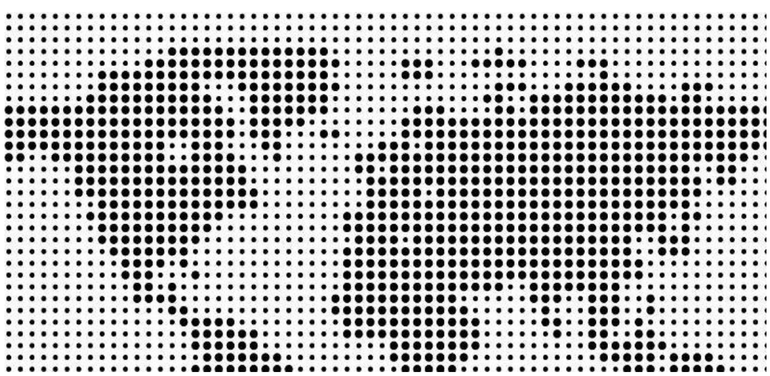
Heterogeneous Networks (HetNets) in HSPA



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1. Introduction

In traditional homogeneous cellular systems, a network of base-stations (macro cells) is deployed in a planned layout with similar characteristics such as transmit powers, antenna patterns, receiver noise floors etc. One way to increase network capacity may be to deploy more macro cells. However, the high site acquisition costs associated with macro deployments makes this option less attractive. An interesting alterative may be to deploy low power nodes, which transmit at a lower power (typically ~ 100mW-5W per carrier) with lower antenna height, compared to macro cells (typically ~20W-40W per carrier).

In this article, we focus on the deployment of low power nodes in High Speed Packet Access (HSPA) networks. HSPA is the Code Division Multiple Access (CDMA) based packet-switched air-interface standardized by the 3rd Generation Partnership Project (3GPP). We discuss a few issues that could arise from the deployment of low power nodes and present solutions for these issues. In addition, we discuss techniques that can be used to expand the range of low power nodes, leading to a further increase in system capacity. Note that the basic range expansion technique can be employed *without any specification changes* in today's networks, whenever at least two HSPA carriers are available. Further enhancements can be achieved through specification changes that allow the use of a dual frequency version of MultiFlow HSDPA, in which the UE can be served by different sectors on different carriers, together with range expansion.

2. Potential Issues in HSPA Heterogeneous Networks

When deploying low power nodes in macro networks, the transmit power difference between the low power nodes and the macro cells is the source of potential issues. In HSPA, as serving cell selection is mainly based on the downlink (DL) received signal strength, the transmit power of each cell determines the area it covers as the serving cell. However, from the uplink (UL) perspective, the strength of the signal received at each node is not directly dependent on its DL transmit power, assuming no adjustment to the Noise Figure (NF) of the low power node to account for the transmit power difference. Thus, the introduction of low power nodes can potentially cause DL-UL imbalance, in the sense that cells other than the serving cell could receive a stronger signal from the UE than the serving cell.

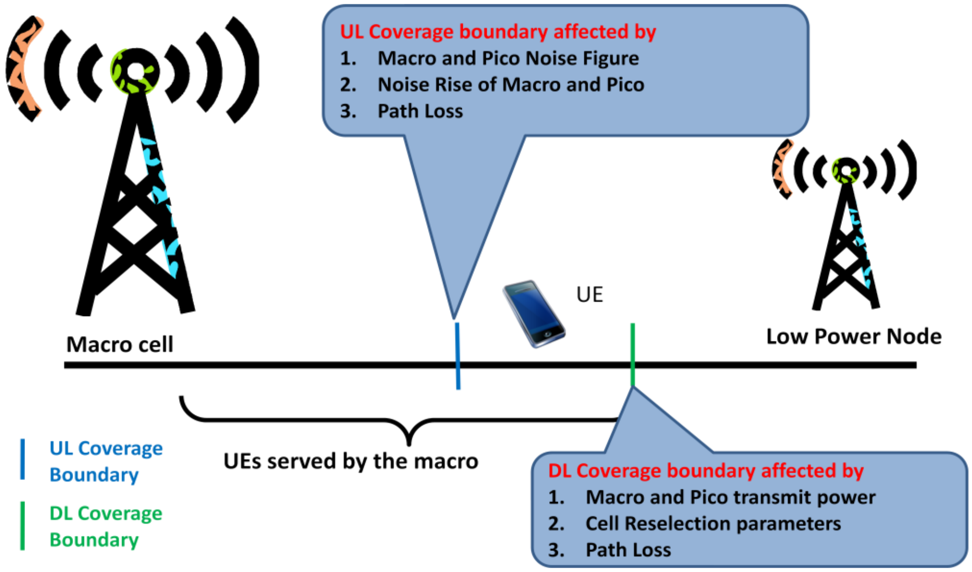

Figure 1: DL-UL Imbalance Scenario in Heterogeneous Networks

Figure 1 illustrates the potential imbalance problem, i.e., UL and DL coverage boundary not being aligned. Such DL-UL imbalance in HetNets could lead to a number of challenges including, but not limited to:

1. Issues in decoding the HS-DPCCH control channel (that carries CQI and ACK/NAK information) at the macro. This issue applies to UEs that are in Soft Handover (SHO) between the macro and the low power node and have the macro as the serving cell. For such UEs, their uplink is power controlled by the low power node.
2. Excessive UL interference from the UEs served by macros to low power nodes. This issue applies to UEs that are just outside the SHO region (closer to the macro) between the macro and the low power node. Such UEs have a stronger uplink to the low power node, but cannot be power controlled by it.
3. Excessive UL interference from UEs served by low power nodes to macros. This issue again applies to UEs that are just outside the SHO region (closer to the low power node) between the macro and the low power node. Low power nodes typically tend to be less loaded than macros (due to their much smaller coverage area), and thus, are able to give high grants on the uplink. When the transmit power of the low power node is relatively high (~5W or so), such large grants given to UEs not in SHO with the macro can lead to excessive interference to the macro.

The above issues can be mitigated through a combination of techniques, including:

1. Application of padding at the low power nodes. Padding increases the noise figure at the low power nodes, and helps to align DL and UL boundaries between the macro and the low power node.
2. Boosting of the HS-DPCCH transmit power. The boost value could be statically picked based on the maximum expected imbalance, or may be picked adaptively by the RNC, per UE, based on received Ecp/Nt values.

3. Other techniques may include limiting the maximum transmit power of UEs served by low power nodes. The RNC may use UE measurement reports to choose appropriate UEs for maximum transmit power limitation (i.e., UEs that may be causing excessive interference to the macro).

In addition to the above techniques, another consideration is that due to the small transmit power of low power nodes, their DL coverage is limited. Since low power nodes are usually less loaded than macros (due to their smaller coverage area), it is desirable to expand their coverage. Limited coverage expansion of low power nodes can be achieved via cell biasing by setting the Cell Individual Offset (CIO) for low power nodes, as specified in the UMTS specifications. Figure 2 illustrates the expansion of the low power node's DL coverage by use of CIO. Note that the use of CIO also helps to reduce imbalance between the downlink and uplink boundaries.

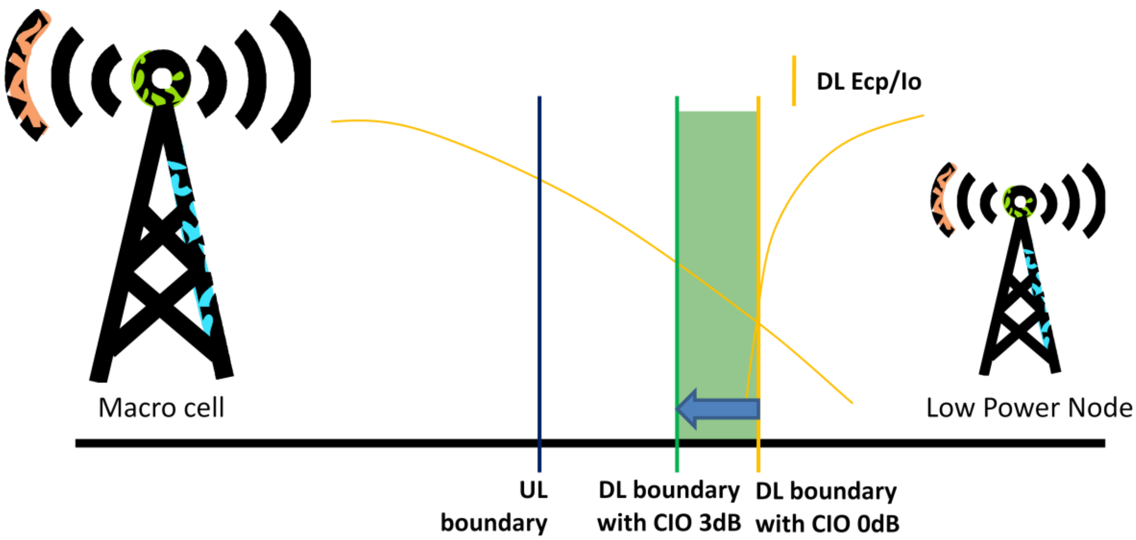

Figure 2: Expansion of Low Power Node's Downlink Coverage by Use of CIO

Using a combination of the above techniques, we evaluate the performance of HetNets in HSPA. Table 1 contains the system simulation assumptions.

Table 1: System Simulation Assumptions

Parameters	Comments
Cell Layout	(1) Macro cell: Hexagonal grid, 19 Node-Bs wrap-around with 3 sectors per Node B. (2) Low Power Node: Uniform dropping with fixed number of low power nodes per macro cell.
Inter-site distance	500 m
Path Loss	Macro to UE: L= 128.1+37.6log10(R) Low Power Node to UE : L= 140.7+36.7log10(R), R in km
Penetration loss	20 dB
Antenna Gain + Cable/Connector Loss	Macro: 14dBi Low Power Node: 5dBi
Antenna pattern	Macro cells: $A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] dB$ θ_{3dB}= 70 degrees, Am = 20 dB Low Power Node: $A(\theta) = 0\ dB$ (Omnidirectional)
Minimum distance between NodeBs	>=75m between low power node and macro >=50m between low power nodes
Minimum distance between UE and nodes	>= 35m between UE and macro >= 10m between UE and low power node between
Channel Model	PA3
Maximum Node Transmit Power	Macro cell: 43 dBm Small power node: 37, 30 dBm
Traffic Model	Full buffer for both UL and DL
CIO Setting at Low Power Nodes	SHO allowed between macro and lower power node: 3dB biased toward low power node SHO NOT allowed between macro and lower power node: 0dB
Padding at Low Power Nodes	Low Power Node Tx Power 37dBm: 0dB Padding Low Power Node Tx Power 30dBm: 6dB Padding
UE Population Density	Fixed number of UEs per geographic area of each macro cell
UE Dropping	Clustered Dropping 50% of UEs are uniformly dropped within a 40 meter radius from the low power nodes. Each low power node has the same number of UEs clustered around it. The remaining 50% of the UEs are uniformly dropped in the geographic area of each macro cell

We consider two types of low power node deployments:

1. Shared RNC deployment, where macros and low power nodes share the same RNC. Under this deployment scenario, SHO is supported between macros and low power nodes.
2. Dedicated RNC deployment, where macros and low power nodes are controlled by different RNCs. Under this scenario, SHO is not supported between macros and low power nodes.

In Table 2, we show the throughput gains of HetNets over the baseline macro-only deployment when a single HSPA carrier is used. *Note that gains shown here are already possible today for single carrier HetNet deployments.* Higher gain is seen with low power nodes that have higher transmit-power, since more UEs can be offloaded from the macro. Further, enabling soft handover between macro and low power nodes leads to higher uplink gains.

Table 2: HetNet Gains: 50% Clustered Dropping, Single Carrier Co-channel, 16 UEs/Macro

HetNet Gains Available Today for Single Carrier Deployment											
		37dBm Low Power Node					30dBm Low Power Node				
		DL		UL			DL		UL		
SHO Between Low Power Node and Macro	#Low Power Node per Macro	Mean Tput Gain	10% Tput Gain	Mean Tput Gain	10% Tput Gain	% UE Served by Low Power Node	Mean Tput Gain	10% Tput Gain	Mean Tput Gain	10% Tput Gain	% UE Served By Low Power Node
Allowed	2	153%	81%	518%	93%	47%	93%	46%	407%	41%	29%
	4	244%	101%	818%	129%	55%	150%	49%	576%	59%	32%
NOT Allowed	2	153%	62%	427%	47%	39%	86%	29%	340%	4%	22%
	4	236%	68%	710%	72%	44%	129%	29%	503%	18%	25%

3. Range Expansion of Low Power Nodes

A key take-away from the results in Table 2 is that low power nodes are typically less loaded than macros, due to their smaller coverage area. As an example, in the case of 1W (30dBm) low power nodes, 4 of such nodes together serve 25% to 32% of UEs, with the rest being served by the macro. Offloading more UEs to low power nodes increases system capacity, as can be seen when comparing the results for 5W (37 dBm) with 1W low power nodes. We, thus, explore techniques to expand the range of low power nodes.

The particular Range Expansion technique we focus on is reducing the power of the macro on one carrier in a two carrier deployment. The beauty of a CDMA-based system lies in the fact that it works in an interference-limited environment, so the downlink coverage of each cell expands or shrinks naturally in response to changes in power of other cells In particular, the UE receives signals from multiple cells simultaneously, which are interfering with each other. Thus, as we lower the macro transmit power on one carrier; we automatically expand the DL coverage of the low power nodes while shrinking the coverage of the macro cell. UEs at the edge of coverage (for example, indoor UEs) can still be covered by the macro on the carrier whose power is not reduced.

We provide an example of this technique in Figure 3, in which both the macro and the low power node have two carriers, F1 and F2. Without range expansion, the transmit power of the macro on both carriers is 43dBm and that of the low power node is 30dBm on both carriers. In this scenario, the intersection of the two yellow Ecp/Io curves of the macro and low power node represents the DL boundary.

With range expansion, the transmit power of the macro on F2 is reduced, e.g., from 43dBm to 30dBm. The Ecp/Io values on F2 are denoted by the red curves in Figure 3, while the Ecp/Io values on F1 are the same as without range expansion. The DL boundary on F2 is now moved towards the macro (from point A to point B), implying that the coverage area of the low power node on F2 has expanded.

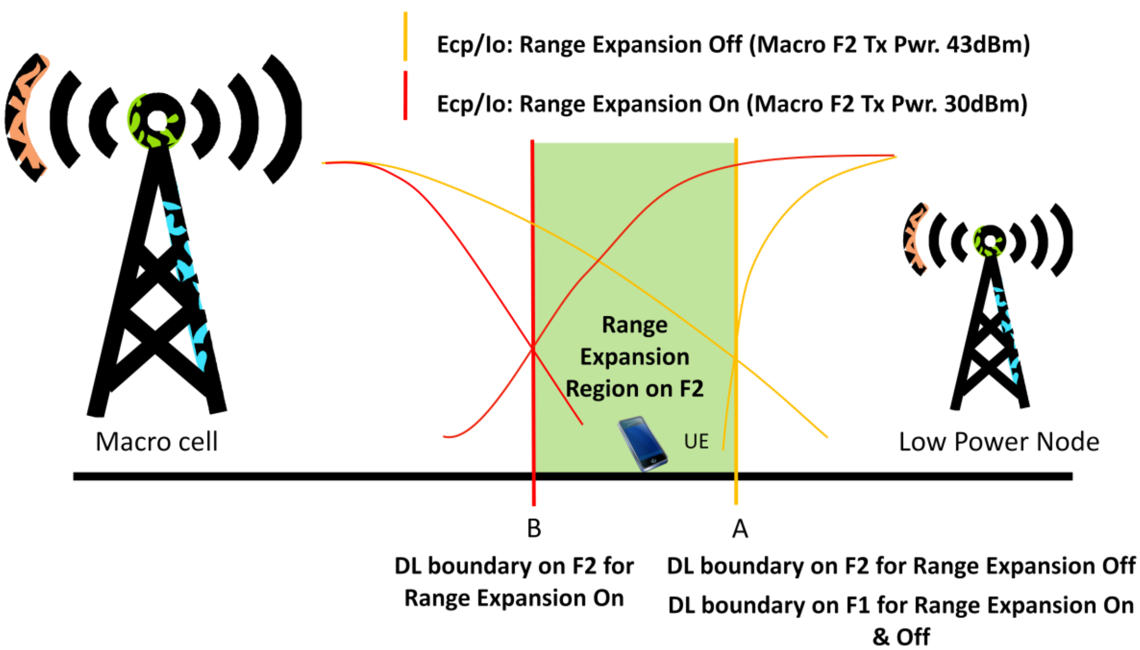

Figure 3: Illustration of Range Expansion in Dual Carrier HetNet deployments

3.1 Range Expansion with HSDPA and DC-HSDPA capable UEs

Release 5, 3GPP standardized HSDPA (or Single Carrier HSDPA), while Release 8, 3GPP standardized Dual Cell HSDPA (DC-HSDPA), which allows a UE to receive data on two carriers from the same sector. It should be noted *that Range Expansion with SC-HSDPA or DC-HSDPA UEs is possible in HSPA deployments today without any new specification changes*.

3.2 Range Expansion with DF-DC capable UEs

If we focus on the range expansion region in Figure 3, the UE sees the macro as the stronger cell on F1 and the low power node as the stronger cell on F2. Thus, techniques that allow such UEs to be served by the stronger cell on each carrier can bring further gains on top of range expansion with DC-HSDPA.

A candidate feature being considered by 3GPP in Release 11 is Multi-Flow HSPA, which allows a UE to be served by two different cells on the same carrier. An extension of Multi-Flow operation, referred to as Dual-Frequency Dual-Cell (DF-DC) operation, also a candidate feature for Release 11, would allow a DC UE to be served by different sectors/Node Bs on each carrier. Note that support of DF-DC in HetNets may require additional specification changes beyond those being considered in Release 11, in the form of a new UE Measurement Event for switching the anchor frequency to reduce uplink imbalance in the range expansion region.

3.3 Simulation Results with Range Expansion

Through simulations, we evaluate the performance improvements achievable today from range expansion with DC-HSDPA capable UEs. We also show further performance enhancements when range expansion is coupled with DF-DC operation.

Table 3 lists system simulation assumptions in addition to those in Table 1. When simulating bursty traffic, we drop 32 UEs per geographic area of each macro sector, with each UE having an offered load of x/5 Mbps (i.e., bursts of size x Mb every 5 seconds). The burst size x is varied to create different loads.

Table 3: Additional System Simulation Assumption for HetNet Range Expansion

Parameter	Value
Bursty Traffic Mode	Bursty traffic is modeled as bursts of size xMb with a mean inter-burst time of 5 seconds exponentially distributed
Maximum Node Transmit Power Range Expansion Off	Macro: 43dBm on F1; 43dBm on F2 Low Power Node: 30dBm on F1; 30dBm on F2
Maximum Node Transmit Power Range Expansion On	Macro: 43dBm on F1; 30dBm on F2 Low Power Node: 30dBm on F1; 30dBm on F2
UE Capability	DC Capable (Available Today Rel 8)
	DF-DC Capable (Requires Standards Changes)

Table 4 summarizes the performance gains of HetNets for full buffer traffic, with different options compared with the baseline macro-only scenario. HetNet deployment with range expansion and DC-HSDPA UEs improves both the mean and the 10% tail UE throughput compared to the HetNet deployment without range expansion. Additionally, DF-DC operation further improves system fairness: with similar mean UE throughput, DF-DC operation improves tail UE throughput compared to no DF-DC.

Table 4: HetNet Gains with Dual-Carrier Deployment, 16UEs/Macro area, Full Buffer Traffic

50% Clustered UE Dropping				UE Association	
		Mean Throughput Gain	10% Throughput Gain	Macro	Low Power Node
	Baseline Macro only			100%	0%
HetNet Gains Available Today (Rel 8 DC-HSDPA UEs)	HetNet Range Expansion Off, DC	150%	49%	68%	32%
	HetNet Range Expansion On, DC	249%	114%	36%	64%
HetNet Gains Possible with DF-DC	HetNet Range Expansion On, DF-DC	246%	150%	28%	72%

Figure 4 shows the mean burst rate for bursty traffic for macro-only as well as Hetnet options. At a given user experience (or burst rate), the supportable offered load per sector (defined as the system load per geographic area of each macro sector) increases significantly with HetNets. For example, in Figure 4, at a user experience of 6 Mbps, baseline macro-only system can support an offered load of 7.5 Mbps per sector, while HetNets without range expansion can support an offered load of more than 12 Mbps per sector. Moreover, HetNets with range expansion can support an offered load of over 23 Mbps per sector.

Looking at the other dimension, at a given offered load per sector, HetNets provide significant gains in mean burst rate. As an example, at the offered load of 7.5 Mbps per sector in Figure 3, the mean burst rate increases from 6 Mbps for the macro-only system to 8 Mbps for HetNets without range expansion and further to 10 Mbps for HetNets with range expansion.

In Figure 5, we compare the 10th percentile burst rate. Similar to our observation for Full Buffer traffic, compared to the case of range expansion with DC only, DF-DC helps to significantly improve the 10 percentile user experience, and hence, the fairness of the system.

It is also important to note that the performance improvement from HetNets is more evident at high system load. For example, at 1.2 Mbps offered load per sector, the average TTI utilization for the macro-only system is ~11% and gains from HetNets are very limited. On the other hand, at 7.5 Mbps offered load per sector, the average TTI utilization is over 75% for the macro-only system and significant gains from HetNets can be seen.

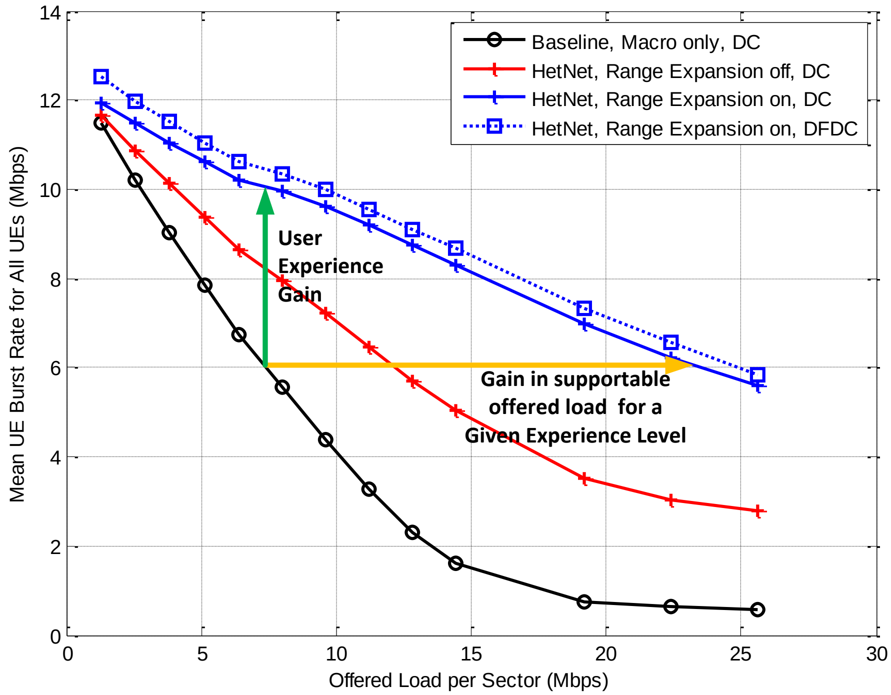

Figure 4: Mean Burst Rate versus Offered Load

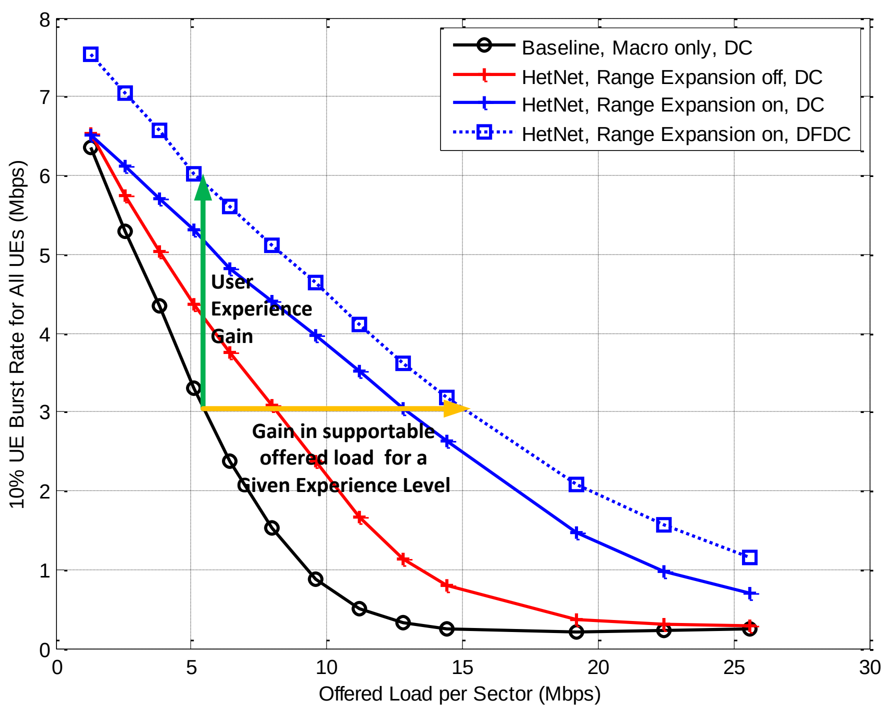

Figure 5: 10 percentile Burst Rate versus Offered Load

3.4 Range Expansion with Indoor UEs

A key issue that needs to be considered when doing range expansion through reduction of macro power on one carrier is the impact to coverage-limited UEs (typically indoor). With the same assumptions as in Table 1, we add an additional Building Penetration Loss (BPL) term to model indoor UEs. Simulation assumptions for indoor UEs are listed in Table 5.

Table 5 System Simulation Assumption for Indoor UEs

Parameter	Value
Building Penetration Loss (BPL) Mean	17.5 dB
BPL Standard Deviation	10.8 dB
Indoor UE Modeling	Each UE is assigned as indoors with a probability of x% (x = 0, 40). For indoor UEs, BPL is randomly generated and added to the path loss.
UL Link Budget	140 dB

Note that reducing macro DL transmit power has no impact to the UL coverage. Therefore, we exclude statistics of UEs that are in UL outage in the baseline macro-only system, i.e., that have total path loss (including BPL) greater than the typical UL link budget of 140dB. With our BPL assumption, ~12% of the indoor UEs are in UL outage. We believe this reflects a fairly conservative path loss scenario.

Table 6 summarizes, for bursty traffic, the performance gains of different HetNet options compared with the baseline macro-only scenario. Even with 40% of the UEs being indoor, neither mean nor tail gains from HetNets are impacted. One reason is that UEs typically become uplink coverage limited before becoming downlink coverage limited, and reduction of macro power does not impact uplink coverage. Furthermore, any throughput loss to macro UEs due to macro power reduction is more than offset by offloading of competing users to picos.

Table 6: HetNet Gains with indoor UEs and Bursty Traffic

50% Clustered UE Dropping		Indoor UE Percentage	Offered Load 5 Mbps/Sector		Offered Load 8 Mbps/Sector	
			Mean Burst Rate Gain	10% Burst Rate Gain	Mean Burst Rate Gain	10% Burst Rate Gain
HetNet Gains Available Today (Rel 8 DC-HSDPA UEs)	HetNet Range Expansion Off, DC	0%	19%	32%	44%	103%
	HetNet Range Expansion On, DC		35%	61%	79%	188%
HetNet Gains Possible with DF-DC	HetNet Range Expansion On, DF-DC		40%	83%	86%	235%
HetNet Gains Available Today (Rel 8 DC-HSDPA UEs)	HetNet Range Expansion Off, DC	40%	24%	45%	47%	128%
	HetNet Range Expansion On, DC		36%	62%	77%	192%
HetNet Gains Possible with DF-DC	HetNet Range Expansion On, DF-DC		42%	85%	85%	244%

4. Conclusion

In this paper, we first focused on HSPA HetNet deployments that are possible without any changes to specifications. We discussed potential issues that could arise from the deployment of low power nodes in HSPA and presented solutions for these issues. With these solutions in place, we demonstrated through simulations that significant DL and UL throughput gains are possible with a single carrier deployment of low power nodes. We then considered a technique for range expansion of low power nodes in a dual carrier deployment by reducing macro transmit power on one carrier. Through simulations, we showed that this range expansion technique further improves system performance. It is important to note that both the single carrier deployment as well as the dual carrier with range expansion deployment of HSPA HetNets is *possible without any changes to today's specifications*.

We then considered HetNets with range expansion; with the further enhancement that UEs in the range expansion region are capable of DF-DC operation *(basic support for DF-DC is being considered in Release 11, while further enhancements for Hetnet scenarios may be considered in future releases)*. We showed that this combination provides even further gains, particularly for the UEs with low throughput. Overall, it should be noted that significant performance gains from Hetnets are seen only when the system is reasonably loaded: these are also the scenarios where Hetnets would typically be employed.

One key issue we considered when evaluating the performance of range expansion is the impact to UEs in coverage-limited regions (typically indoor UEs). Even with an aggressive assumption for Building Path Loss, we saw almost no impact to either the mean or tail performance. The reasons for this are twofold: (a) UEs typically first become uplink coverage limited before becoming downlink coverage limited, and (b) the reduced power for the macro UEs on one carrier is more than offset by a large percentage of UEs being offloaded to the picos.