Achieving Inter-Cell Interference Coordination in a multi-vendor small cell LTE network

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Executive summary

This paper provides an overview of multi-vendor, LTE small cell SON interoperability testing with a focus on Inter-Cell Interference Coordination (ICIC). To the best of the authors' knowledge this is the first time such multi-vendor SON testing has been performed by an operator. The paper is the result of a joint effort by British Telecom's Research and Innovation group and the technical teams of Qucell and Node-H. It addresses some of the major challenges of LTE HetNets; expands on the work of the 2016 ETSI Plugfest under the auspices of the Small Cell Forum and illustrates the benefits of SON through validation testing on interference mitigation.

The LTE Small Cells environment at BT's premises was used to analyse the implications of dense deployments of HeNBs from different vendors. The tests confirm that, despite algorithmic differences on the HeNB side, multi-vendor interference mitigation is achievable with Qucell and Node-H LTE Small Cells. This is largely due to the existence of 3GPP standards for ICIC, which enable smooth communication of SON decisions even between HeNBs from different vendors. Such a high level of interoperability is also anticipated for other SON functions for which 3GPP standards exist (e.g. ANR, MRO, etc).

Many operators consider the use of multiple small cell vendors as essential to a commercially viable deployment. The authors' conclusion is that interoperability between vendors' SON implementations is achievable and so operators can look forward to robust, seamless and tailored solutions from multiple vendors.

Introduction

Small cells are set to be a critical element of both 4G and future 5G networks. Indeed hyper-dense small cell networks are an important tool to meet the growing mobile traffic density; demands for high-quality indoor coverage and expectations of high data throughput. A reliable radio access network with the ability to self organise and supported by multiple vendors is at the heart of meeting these new challenges. Research is suggesting that by 2020, a significant proportion of LTE networks will have hyper-dense deployments – which the Small Cell Forum (SCF) defines as more than 200 small cells per square kilometre [1]. To enable such densities, today's 4G networks have to be strengthened with future proof functionalities such as Self-Organising Networks (SON), with ICIC being one of the key features.

Since Heterogeneous Networks (HetNets) will also play a significant role in the global approach towards current 4G and tomorrow's 5G networks, it is becoming necessary to identify a multi-x environment – multi-technology, multi-domain, multi-spectrum, multi-operator and multi-vendor. As small cell deployments gain greater adoption, the importance of self-organizing network capabilities and automation increases. The costs and complexity of small cell operations have to be manageable within the overall HetNet. Operators and service providers must be able to automate their operations to deliver assured service quality seamlessly across the entire network, and the networks must be flexible enough to accommodate changing user needs, business goals and subscriber behaviour [2].

Multi-vendor deployments are expected to encounter a range of challenges including:

- **Provisioning**: Sophisticated multi-vendor environments require small cells to be provisioned through a variety of mechanisms. In addition to developing Home eNBs (HeNBs) management systems to support the critical demands of dense deployments, vendors will also need to follow open standards such as TR-196 and TR-069 to allow other solutions to integrate. This is designed to allow the small cell industry to deliver cost-effective and scalable provisioning solutions to LTE network operators for the management of small cells.

- **Algorithmic co-existence**: Different approaches to the development of LTE HeNBs will not preclude their smooth interoperability and co-existence, especially when features like ICIC are in place and the density of small cells increases. The coordination of radio resources among cells is essential to reducing interference and to improving the Signal-to-Interference-plus-Noise-Ratio (SINR) at the cells edges. Cell communication standards (e.g. X2AP) will be instrumental in enabling an amicable conjunction of heterogeneous ICIC algorithms.

In order to assess the multi-vendor challenges listed above, the Small Cell Forum [3] in partnership with ETSI, has organized several Small Cell LTE PlugFests in recent years. These events provide vendors with an opportunity to demonstrate that their implementations are interoperable with other vendors' equipment creating an effective ecosystem for widespread small cell deployment. The 4th Small Cell LTE Plugfest was held from 27th June to 8th July 2016 [4] under the auspices of the Small Cell Forum and offered on-site and remote test sessions where vendors were able to assess the level of interoperability of their implementations and verify the correct interpretation of 3GPP and other specifications.

The Small Cell Forum, through industry surveys and group discussions, concluded that one of the main barriers to the mass deployment of small cells is the concern about how to achieve automation/SON with multi-vendor interoperability [1]. As a result, the 2016 LTE PlugFest had a particular focus on SON.

The Small Cell Forum created the SON test cases for the 2016 PlugFest. This extended some existing SON test cases ([5] and [6]), resulting in a test specification covering a broad range of SON features. The list of SON features can be summarised as:

- Basic self configuration (e.g. X2 setup, Automatic Neighbour Relations, PCI selection)
- Mobility optimisation (e.g. Mobility Robustness Optimisation, Frequent Handover Mitigation)
- Interference mitigation (e.g. Inter-Cell Interference Coordination)

These tests were carried out in multi-vendor environments where there were either two small cell vendors, or one small cell vendor and a macro cell vendor. The 2016 Plugfest event lasted for two weeks, during which interoperability was demonstrated with many combinations of vendors. However, there was not sufficient time to show interoperability for all SON features. Results are very impressive for the basic self-configuration features, showing a high number of test executions and a high success rate. However there were few results on interference mitigation [4]. After the PlugFest, there was a desire from the authors to continue the interoperability testing, to establish the position on interference mitigation.

Overview of ICIC

LTE was designed for full frequency reuse. In such networks, neighbour cells share the same frequency channels, therefore interfering with each other. It often happens that a resource block scheduled to a cell edge user is also being used by a neighbour cell, resulting in high interference and poor throughput or call drops. The LTE traffic channel can sustain up to a 10% Block Error Rate (BLER) but control channels cannot. Neighbour cell interference can therefore result in radio-link failures at the cell edge. This problem is especially serious in heterogeneous networks since the coverage areas of small-cells and macro-cells overlap each other significantly in many scenarios.

Co-channel interference can be minimized by means of network optimization in planned networks, or through automated techniques in networks with non-deterministic cell sites. LTE small-cells use the paradigm of 'non-planned' networks, meaning that the cells are located in a random fashion and must arrange themselves to optimize their coverage. In a non-planned network, interference mitigation is accomplished by autonomous distributed algorithms that coordinate the level of co-channel interference that neighbouring cells cause to each other. This approach allows physically separated eNBs to coordinate the use of RF resources jointly in a manner which minimizes interference.

In the 3GPP LTE standard, Inter-Cell Interference Coordination (ICIC) is targeted at the physical channels and in particular at the Physical Downlink Shared Channel (PDSCH). This was introduced in 3GPP Release 8 to deal with interference at the cell-edge on traffic channels. ICIC uses both the power and frequency domains to mitigate cell-edge interference from neighbour cells. Based on this, the LTE system bandwidth can be fragmented in multiple ways:

- In one scheme of ICIC, neighbour cells use different sets of resource blocks at any given time, so that no two neighbour cells schedule their UEs in the same resource blocks. This greatly improves cell-edge SINR at the expense of a decrease in throughput due to the smaller available bandwidth.
- In the second scheme, all eNBs utilize the same resource blocks for cell-centre users, and orthogonal resource blocks for cell-edge users.
- The preferred scheme is one in which neighbour cells use different power allocations over the whole spectrum in a Soft Frequency Reuse (SFR) fashion. eNBs use this approach to power-

boost their cell edge users on some resource blocks, while keeping a low signal power for cell-centre users (see Figure 1).

In Release-8, 3GPP standardised X2AP procedures [7] that allow neighbour eNBs to coordinate the RF spectrum usage for PDSCH transmissions. One such procedure is the *Load Information* procedure, through which eNBs gain awareness about which Physical Resource Blocks (PRBs) are more interfered by neighbour cells (e.g., *RelativeNarrowbandTxPower field)*. eNBs can then use this knowledge to schedule their own UEs in an informed manner that avoids heavily interfered PRBs on downlink and uplink. An illustration of this is shown in Figure 1, in which four LTE small cells coordinate on PDSCH power allocation across PRBs to minimise interference for cell-edge UEs. Furthermore, this low interference scenario can be accomplished through the exchange of only four *Load Information* messages over X2.

The X2-based information exchange mechanisms have been standardized by 3GPP. However, the way this information is exploited by each eNB is a design choice left open to eNB vendors. 3GPP standards also do not specify when the Load Information messages must be exchanged. Vendors of eNBs have therefore many degrees of freedom for implementing these procedures, which makes multi-vendor inter-operability testing an unavoidable phase of the network deployment process.

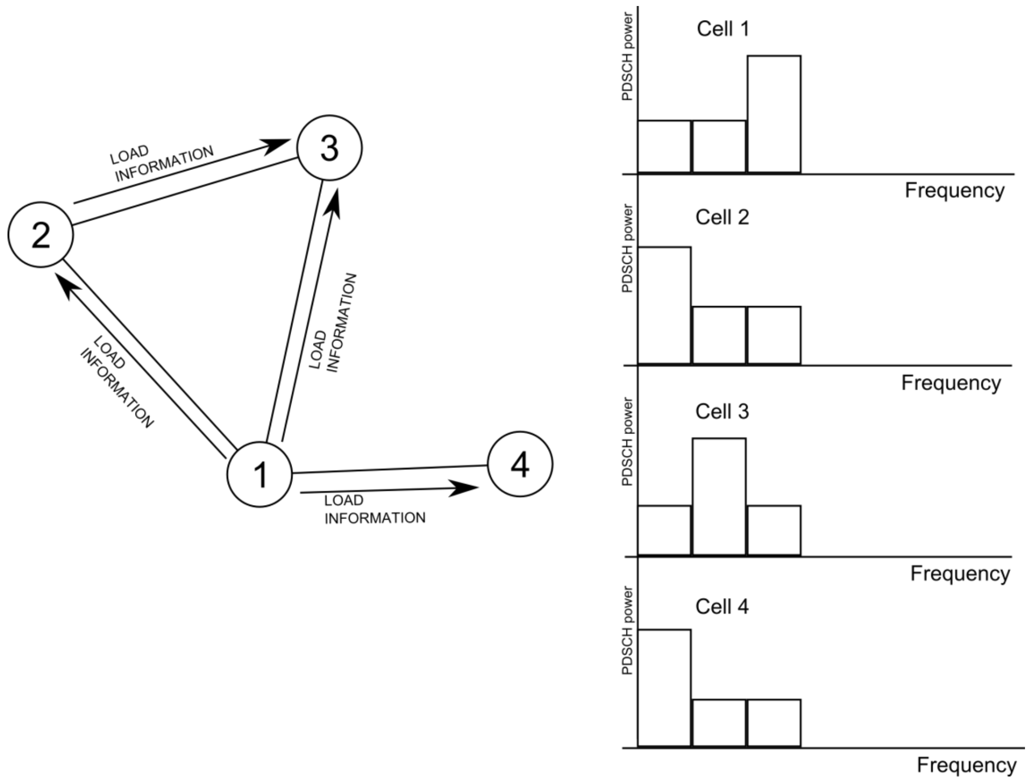

Figure 1: Low cell-edge interference scenario through X2 Load Information exchanges.

ICIC Test Cases

The ICIC testing was carried out at BT premises at Adastral Park in the UK. A multi-office building, which has previously been used for performance evaluation and characterisation of high-density small cells deployments, was used for the tests. All testing is performed over-the-air, so that the results reflect a real-world service environment.

The HeNBs-under-test used band 7 FDD LTE and were configured with a downlink centre frequency of 2.6475GHz (EARFCN=3025) and 15 MHz bandwidth. The value of the parameter P_A, as described in section 5.2 of [8], depends on the user classification. The values P_A=-6 dB (cell centre user) and P_A=0 dB (cell edge user) were used.

The tests involved two HeNBs. They were placed in nearby rooms (as can be seen in Figures 2 and 3). The approximate distance between the two HeNBs was 23m with a measured path-loss, at the downlink centre frequency 2.6475 GHz of 82 dB. Each cell used 2x2 downlink MIMO and a reference signal power of -13 dBm. This setting maximised the range of each HeNB whilst ensuring the total transmit power for each HeNB was always below 20 dBm.

From the full list of SON test cases at the 2016 Plugfest there were 13 test cases related to ICIC. In this paper we have focused on the three test cases that we believe are the most essential aspects of ICIC. One of ICIC's primary goals is to improve cell-edge user throughput. This is what the first test case, "Two User per Cell Throughput comparison – Near Cell and Far Cell User", evaluates. In order for ICIC to implement Soft Frequency Reuse it is important that a cell classifies users as "cell-centre user" (CCU) and "cell-edge user" (CEU) as they move around the coverage area. By setting P_A based on a UEs classification, SFR in PDSCH can be achieved. The test cases "P_A update for CEU to CCU" and "P_A update for CCU to CEU" cover the P_A adjustment when a user classification changes for both directions.

Each test is carried out for the following combinations of vendors:

1. SC1=Qucell, SC2=Qucell
2. SC1=Node-H, SC2=Node-H
3. SC1=Qucell, SC2=Node-H
4. SC1=Node-H, SC2=Qucell

The first two test combinations represent "intra-vendor" testing. This is useful as a way for a vendor to demonstrate that their solution can pass the test case. The third and fourth combination represent "multi-vendor" testing. This is the most important aspect of the testing, as it shows if each vendor's solution can co-exist in a multi-vendor environment.

Test Case 1 - "Two User per Cell Throughput comparison – Near Cell and Far Cell User"

This test compares the throughput performance with ICIC enabled and disabled. The test configuration is shown in Figure 2. There are two HeNBs. Each HeNB has two UEs attached, placed so that one UE is classified as cell centre, and the other as cell edge. Each UE is requesting full buffer UDP traffic in the downlink. The total traffic for each UE is recorded for ten minutes.

This procedure is repeated with ICIC enabled and with ICIC disabled. The pass criteria for this test case, matching that used at the 2016 Plugfest, is that CEU throughput should be better when ICIC is enabled.

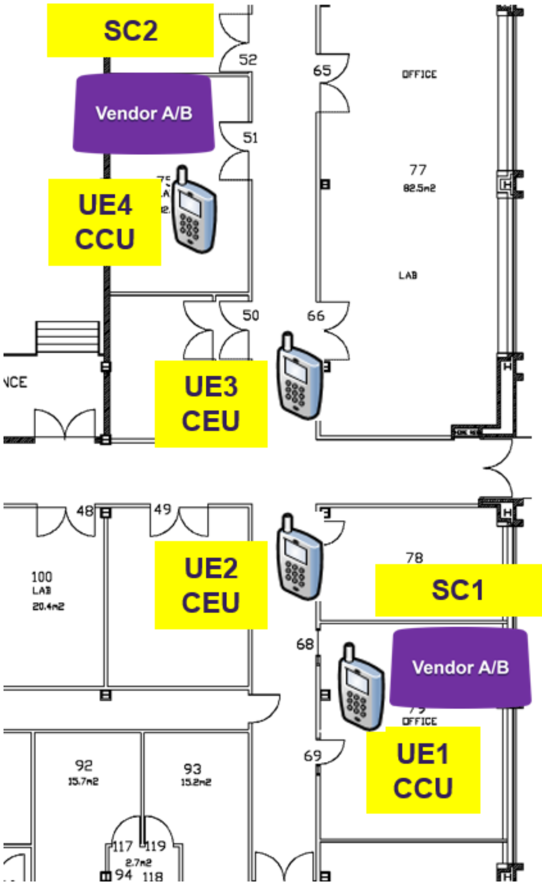

Figure 2 - ICIC user throughput test layout

Test Case 2/3 – “P_A update for CCU to CEU”/“ P_A update for CEU to CCU”

These tests were carried out sequentially as part of a single test. This test was looking at the functionality that classifies users as “cell-centre user” (CCU) and “cell-edge user” (CEU) as they move around a cell.

The test configuration is shown in Figure 3. This initial setup is identical to test case 1. ICIC is enabled throughout this test and all UEs are requesting full buffer UDP traffic in the downlink.

The cell under test is SC1. For test case 2, “**P_A** update for CCU to CEU” UE1 is moved from its start position as a CCU, away from SC1, until it becomes a CEU. Upon this classification UE1 should receive an *rrcConnectionReconfiguration* message from SC1 confirming that the **P_A** value for UE1 is now set to the value assigned for cell edge users. If this occurs, test case 2 is successful.

From the end of test case 2, we continued onto test case 3 “**P_A** update for CEU to CCU”. With UE1 now classified as a CEU, we move it back to its original position where it should be classified as a CCU again. Upon this re-classification UE1 should receive an *rrcConnectionReconfiguration* message from SC1 confirming that the **P_A** value for UE1 is now set to the value assigned for cell centre users. If this occurs, test case 3 is successful.

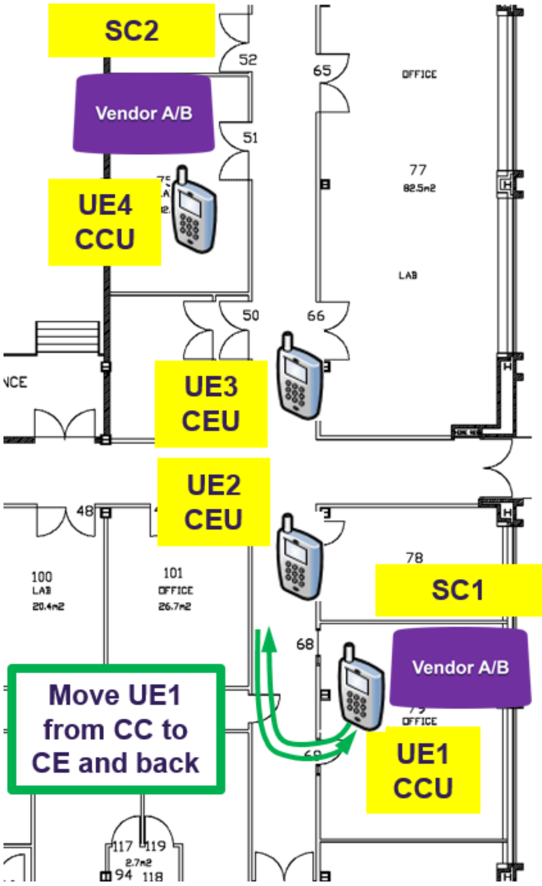

Figure 3 - ICIC P_A adjustment based on UE classification

Test Results

While running these tests in a multi-vendor scenario the following observations were made:

- X2 message formatting – X2 allows for many optional fields, depending on the functionality enabled by each cell. Both vendors populate a similar, but different, set of fields. This may need further attention in the future when testing multiple SON features together. For these ICIC tests the *relativeNarrowbandTxPower* fields are used and both populate these same fields.
- The *rNTP-PerPRB* field shows a bitmask of the resource blocks using high power. From these messages it was confirmed that orthogonal high power resources were being selected.
- X2 message reporting – The timing of X2 message exchanges varied between the two vendors. One vendor opted for a regular periodic update, while the other opted to send a message after changes to its resource allocation.
- *rrcConnectionReconfiguration* messages were received at the UE as expected. (RRC messages were viewed using an air interface monitoring tool, connected to the UE). As soon as the threshold for CCU/CEU was crossed, the UE would receive an *rrcConnectionReconfiguration* update, changing the P_A value to the new setting. This was very robust and repeatable, even in the over-the-air test environment.

The results of the ICIC testing are shown in Table 1. Of the test cases investigated, all test combinations achieved a pass. This means that each vendor (Qucell and Node-H) have solutions that work in an intra-vendor environment, but also in a multi-vendor environment. This demonstration of multi-vendor ICIC is an important step beyond the success of the 2016 Plugfest, showing that multi-vendor interference mitigation is achievable.

It is also worth noting that basic self-configuration SON features (i.e. X2 setup, Automatic Neighbour Relations and PCI selection) were used as part of the test setup, further demonstrating the value that SON has for the widespread deployment of small cells.

Table 1 - ICIC Interoperability Results

	Intra-vendor testing		Inter-vendor (multi-vendor) testing	
Vendor combination:	Qucell only	Node-H only	SC1=Qucell SC2=Node-H	SC1=Node-H SC2=Qucell
Two User per Cell Throughput comparison – Near Cell and Far Cell User	Pass	Pass	Pass	Pass
P_A update for CCU to CEU	Pass	Pass	Pass	Pass
P_A update for CEU to CCU	Pass	Pass	Pass	Pass

Conclusions

This paper shows that it is possible to operate mobile networks in which the individual LTE cells execute different ICIC algorithms. These findings challenge preconceptions about SON that are common in the mobile industry and make the case towards larger multi-vendor deployments of LTE small-cells and call for bolder efforts in multi-vendor SON testing.

The ICIC algorithms used during these tests have been developed independently and without exchange of technical details between two separate HeNB vendors. Despite this, it has been shown that both algorithms can gracefully co-exist in the same LTE network. ICIC standardization efforts within 3GPP have been key to this success. Such efforts include the X2 messages that shall be used for ICIC purposes, as well as the UE-specific parameters at the RRC level.

Despite the performance gains and harmonious interworking, difficulties have also been encountered. These include differences in the provisioning systems of both vendors, as well as on the Key Performance Indicators (KPIs) provided by the different HeNBs. Such challenges are best overcome by means of industry-wide standardization. It is due to these reasons that inter-operability events such as ETSI's Small Cell LTE Plugfest [4] are essential to nurturing a high degree of inter-operability to meet the needs of mobile network operators.

From an operator perspective, the next stage after being satisfied at the level of interoperability between vendors, would be an integration exercise, for trialling and deployment. This typically involves integration with the operator's own management systems, core network and existing RAN solutions. Parameter selection and algorithm adjustment can occur at this stage, and overall performance optimisation becomes a focus.

References

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[8] ETSI, “TS 36.213 v9.3.0; E-UTRA; Physical layer procedures,” 2010.

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Links to participant companies:

www.node-h.com

www.qucell.com

www.qualcomm.com