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Application Notes

Multibeam antennas planning—limitations and solutions

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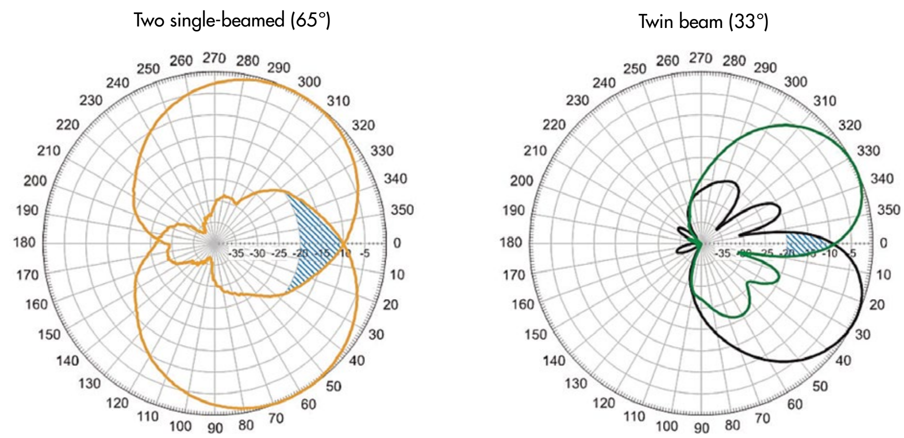
Contents

I. Introduction

As mobile data traffic continues to rise, there are three main ways to expand networks' capacities: densification of sites, adding spectrum, and enhancing through technology upgrades. While the second and third dimensions are costly, operators tend more to densify their networks infrastructures. In mature networks, densification is achievable through a number of techniques, such as the addition of small cells and macro sectors. While the latter is easier to implement, it faces interference risks as a result of sector overlap.



Two single-beam vs. twin beam antenna overlap[1]

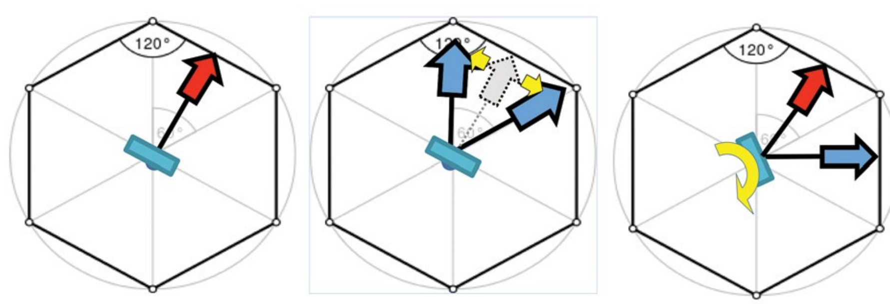
Multibeam antennas add instantaneous cost-efficient capacity, eliminating the need for new spectrum and sites building, in a minimized overlap pattern design. In this application note, we highlight some of the major challenges and concerns with the deployment of multibeam antennas deployment—together with recommended solutions.

II. After upgrade coverage gaps

Antenna azimuth plans

Upon upgrading from traditional to multibeam antennas, RF planners might maintain existing panel azimuth with new beam directions (**inherited panel azimuth**) or preserve their beams, bores' plans by changing the panel azimuth (**inherited beam azimuth**). This is illustrated in the figure below for a twin beam case.

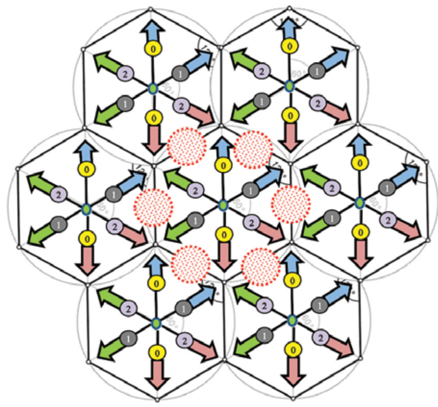
For maintaining beam bores (inherited beam azimuth), a slight change in the new antenna panel bore is made, such that one of its twin beams inherits the former single beam's direction. This deployment might be appealing for adding capacity with minimal disruptions.



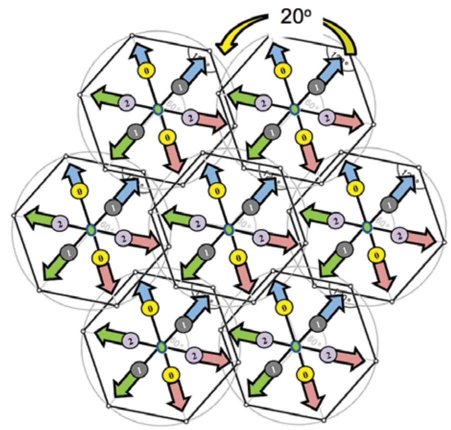
Traditional antenna original azimuth | **Inherited panel azimuth** changed beams azimuth | **Inherited beam** azimuth adjusted panel

Coverage holes with twin beam antennas

As a result of deploying dual-beam antennas with "inherited beam azimuth" some coverage gaps might arise. For twin-beam antennas, rotating **ALL** sectors by **20 degrees** solves this problem, as shown below.



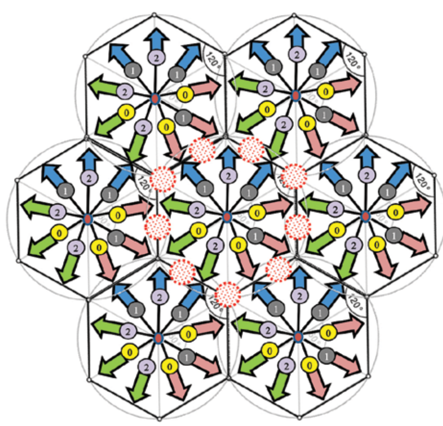
Problematic



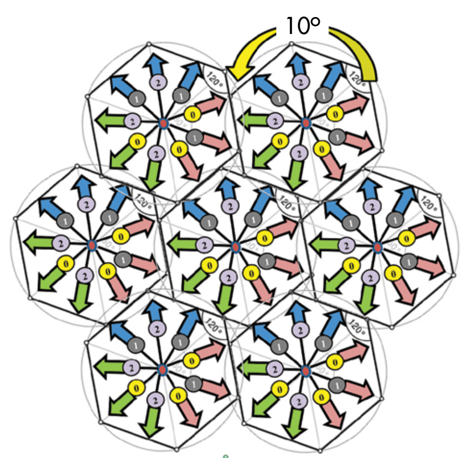
After 20-degree rotation

Coverage holes with tri-beam antenna

For tri-beam deployments, rotating **ALL** sectors by **10 degrees** eliminates sectors shooting at each other and fills up coverage gaps. This also helps in having a dominant serving cell per area.



Problematic

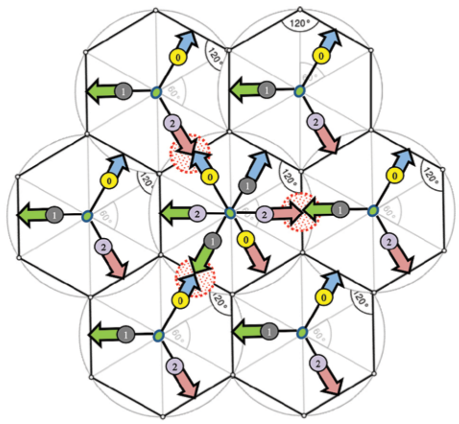


After 10 degree rotation

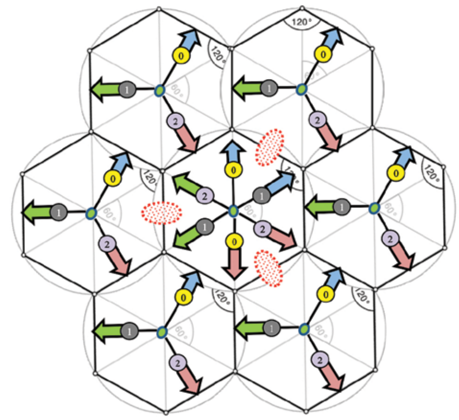
Coverage holes with a twin beam surrounded by three-sector sites

Again for the "**inherited beam azimuth**" upgrade, as shown in the left figure below, three sectors are found shooting at each other, but no gaps (nulls) are introduced.

In the case of "**inherited panel azimuth**" antenna upgrade, as in the right-side figure below, no sectors are shooting at each other but three null areas are created.



Inherited beam azimuth swap



Inherited panel azimuth swap

The first arrangement (inherited beam azimuth) is thus recommended, after necessary **tilts adjustments**, to overcome the direct shooting bores.

III. PCI planning

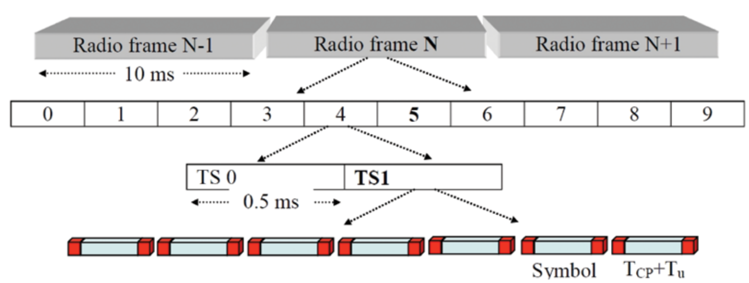
Proper physical cell identities (PCI) planning, for LTE networks can result in improved performances. With the introduction of multibeam antennas, operators have raised some PCI planning concerns that have limited their adoption of such solutions. In this section, we explore these concerns and propose specific workarounds.

Background

LTE air interface

To better understand these PCI planning concerns, let us remind ourselves about the structure of LTE radio frames.

An LTE frame (10 ms) = 10 sub-frames (1 ms)
A sub-frame (1 ms) = 2 time slots (TS)
A TS (0.5 ms) = 7 symbols (normal cyclic prefix case)



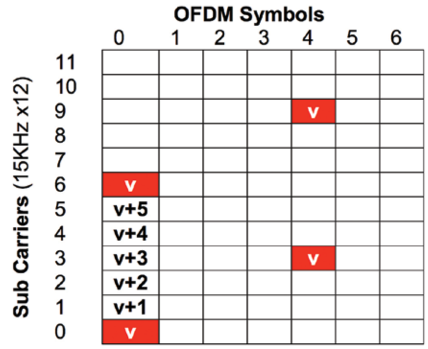
The resource block (RB)

A resource block (RB) is two-dimensional: **Time** (1TS, x-axis) and **Frequency** (12 subcarriers, y-axis) e.g. 100 RB = 20 MHz bandwidth (maximum LTE bandwidth before carrier aggregation).

Now the system needs to insert cell **reference signals** (RS) into fixed predetermined Time (symbol) and Frequency (subcarrier) locations. These are marked in red in the following diagram, depicting a system with one antenna port.

Notice that

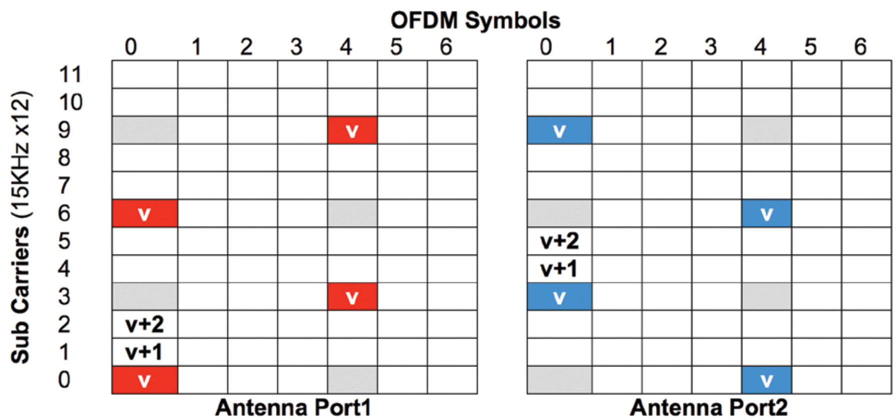
- Time locations are at symbols **0** and **4**.
- Frequency locations depend on **v** and **v-shift**.



V-shift is used to shift the RS frequency allocations between neighboring sectors, reducing interference.

The v-shift **= PCI mod 6** for systems with one antenna port (v+0 to v+5)
= PCI mod 3 for systems with two or four antenna ports (v+0 to v+2)

Why PCI mod 3?
Here we consider a system with two antenna ports (2x2 MIMO). The RS allocations of the first and second antenna ports are shown in red and blue, respectively. However, each port blocks its transmission in the other ports RS time/freq allocations (shown shaded). This gives room for only two possible v-shift locations.



Reference signals-RS vs. users traffic
Without applying v-shifts, neighboring sectors RSes might interfere each other. With v-shift applied, neighboring sectors RSes won't collide any more. However, at **high loads**, users' traffic can still impact the RSes, diminishing the benefits of v-shifts.

The physical cell identity (PCI)
The PCI is analogous to the UMTS PSC. The total of 504 PCI's are grouped as follows
ID = 0 to 2, group = 0 to 167
PCI = ID + 3*group
PCIs are, thus, divided into 168 groups with three IDs in each group.

	0	1	2	3	4	5	6	7	...	167
0	0	3	6	9	12	15	18	21	...	501
1	1	4	6	10	13	16	19	22	...	502
2	2	5	8	11	14	17	20	23	...	503

This shows 168 groups (sites) with three sectors per site (group), such that each sector has a unique PCI mod 3. For example, the highlighted **group 1** has sectors PCI = 3, 4 and 5.

Two arrangements are further proposed for better PCI spreading, preserving mod 3 uniqueness between sectors

	0	1	2	3	4	5	6	7	…	167
0	0	3	6	9	12	15	18	21	…	501
1		4	7	10	13	16	19	22	…	502
2			8	11	14	17	20	23	…	503

⇨

	0	1	2	3	4	5	6	7	…	167
0	0	3	6	9	12	15	18	21	…	501
1	4	7	10	13	16	19	22	…	502	1
2	8	11	14	17	20	23	…	503	2	5

	0	1	2	3	4	5	6	7	…	167
0	0	3	6	9	12	15	18	21	…	501
1			8	11	14	17	20	23	…	503
2						16	19	22	…	502

⇨

	0	1	2	3	4	5	6	7	…	167
0	0	3	6	9	12	15	18	21	…	501
1	8	11	14	17	20	23	…	503	2	5
2	16	19	22	…	502	1	4	7	11	15

The PCI ID (0 to 2) is used to derive the **primary sync sequence** and the PCI group is used to derive the **secondary sync sequence** (0 to 167).

Intra site PCI v-shift planning

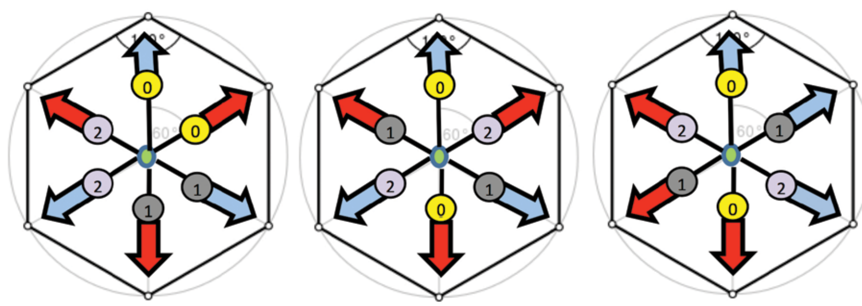
Problem description

Since normal LTE deployments use 2x2 MIMO (with two antenna ports), v-shift will always be limited by PCI mod 3, from 0 to 2 only. This has raised concerns about complicated PCI planning—threatening the deployment of multibeam antennas.

Possible six-sector site arrangements

As a workaround, for dual-band antennas in six-sector arrangements, the best that can be done is to use **two PCI groups** per site to avoid having the same PCI mod 3 (v-shift) values **between <u>direct</u> adjacent sectors**.

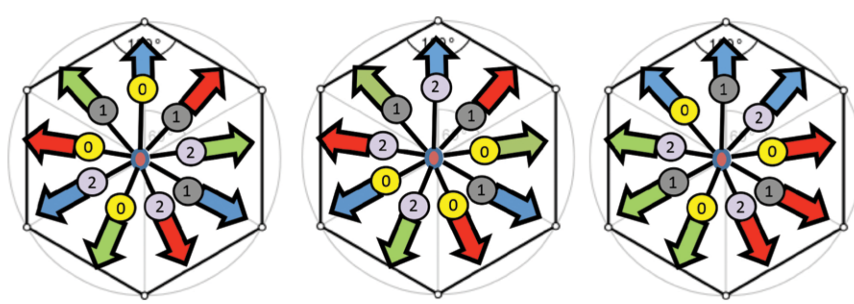
The figure below shows the possible arrangements of assigning two PCI groups to each site. The sector color indicates the same PCI group and the numbers reflect PCI mod 3 v-shift values.



Problematic!! Arrangement 1 Arrangement 2

Possible nine-sector site arrangements

Similarly, the case with tri-beam antennas/nine-sector sites can be treated by assigning three PCI groups per site. A number of arrangements are possible, as displayed below.



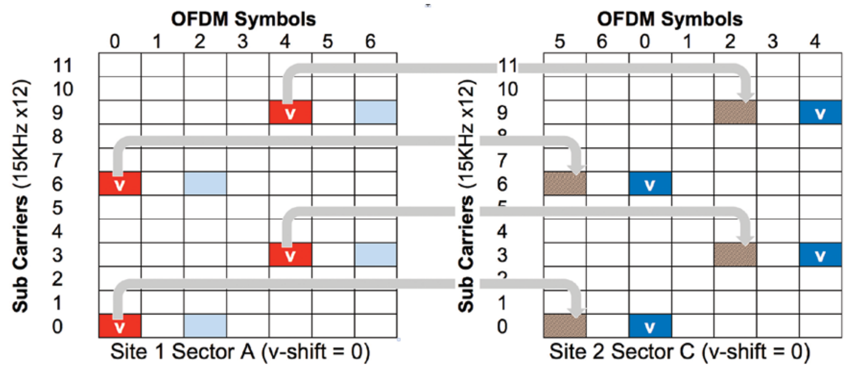
Arrangement 3 Arrangement 4 Arrangement 5

Intersite PCI v-shift planning

Some concerns were raised also about potential conflicts between neighboring sites as well—especially in the case of nine-sector sites.

LTE-FDD case

The LTE-FDD neighboring sites are not phase synchronized. Consequently, the OFDM symbols 0 and 4—carrying the reference signal (RS)—won't be in sync and have much less of a chance to collide in the neighbor site's v-shift conflicts' case.



In the example shown above, site 1 sector A and site 2 sector C have the same PCI v-shift values and are direct neighbors. Since they are not phase synchronized, symbol 0 of site1A lands on symbol 5 of site 2C. In this case, the chances of landing on the same OFDM symbol are much less. As a result, PCI v-shift planning will be more useful for the same site's sectors, which are in exact phase sync.

Current networks situations

Moreover, the majority of operators won't face neighbors, PCI v-shift conflict issue, with multibeam antennas, for two reasons:

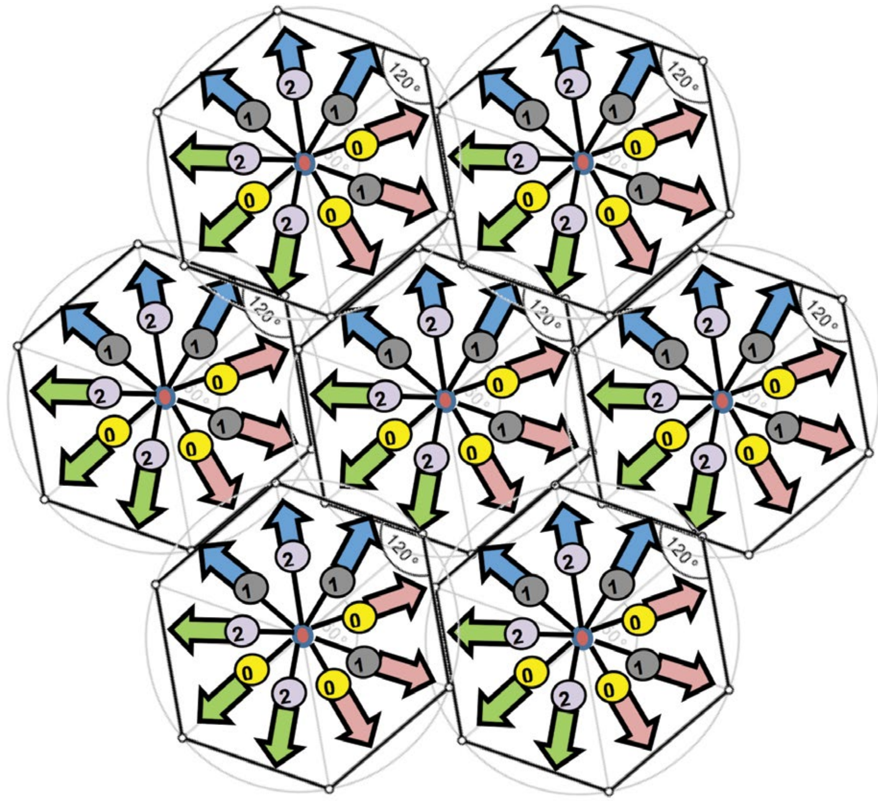
1. Their deployments are not following the uniform tessellation patterns.
2. Modern SON should be able to configure eNode B's PCI values automatically.

C-RAN case

With the C-RAN concept, baseband units (BBU) are centralized as a shared pool resource for their connected remote radio units (RRU). Not only will such a concept improve the efficiency of hardware utilization, it also enables some of the long-anticipated LTE-A features, such as the DL COMP. Here, C-RAN deployments will imply synchronization with neighboring RRUs, as if they are from the same base station. Eventually, PCI v-shift planning for neighbors might be then required, as described next.

PCI v-shift neighbors plan for tessellation deployments

The following figure proposes an example for how PCI v-shift planning can be optimized for a three-sector tri-beam antenna site. Note that the patterns are rotated by 10 degrees avoiding coverage gaps as explained before.



With such a distribution, with an arrangement like pattern 4, direct neighbors are not conflicting and there is at least one sector between each two neighbors' sectors (dominant server).

IV. Multibeam antennas and neighbor list limitations

Background

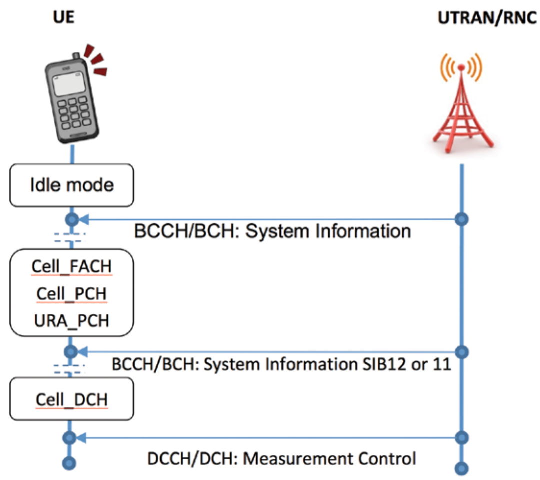
In UMTS WCDMA, a missing neighbor is an interferer. Neighbor relations always have to be carefully planned. In this section, we address another major concern when it comes to multibeam antennas: exceeding the limited possible neighbors' definitions numbers as per the 3GPP releases. We also compare the risks imposed via expansion by multicarriers compared to multibeam antennas.

Neighbors' limitations in 3GPP

3GPP defines max neighbors, for a UE to handle, as follows[2]

- 32 intrafrequency (31, excluding serving cell)
- 32 interfrequency (for all other carriers)
- 32 inter-RAT

Neighbor relations are sent to UE over system information block SIB11 (idle mode state), SIB11/12 (cell_FACH, cell_PCH, URA_PCH) and over measurement control (dedicated cell_DCH state), as shown in the figure below.



Measurement control procedures in different UE states[2]

SIB11 limitations and 3GPP releases (idle mode)
However, **SIB11** has a max capacity of 444 bytes (**3552 bits**).
This size limitation results from the maximum 16 segments used to transfer a single ASN.1-encoded SIB11. "**A**bstract **S**yntax **N**otation One" is a standard data communications message description in OSI.

SIB11 dimensioning
SIB11 data load is not fixed, but is dimensioned based on the below requirements:

Neighbor relations

- Each **intra**frequency neighbor, 2 bytes (**16** bits)
- Each **inter**frequency neighbor, 6 bytes (**48** bits)
- Each **FEMTO** neighbor, 7 bytes (**56** bits)
- Each **IRAT/GSM** neighbor, 5 bytes (**40** bits)
- Parameters
- Each neighbor **QQUALMIN** that deviates from serving cell, 1 byte (**8** bits)
- Each neighbor **QRXLEVMIN** that deviates from serving cell, 1 byte (**8** bits)
- Use of **QOFFSET**, 1 byte (**8** bits)
- **Header**: e.g., 192 bits Ericsson, 287 bits ZTE

SIB11 calculations
Ericsson formula (source: Internet blogs)

16*intrafrequency + 48*(interfrequency – FEMTO) + 40*irat + 56*FEMTO + 8*QQUALMIN + 8* QRXLEVMIN + 8*QOFFSET1SN + 8* QOFFSET2SN + Header

ZTE formula (source: Internet blogs)
48* number of intra-neighbouring cell + 79* (number of inter-neighbouring cell - 1) + 75* (number of GSM neighbouring cell - 1) + Header (287)<=3330
Huawei formula (source: Internet blogs)

- Intrafrequency: serving cell: 23 bits
- Nonserving cell: 48-55 bits
- Interfrequency: per neighbour: up to 67 bits
- IRAT: per neighbour: up to 63 bits

SIB11 example

Assuming Ericsson case without parameters' deviation and no femtos
48*interfrequency (31) + 16*intrafrequency (32) + 40*iRat (32) + 192 = **3472** (<3552)

Assuming Ericsson with parameters' deviation and no femtos
(48+16)*interfrequency (31) + (16+16)*intrafrequency (32) + 40*iRat (32) + 192 = **4288** (>**3552**)
This shows **SIB11** might be **unable to include all 95 neighbor relations** and parameters information.

3GPP releases solution

3GPP has introduced **SIB11-bis** to satisfy the full 95 neighbor relations requirements in **Release 6**. Only UE's supporting Release 6 onwards can decode SIB11-bis.

Vendors proprietary solutions

Some vendors allow definitions of more than 32 relations per category. Certain algorithms are used to prioritize and truncate the list before sending to UEs. Others restrict the list to the standard 32.[3]

Multicarrier vs. multibeam expansions

Expansion types

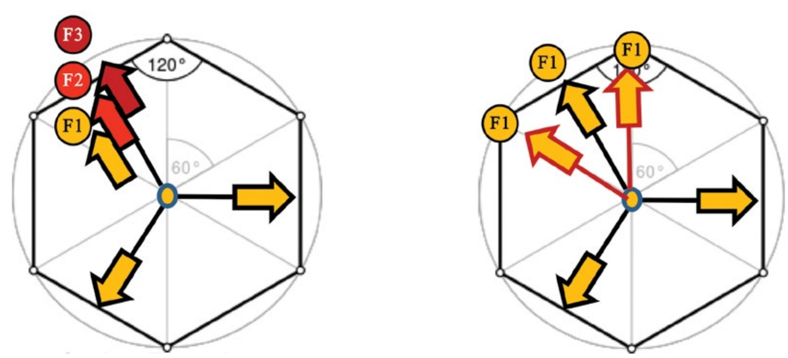
When traffic overloads existing cells' capacities, the need for expansion arises. There are different expansion types depending on the nature of the congestion. For instance, in the UMTS HSPA case, we have three main congestion types, as listed in the following table.

Congestion type	Expansion in	BBU	Radio	Spectrum	Sector
Channel element	Baseband units	Yes	No	No	No
HSDPA code	More carriers (cells)	No	No	Yes	No
	Multibeam antennas	No	Yes	No	Yes
Power	New radio addition	No	Yes	No	No
	Multibeam antennas	No	Yes	No	Yes

HSDPA code congestion can be expanded by adding more carriers (spectrum) or more sectors (multibeam). In the case of spectrum constraints, the multibeam antennas are the best way forward for adding sectors.

Power congestion can be solved by additional radios and redistributing the carriers among all radios. Here, too, in case of spectrum shortages, multibeam antennas can be a good remedy.

Neighbor list load calculations



Carriers expansion

Sectors expansion

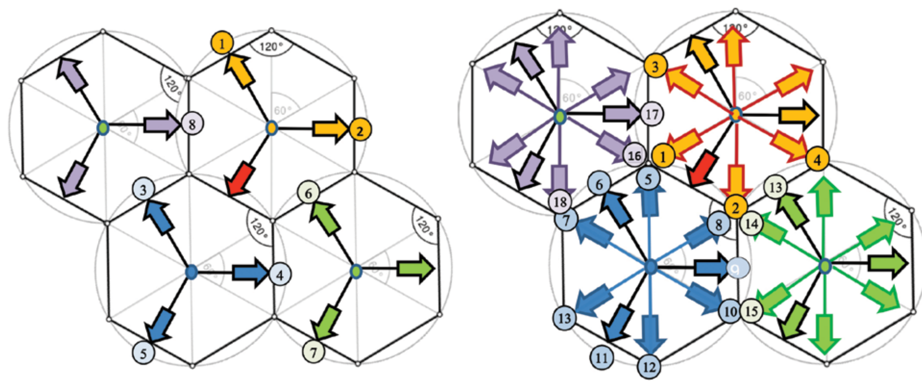
The diagram above, illustrates two expansion methods: additional carriers and multibeams.

Expanding with carriers (F1/F2/F3) will utilize both the **32 intrafrequency relations (F1→F1) and the 32 interfrequency relations, pools (F1→F2 + F1→F3)**. Referring to the figure above, each existing (F1) will get an additional x2 interfrequency relations (F2, F3). Note: we can add only 32 more interfrequency relations to the existing 32 intrafrequency max relations.

→ That is, neighbor relations, loading for interfrequency relations is **doubled** compared to the intrafrequency case. (F1→F2 + F1→F3) / 32 → 2x (F1→F1) /32

On the other hand, expanding by way of tri-beam antennas and using the same carriers has **only one pool of 32 intrafrequency** relations to utilize (no additional 32 interfrequency relations in this case). However, the neighbors, relations do not triple, as the new sectors in-between provide sufficient isolation and not all new sectors need to be defined as neighbors.

From the below figures, immediately adjacent neighbors count (for the serving sector shown using the **red arrow**) jump from 8 to 17 after deploying tri-beam antennas.



→ That is, the number of relations nearly double.

Comparing both expansion scenarios, we see that the **neighbor list loading is doubled in both cases**.

Automatic neighbor relations (ANR)

Historical

In the 2G/3G era, neighbor relation definitions were mostly manual. ANR was only a function in simulation tools. This made ANR unaware of actual users' movements and locations, to properly rank and prioritize.

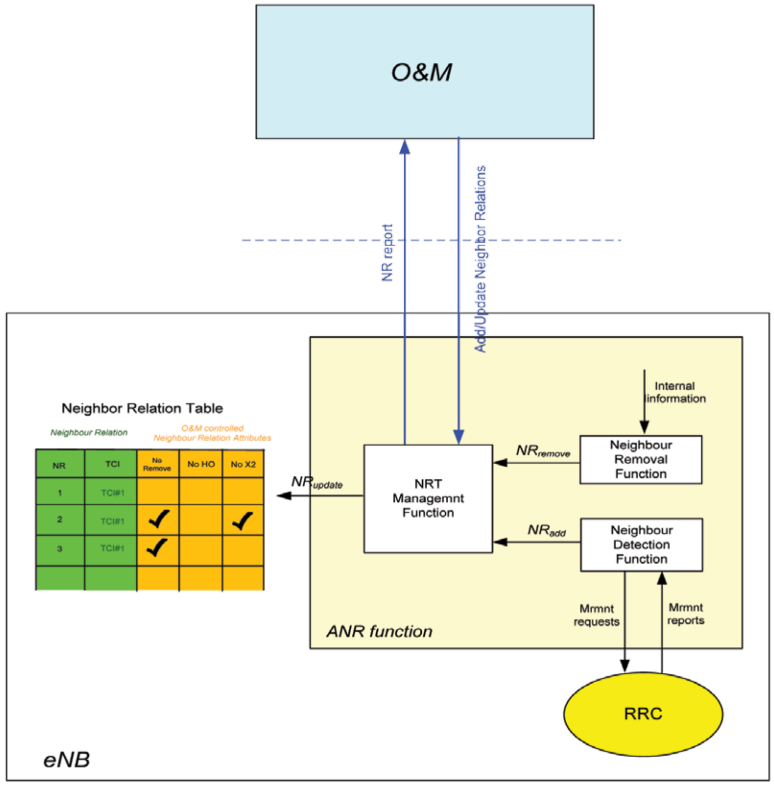
Optimizers used to periodically check attempted handover counts. The defined relations with the fewest handovers, over a certain span, made good candidates for deletion.

On the other hand, drive tests with UEs and attached scanners are used to identify missing relations.

Then came some advanced features—like mobile assisted frequency allocation (MAFA). The feature modifies neighbor lists sent to UEs, forcing them to measure and report on non-defined neighbors for assessment.

LTE case

When LTE was introduced, it came along with its SON concepts. So, this time, **ANR resides in eNode B**. The serving cells' eNode B can instruct its UEs to report on certain cells, PCI (similar to the 2G MAFA concept). Such systems also have some intelligence in detecting conflicting PCIs and reassigning proper values. More details are in a 3GPP publication.



V. Conclusion

Out of the two common antenna upgrade bore planning techniques, the "inherited beam azimuth" is seen as less disruptive. However, a calculated uniform azimuth shift will be required to eliminate coverage gaps in the case of multibeam antennas, tessellation deployments.

Moreover, PCI planning is crucial in optimizing LTE networks' performance. The v-shift values are intended to reduce intersector interferences at low-load conditions. V-shift values run from 0 to 5 (PCI mod 6) for antenna systems with one port (SISO), and from 1 to 2 (PCI mod 3) for antenna systems of two and four ports (MIMO), since it is impossible to have unique v-shifts for sites with six or nine sectors deploying 2x2 MIMO. A number of v-shift have been proposed to avoid direct neighbors conflicts. The impact of conflicting PCI v-shift values, for direct neighbors, is found to be more severe in intrasite cases than in intersite cases.

And finally, capacity expansions by multibeam antennas and multicarriers' effects on neighbor lists capacity loading were studied and found to be comparable.

VI. References

[1] Philip Sorrells, white paper, Twin beam technology adds immediate capacity without additional antennas

[2] Harri Holma and Antti Toskala, WCDMA for UMTS, 4th Edition, John Wiley and Sons

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[3] http://www.telecomsource.net/showthread.php?3936-SIB11-calculation/page2

[4] 3GPP 36.300, sub-clause 22.3.2a

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