, especially in synchronous deployments when they "collide" in time and frequency. The UE is required, therefore, to implement a robust interference cancellation receiver to fully support the eICIC feature.

As discussed, the introduction of eICIC allows UEs to detect weak cells and in doing so requires that the UE differentiate between different sets of sub frames. The UE's capability to support sub frame specific measurement procedures and CSI feedback represents a core performance for eICIC. Other recent studies [9] and [14] show that mobility challenges in HetNets will more likely require a mobility-based eICIC feature (section 2.4).

Coordinated Multipoint

Interference coordination in HetNets is a complex topic that still requires significant improvement and expansion to other aspects that need to be considered. One important aspect is that the interference coordination messages exhibit delays that depend on the backhaul technologies. To cope with various backhaul bandwidths and avoid various messaging delays, interference coordination techniques such as coordinated multipoint (CoMP) transmission and reception methods [5] and [6] are designed to facilitate cooperative communications across multiple cells for LTE-A (Rel. 11) in such a way that interference either does not occur or can even be exploited as a meaningful signal as described in 3GPP technical report [12]. The assumed deployment scenarios for CoMP include homogenous configurations, where the points are different cells, as well as heterogeneous configurations, where a set of low power points are located in the geographical area served by a macro cell.

The concept relies on the base station's functionalities split into a baseband unit (BBU) and a remote radio head (RRH). The BBU, which is typically placed in a technical room, performs the scheduling and the baseband processing. The RRH located close to the antenna - potentially hundreds of meters away from the BBU - is responsible for all of the RF operations such as carrier frequency transportation, filtering, and power amplification. Therefore, the antennas configured as a cell to which a UE is connected at a given moment in time might not be geographically collocated.



Thus, the term transmission point (TP) refers to a set of collocated antennas and a cell corresponds to one or more such TPs. For coordinated transmission in the downlink, the signals transmitted from multiple TPs are coordinated to improve the received signal strength of the desired signal at the UE, or to reduce the co-channel interference. The major purpose of coordinated reception in the uplink is to help to ensure that the uplink signal from the UE is reliably received by the network while limiting uplink interference and taking into account the existence of multiple reception points.

Therefore, the CoMP measurement set is a set of CSI reference signal (CSI-RS) resources for which the UE is required to measure the CSI, including rank indicator (RI), precoding indicator (PMI), and channel quality indicator (CQI). There is typically a one-to-one mapping between a CSI-RS resource and a transmission point TP. Large uplink signaling overhead is avoided by limiting to three CSI-RS resources the size of a CoMP measurement set that can be configured to the UE. Since UEs at different locations may observe different sets of strongest TPs, the configuration of the CoMP measurement set is UE specific.

Future 3GPP releases will bring more optimized interference avoidance solutions for HetNet operation. However, until then the ability to evaluate and monitor all of today's interference aspects, such as ABS configuration schemes, cells' shift levels, and detection of possible collisions between CRS of macro and small cells, is crucial for troubleshooting and optimizing HetNets so they can provide substantial increases in data capacity.

In addition, UE interference cancellation performance evaluated based on UE measurement reporting and CSI feedback is very important to understand the network's feature efficiency for interference avoidance. Furthermore, performance evaluation of interference coordination techniques such as CoMP will require continuous monitoring of downlink reference signals and CSI feedback for coordinated transmission in the downlink, as well as uplink reference signals, power control and control signaling for coordinated reception in the uplink. Various performances are expected due to the fact that CoMP techniques can use various deployment scenarios depending on the operator's priorities, see references [5], [6] and [12].

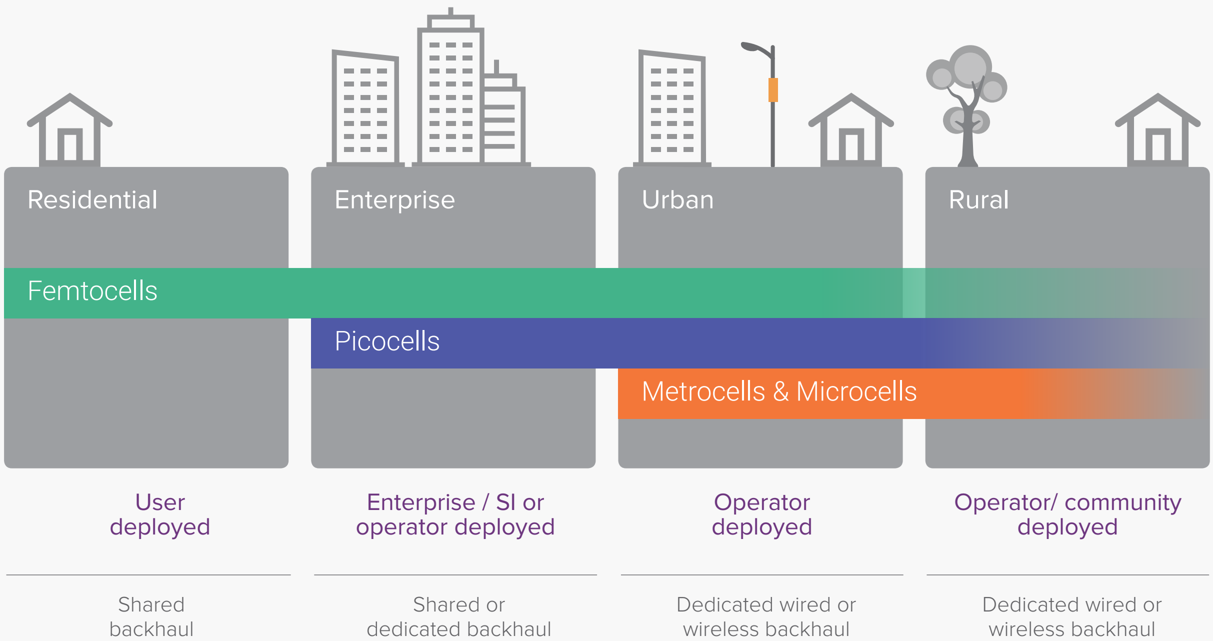
Aspects of Mobility Management in HetNets

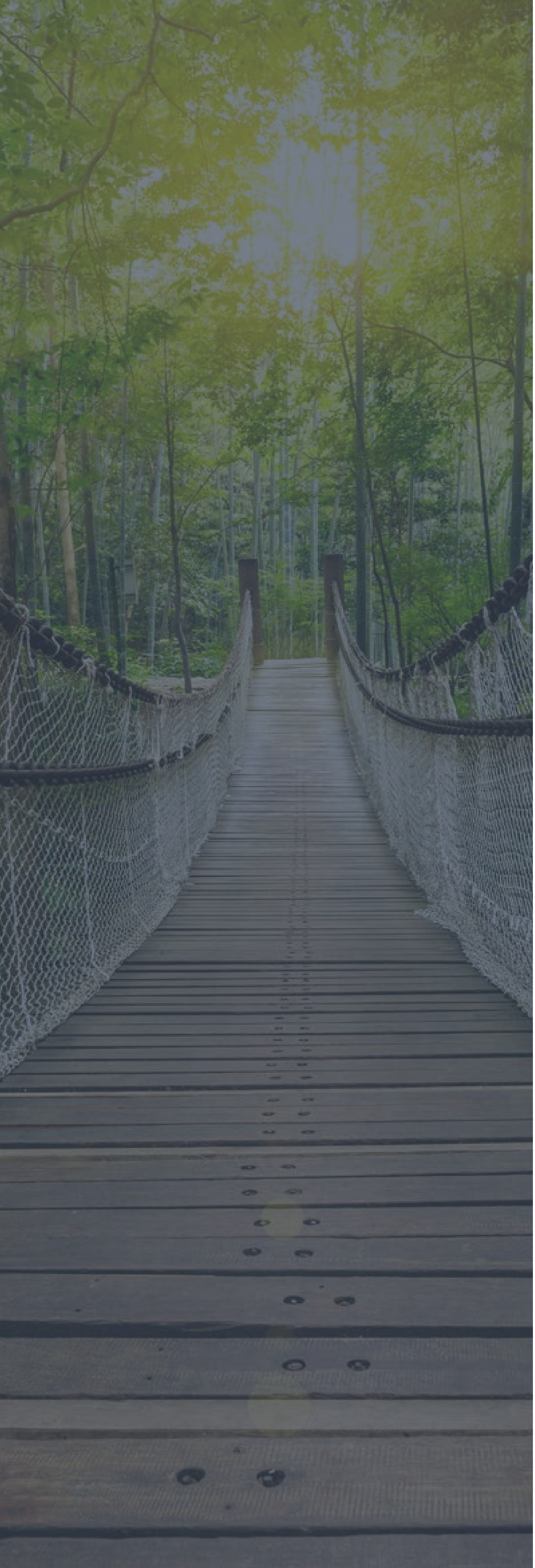
The deployment of a large number of small cells can come with an increased complexity of the mobility management, possibly caused by frequent UE handover when the UEs move across the small coverage area of the small cells.

In HetNets, where macro, micro, pico, and femto cells have different coverage, the mobility performance could be degraded if the same set of handover parameters such as hysteresis margin and time to trigger (TTT) for all cells and/or for all UEs are used like they are with macro only networks. For example, the CRE with different small cell bias will affect when and where the handover process is initiated in each cell. Therefore, HetNets require a cell-specific handover parameter optimization. In addition, high mobility macro cell UEs may run deep inside the small cells' coverage areas before the TTT optimized for macro cells expires, and, therefore, cause handover failure due to degraded SINR. Handover performed for high mobility macro cell UEs might not be necessary (e.g., ping-pong) when the UEs quickly cross small coverage areas of small cells. These facts further emphasize the need for handover parameter optimization based on the specific mobility condition of the UE (e.g., crossing from macro to small cell areas; mobility speed).

Therefore, the crucial issue related to mobility performance optimization in HetNets is the trade-off between handover failures and ping-pongs; reducing handover failures would increase ping-pongs and vice versa [14]. To manage this trade-off, cell-specific and UE-specific handover parameter optimization is needed. The optimization becomes more challenging when a large number of small cells are underlain below the macro cells and also when UEs are moving fast. Therefore, it is important to tune handover parameters (e.g., TTT) based on mobility state information. In a homogenous macro cell network, the number of handovers within a given time window can be compared with two different thresholds to estimate whether a UE is at the low, medium, or high mobility state. This is not possible anymore in HetNets due to varying cell sizes. The higher densities of pico cells, for example, yield mobility state estimates that are biased toward medium and high mobility states. Different solutions for improving mobility status information estimation are still under study within the 3GPP [14]. HetNet mobility control and management requires extensive monitoring and evaluation of KPIs related to handover parameters along with statistics of handover failures and/or ping-pongs. In addition, testing of the mobility status information is important since different solutions are expected to affect the mobility performance.

Figure 3. Applications of Small Cells





Backhaul Scalability and Provisioning

With increasing data capacity enabled by traffic offload to small cells, backhaul limitations could bottleneck the advantages brought by HetNet deployment. Backhaul scalability and provisioning are an area of significant concern for operators as well as for the 3GPP that already with Rel. 11 specified the CoMP feature as previously discussed in section 2.3.2.

The Small Cell Forum [7] also recommends approaches for backhaul provisioning depending on the application of the small cells (**Figure 3**) and the HetNet provider. With the start of Rel. 12, the 3GPP takes into consideration new backhaul recommendations to improve HetNets [10]. It decided to study and evaluate the feasibility of both ideal (very high throughput, low latency), and non-ideal backhaul solutions. In the first case, dedicated point-to-point connections using optical fiber or line of sight (LOS) microwave are being considered. The latter case includes the typical backhaul largely deployed today, such as xDSL, and non-LOS microwave.

Self Organizing Network (SON) Impact

One of the main challenges that comes with HetNet deployments is that operators will face a multidimensional problem: multi-RAT, multilayer, multiarchitecture, and multivendor.

An operator could try to manage 100,000 small cells and 1,000 macro cells, some WCDMA, and some LTE, all from different vendors', sharing some RAN resources, and leasing backhaul from another player. However, connecting and managing such a network is one of the biggest operational challenges facing operators moving to HetNets. Self organizing networks (SONs) come into play to address this with device-based SON, which allows UEs to collect measurements on network performance and act accordingly. These measurements need to cover both uplink and downlink measurements related to the radio environment, such as mobile neighbors' reports, location determination and reporting, transmit power, frequency, and code setting within parameters set by the management system. The standardization of device–based SON features has been slow, especially with the access network discovery and selection function (ANDSF), which is crucial within the HetNet context for Wi-Fi-small cell integration [13]. Extensive work regarding this is ongoing within the 3GPP and the Small Cell Forum.

However, SON features need to be evaluated and monitored, at least in the initial and early deployment phases which still require human intervention. Some of the few SON use cases released (e.g., ANR-PCI) prove to be hard to control within the HetNet context. Therefore, iterative tests performed one at a time per multilayered network area of interest are recommended.

Energy Saving

To make the HetNet implementations efficient, self-organizing functions will be needed for initial neighbor configuration of the deployed cell, as well as to make sure that during the life of the network, interference and power consumption are minimized.

By reducing the output power or even turning off cell capacity that is not needed, both of these functions will be supported. Cells that are powered off when they are not needed save both energy and reduce interference. However, this also adds additional functions on the network to make sure that the network can activate cells when they are needed, for example, when devices are moving into a neighboring cell and new capacity is needed. In these instances the network must be able to wake the cell before handing over traffic to the cell. T

There are several potential solutions for how dormant cells are turned on and off. One way is to turn the cells on and off based on a predefined schedule generated from historical traffic statistics. In this case, monitoring of the traffic patterns is needed in order to verify that the pattern hasn't experienced significant changes.

Another way is to periodically switch on all hot spots and then switch off those that experience low load. The identification of low load requires consistent monitoring across a predefined time window making sure that local traffic dips are not just random events. Therefore, monitoring and controlling the dormant cells can be essential for energy-saving features in HetNets.

Wi-Fi Scenario

As mentioned in section 3.1, offloading traffic to Wi-Fi is an approach that started to get traction from operators. However, Wi-Fi hot spots are expected to serve only a few users at very high rates depending on the application types and backhaul capacity. In addition, the attempt to smoothly integrate Wi-Fi hot spots within operators' HetNets can create big challenges.

An optimal integration needs to meet a series of requirements such as: ensure UE connectivity with minimal radio coordination, scalable backhaul able to support the offloaded traffic, no authentication problems, and no service interruptions while moving when connected to Wi-Fi. The latter requirement imposes special difficulties because although Wi-Fi hot spots can ensure high bit rates, they do not necessarily ensure full coverage, and they are also missing handover possibility to LTE. Therefore, the Wi-Fi traffic offloading deployment requires extensive testing of the coverage footprint in correlation with various applications' data rates and number of served users.

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How TEMS can help with HetNets

Managing your HetNet deployment

Implementation of a massive rollout of a HetNet with thousands of low power cells is a very challenging task. Automatic cell degradation detection, diagnosis, and healing functionality will be crucial for operators looking to control their OPEX. While the existence of multiple layers and multi-RATs offers some redundancy to mitigate the need for automatic healing, the existence of user-deployed femto cells will require novel fault management techniques. In HetNets, there are a series of possible failures and malfunctions that are difficult to identify.

Some of these include RF failures such as antenna direction or connectivity, scheduling problems or persistent handover failures due to wrong parameter settings, and "sleeping" cells. The latter are very problematic because sleeping cells are not functioning at all, are not accepting traffic, and do not send alarms. Therefore, minimizing OPEX requires troubleshooting and locating specific areas affected by a problem, such as interference around a new small cell or handover problems in a certain area. This needs to be achieved with a focus on problems from the UE's perspective, and, therefore, terminal-centric measurement data is crucial, including time stamps and location information.

Drive and walk test tools such as TEMS™ Investigation and TEMS™ Pocket for both indoor and outdoor canvassing, along with post processing tools such as TEMS™ Discovery are very valuable, especially in the HetNet's initial deployment phase. They can evaluate a set of cells in a cluster, and verify that the network features perform as expected. For troubleshooting after the initial deployment phase, TEMS Investigation can play an important role in detecting problems on site.

In this section, several use cases for HetNet evaluation and troubleshooting are discussed. The use cases refer to both LTE macro/LTE small cells and LTE macro/Wi-Fi small cells. While the LTE technology is emphasized below, the use cases can apply to any of the other 3GPP technologies as well.

Interference Coordination and the Role of UEs

Cell Range Expansion Identification

As described in section 2.1, in a HetNet where low-power pico cells coexist with macro cells, the coverage of a small cell may differ between the uplink and downlink. There is then a transitional zone around the small cell where it is still preferred to provide service on the uplink, but is overwhelmed by the macro cell on the downlink. The effect of biasing the cell selection mechanism by adding an offset to the downlink signal strength received from the low-power node expands the low-power node's uptake area, without increasing its output power. As mentioned in section 2.1, the method is referred to as cell range expansion, and it brings enhanced uplink data rates as well as increased capacity.

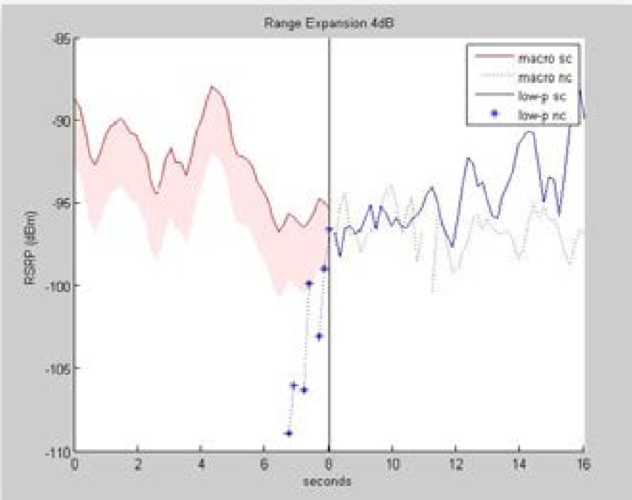
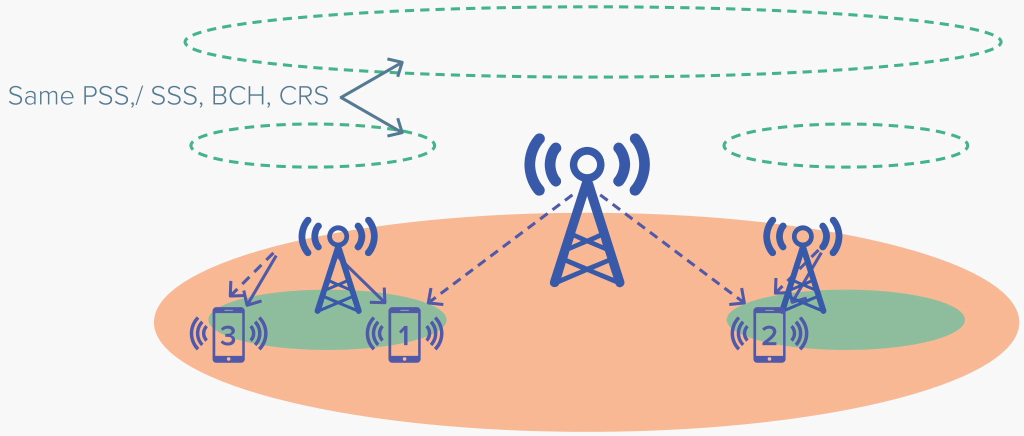


Figure 4. Received Signal Strength Measurements for the Macro Cell and Low-Power Node in the Transition Zone (CRE)

Figure 4 shows received signal strength (RSRP) measured with TEMS Investigation in an LTE network with cell range expansion activated. The data post processing and analysis has been performed with Matlab designed routines that are easy to implement in TEMS Discovery. The red curve represents the macro cell, while the blue curve represents the low-power cell. Where a line is drawn solid the cell is serving, and where a line is dotted the cell is a neighbor. What happens after about eight seconds is that the UE is switched to the low-power node earlier than normal, that is, while the low-power node is still weaker (max. 4 dB in this case: the blue dotted line enters the zone shaded pink). The detected UE switch to the small cell is the effect of the range expansion.

Figure 5. Synchronizing Frame Timing of Small Cells in a Macro Area (Three Scenarios)



UE 1 - Control from macro cell, data from small cell (DRS in small cell important)
UE 2 - Identical control from both macro and small cell (timing between the two cells important)
UE 3 - Control and data from small cell

Soft Cell Monitoring

As discussed in section 2.1, the cell range expansion uses the soft cell concept, which involves breaking the cell into downlink control channels and traffic channels which might originate from different transmission points. Channel estimation and CSI will be based on reference symbols dedicated to a particular UE and mixed with the end-user data.

TEMS Investigation is already prepared for such downlink reference signal (DRS) measurements, using the information elements Serving Cell RSRP-DRB (dBm) and Serving Cell SINR-DRS (dB). As soon as such features are activated in the networks, detailed studies for comparing DRS and CRS performance and techniques can be made. These studies play a crucial role in performance analysis and the troubleshooting of HetNets. TEMS Investigation can play an important role in this comparison due to its unique capabilities and support for many devices with different radio access capabilities.

Synchronization Evaluation and Analysis

As discussed in sections 2.1 and 2.2, when deploying low-power cells within a macro cell coverage area in an LTE network, it is crucial for performance reasons to synchronize the frame timing of the cells. For example, synchronization is the key factor in the interaction between the macro and small cell within the cell range expansion area. **Figure 5** shows three typical scenarios when the soft cell concept is used. Each of these scenarios represents instances that can be experienced by the same device while passing through a multilayered network area. It can be seen that in the case of UE1 and UE2 when either the control and data channels originate from the two different layers (macro, small), or the control channels are coming from the both layers, then it is crucial that the small cells are in time alignment with the macro cell with an error smaller than the cyclic prefix length.

On small sets of cells, drive-test tools such as TEMS Investigation can iteratively evaluate the timing synchronization techniques based on which tuning of cell timing offsets can be performed. Based on these evaluations, the cells can be categorized by size and appropriate settings. Based on these settings, the cell edge/handover performance can be further analyzed in a post-processing tool such as TEMS Discovery.

Another benefit of using TEMS Investigation for synchronization verification is that it presents the frame timing in a compact and easily understandable manner. **Figure 6** presents a line chart showing a well-designed set of TD-LTE cells. In the bottom sub chart, the frame timing of the neighbors stays consistently within less than 100 Ts (Time symbol) units of the serving cells. This shows a good enough performance, since the offset is well below the length of the normal cyclic prefix (144 Ts units) and therefore the ISI (Inter Symbol Interference) is avoided.

Interference Coordination Evaluation

Figure 7 depicts the enhanced inter cell interference coordination (eICIC) technique based on Almost Blank Subframes (ABS). One can see how the small cell is using the subframes left “almost” blank (blue) by the macro cell within the CRE area, and then all the subframes (green) within its own coverage area. With drive-testing tools such as TEMS Investigation, the eICIC feature’s performance can be evaluated by measuring with the ABS feature turned on and off. In addition, using data collected by drive tests the resource block allocation can be studied, ensuring no collisions are happening.

Unique Device-Based Measurements for HetNet Testing

When deploying low power cells, the antennas at the base station should be designed for optimal MIMO performance, while keeping the installation cost low. This trade-off in installation cost vs. performance can be evaluated using drive-testing tools, such as TEMS Investigation or TEMS Pocket. This evaluation is achieved by collecting data using different antennas and then analyzing the polarization diversity vs. space diversity techniques for the low-power cells’ MIMO antennas. This can be performed using advanced post processing scripting in TEMS Discovery that allows correlating MIMO rank with MIMO performance’s geographical distribution for the different antennas. The analysis can be automated by designing script templates.

In addition, after the deployment, a quick check of the antenna installation is required. TEMS Investigation can work with UEs and scanners that can measure LTE signal strength (RSRP) per transmit antenna. Post processing and analysis of these measurements by TEMS Discovery enables operators to detect installation problems such as swapped feeders or a malfunctioning antenna.

Distributed Antenna System (DAS) Testing

To maximize the femto cells’ features it is important to achieve good indoor coverage. Therefore, a distributed antenna system (DAS) is sometimes preferred. Using the indoor pinpointing function in TEMS Investigation and TEMS Pocket makes it possible to check the DAS installation. The performance comparison of each antenna against all the others can be performed by collecting data in a walk test passing by all the installed antennas and then using the intelligent default scripting of the TEMS Discovery indoor solution package. The comparison is based on averaged metrics over the measurement points closest to each antenna. The comparison uses not only signal strength, but also the signal to interference ratio (CINR/SINR) and throughput, as well as the neighbor cell interference evaluation.

Testing SON Features’ Role in LTE Macro/ Small Cell Environment

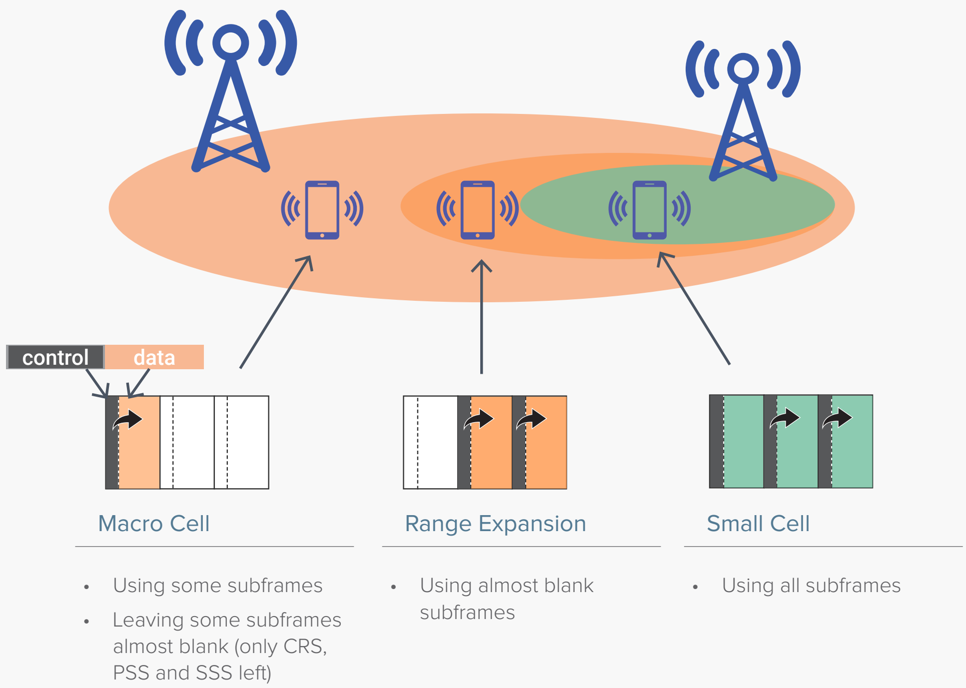
Activating and controlling SON use cases such as ANR-PCI and RACH optimization in the small cell environment is a very challenging task, and difficult to fully accomplish across the entire network. Therefore, careful studies performed one at a time on various network areas can be done using drive-test tools. TEMS Investigation is a good tool for checking that a feature such as ANR is enabled and that it works as expected without overloading the devices with Layer 3 signaling.

SON-ANR

The SON-ANR feature activated in the network requires the UE to decode and report back the CGI (cell global identity) anytime it detects a PCI that is not known to the neighbor relations of a particular cell. If the UE is fully occupied and does not find a gap in the transmission, it will report the PCI again without the CGI included, and the network will order the UE again to report the CGI. This will result in extensive Layer 3 signaling and unnecessary network load. Figure 8 shows an example of the Layer 3 signaling at ANR activation and reporting.

Figure 6. An Example of a well synchronized TD-LTE Network

Figure 7. Enhanced Inter Cell Interference Coordination (eICIC)



SON-RACH

The RACH feature in SON consists of asking the UE to report back the number of preambles used for each RACH procedure. This is valuable information, as there is a trade-off between access setup time and the amount of interference created and the total RACH capacity. If the UE uses too high power for the first preamble, unnecessary interference will be caused. If too many preambles are needed before the eNB hears the preamble, the access setup time will be increased for each new preamble, thereby consuming more of the RACH capacity in the cell.

UEs supporting such RACH reporting are still under development. However, using drive-test tools for RACH analysis allows an in-depth understanding of the path loss calculations made for the initial preamble sent without having to wait for such UE RACH reporting features. Therefore, RACH optimization can be analyzed already with drive-test tools.

SON PCI Planning

The reference symbols in LTE (used for channel estimation and measurements) are spread out in time and frequency domain. There is a correlation between the PCI and the position of those symbols. To assure good performance in cell overlapping areas, it is important to avoid some combinations of PCIs between cells. These can be detected and evaluated using drive-test data. An example is presented in **Figure 9**.

Data from a drive test in a TD-LTE network (site synchronized with GPS, TDD mode) has been uploaded and processed in Matlab software to plot the downlink SINR before and after each handover. Collected data contained a total of 25 handovers.

In **Figure 9,** the lines start with the SINR values before the handover and end with the SINR after the handover (indicated by a circle).

Even though the number of handovers is limited, it is clear that the SINR is lower in areas with non-optimal PCI combinations (the red lines in the picture). This will affect the channel estimation and the measurements, resulting in impaired customer experience in terms of performance and handover failures.

Figure 8. Layer 3 Signalling at ANR Activation and Reporting (Example)

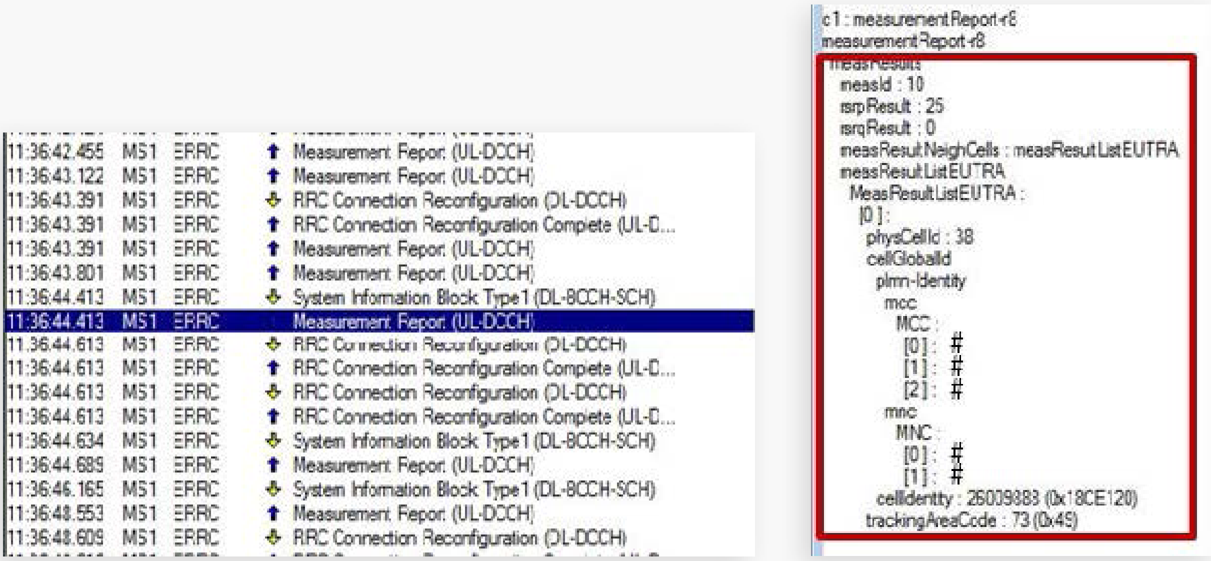
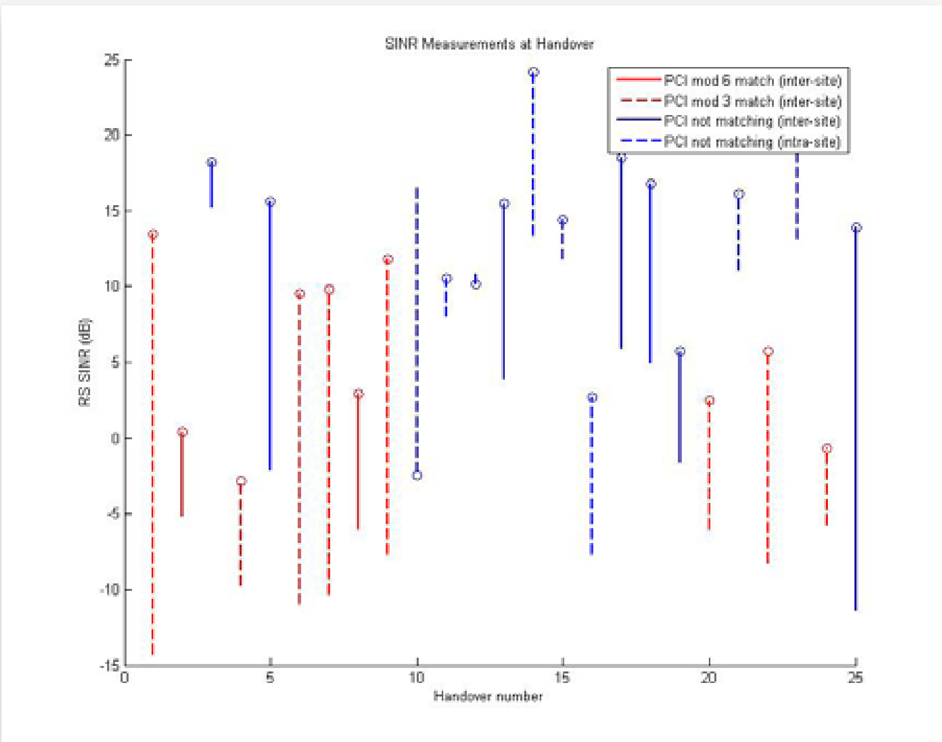


Figure 9. SINR Measurements at Handover



Wi-Fi Use Cases

Device-based walk test solutions such as TEMS Pocket are best suited for indoor measurements for evaluating Wi-Fi performance. These evaluations become very valuable when devices capable of both Wi-Fi and 3GPP RATs are used. Both TEMS Investigation and TEMS Discovery can read the TEMS Pocket logfiles and present information from both Wi-Fi and 3GPP networks.

Wi-Fi Measurements

Coverage and its distribution within buildings define the performance of Wi-Fi networks. Therefore, coverage plots of various floors' maps are important for analyzing the Wi-Fi performance in more detail. TEMS Pocket Wi-Fi measurements (e.g., channel, frequency, link speed, RSSI, SSID, and BSSID), correlated with IP logging and plotted on the building's floor map using the pinpoint functionality, can provide a comprehensive view of the Wi-Fi coverage and performance levels and their distribution within the building.

3GPP Signaling

As the 3GPP specifications evolve and design a more seamless technology change to Wi-Fi, tools such as TEMS Investigation will be used for detailed signaling studies, optimization and troubleshooting.

The main focus here will be on the "handover" situation, when the UE is transferred between LTE and Wi-Fi, making sure the point of presence/multihome mechanisms and the services work as expected. This is especially helpful for scenarios testing voice services such as VoLTE and CSFB while navigating to Wi-Fi due to the need for both domains to be working simultaneously.

Performance Evaluation and Benchmarking in Macro/Wi-Fi Cell Overlapping Areas

Using a walk test tool such as TEMS Pocket, it is possible to test both the Wi-Fi network and the 3GPP network using the same device. Walking a test route twice on a building floor, once while locking the device on Wi-Fi and once while locking on LTE based on the RAT lock functionality, two data sets can be created. The measurement results can be plotted on the floor's map, and then coverage and performance can be compared. shows signal strength and throughput for LTE femto and Wi-Fi networks in an indoor environment.

Using the TEMS Discovery unique post processing feature of handling 3GPP and Wi-Fi simultaneously, statistically significant benchmarking of the LTE macro/LTE small cell vs. LTE macro/Wi-Fi small cell solutions can be also performed. In addition, the evaluation of the benefits and performance of the indoor environment within the outdoor context can be performed, plotting and analyzing results of indoor measurements on the outdoor map, as shown in **Figure 11**.

Figure 10. Indoor LTE Femto and Wi-Fi Compared for Signal Strength and Throughput

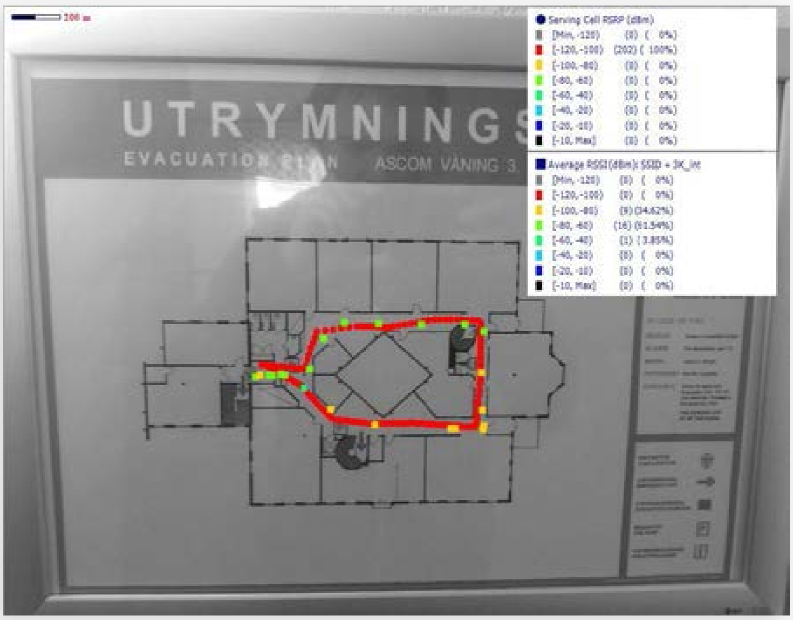


Figure 11. Visualization of Indoor Coverage within the Outdoor Environment

Conclusions

Understanding the HetNet Environment

Major performance improvements in spectrum efficiency and spatial reuse are expected from HetNets, but only if operators properly account for and deal with the inherent interference of the multilayered architecture, efficient mobility management between these layers, as well as the backhaul available bandwidth. This requires complex evaluation and optimization, which can be challenging due to the fact that in HetNets serious failures and malfunctions are difficult to identify.

Therefore, minimizing OPEX requires locating specific areas affected by a problem, which requires UE centric measurement data, including time stamps and location information.

This can be achieved only using drive-test tools such as TEMS Investigation and TEMS Pocket along with intelligent post processing tools such as TEMS Discovery.

These tools enable operators to evaluate a set of cells in a cluster manner, and ensure that network features perform as expected without overloading the devices in the network with extensive Layer 3 messaging.

TEMS Portfolio supports cost-efficient troubleshooting and intelligent automated analysis for range cell expansion, interference coordination and synchronization. DAS and Wi-Fi solutions' performance can be plotted on indoor floor plan maps and benchmarked.

In addition, TEMS solutions allow for a controlled launch of SON features that can be intelligently analyzed, thereby ensuring the advanced functions are working as expected within the HetNet environment and that they are performed without, once again, overloading the UEs with Layer 3 signaling.

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