ESG

Engineering Services Group

WCDMA Multi-Carrier Support:

Deployment & Parameter Settings Guidelines

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QUALCOMM®

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Table Of Contents

Figures

Tables

Summary

This paper presents a discussion on Multi-carrier deployment strategies. In particular, the paper presents:

- Different multi-carrier deployment scenarios (Hot spot deployments, fully over-lapped One-on-one deployments, and Disjoint and Inter-band deployments) which can be used to attend a variety of network operation objectives in terms of mobility and capacity management.
- Associated to these multi-carrier deployment strategies, different multi-carrier traffic type distribution strategies are presented.
- For each multi-carrier deployment strategy and/or traffic type separation strategy; the required inter-frequency cell reselection and handover parameter recommendations are also provided.

The paper also presents in Appendix 7Appendix A and Appendix 7Appendix B the fundamentals of Inter-Frequency Cell Reselection, and Inter-Frequency Handover, respectively. This paper can be used by UMTS operators as a reference for the deploying and configuration of WCDMA multi-carrier networks.

1 Introduction

As the deployment of UMTS/WCDMA systems continuous to grow all over the world, new capabilities are being added to the system, and new services and applications, such as high speed data, video streaming, video broadcasting, push to talk, and voice over IP, are being provided or evaluated by 3G operators. In order to provide 3G services in a most economical way, 3G operators have also been considering or deploying multiple carriers[1] in their networks to meet these ever increasing demands.

The multi-carrier deployment scheme was envisioned from the start of the UMTS/WCDMA system standardization activity. In particular, the support of inter-frequency handover necessary for high-capacity hierarchical cell structures (HCS's) was specified by the standard in Rel-99, with an intention to satisfy both mobility and capacity management requirements. In practice, while most of the multi-carrier deployments are used to address the network capacity increases, some multi-carrier deployments are used to provide different services, or different coverage and mobility management schemes. As a result, the handling of inter-frequency handover and cell reselection in multi-carrier networks varies with respect to different network deployment scenarios and network operation objectives. In addition, the transition between the 3G UMTS radio access network (UTRAN) and the 2G GSM/GPRS/EDGE radio access network (GERAN) also affects how the inter-frequency handover and cell reselection should be controlled.

The variety of multi-carrier deployment schemes put a challenge in the 3G network optimization. That is how to best manage the inter-frequency transitions (through inter-frequency handover or cell reselection or other means), so the desired quality of services can be delivered in a most economical way. This is a multi-dimensional problem with many system and air interface parameters involved, and the solutions, i.e., the optimized parameter settings, will also depend on the service and network operation objectives. Hence, understanding the tradeoffs between various parameter settings towards meeting various deployment/service objectives will be the key for effectively addressing this multi-carrier network optimization problem.

1.1 Scope of the paper

This paper provides an overview of different multi-carrier deployments scenarios:

- For each scenario, in addition to the discussion of the deployment principles, the corresponding inter-frequency handover and cell reselection schemes are considered.
- Through the discussion of the typical multi-carrier scenarios, we provide guidelines on what network performance or operation issues should be considered to make educated tradeoffs for the inter-frequency parameter settings.
- Each scenario also comes with an initial set of recommended inter-frequency cell reselection and handover parameters which are subject to change without notice. It should be observed, however, that the optimal parameter settings must be fine tuned based on actual field testing and performance evaluation.

Although it may be straight forward to discuss how to deploy multiple carrier networks from the network design principle point of view, it is never a clear cut when dealing with individual deployment scenarios. The engineering consideration is always unique for each individual case and the tradeoffs are not necessarily straight forward. In this paper, without the loss of generality, we present a few, we consider as typical, examples of deploying secondary carriers on top of the existing single carrier network with (or without) underlying GSM networks.

[1] The terms carrier and frequency in this paper are used loosely and interchangeable, especially when we discuss air interface issues with respect to WCDMA deployments with multiple carriers (or frequencies). Strictly speaking, c*arrier* refers to the radio signal band that carries the WCDMA signals, and *frequency* refers to the radio center frequency assigned to the carrier.

1.2 Organization

The document is organized in such a way that does not require a sequential reading of all its Sections. For instance, an interested reader in only hot spot multi-carrier deployments can directly proceed to Section 3. Section 2, however, presents an interesting overview of different multi-carrier deployment strategies and it is a recommended reading, suitable as an introductory section for any of the subsequent sections where specific multi-carrier deployment details are covered. Section 3, as mentioned earlier, presents details of multi-carrier Hot spot deployments with and without traffic type separations among the deployed carries. Section 4 covers the configuration details and tradeoffs of a fully-overlapped One-on-one multi-carrier deployment, with and without traffic separation. Section 5 and Section 6 present a discussion of multi-carrier deployments with disjoint carriers and with carries pertaining to different frequency bands, respectively.

Finally, and as a necessary fundamental support to all previous sections, Appendix 7Appendix A and 7Appendix B provide the operational basics and parameter descriptions of Inter-frequency cell reselection and Inter-Frequency handover, respectively.

1.3 Revision History

Date	Revision	Description
2007-01-31	A	Initial Release
2007-03-23	B	Multiple technical modifications, refinements, and editorial changes
2007-02-19	PC7	Reorganized paper for the final review
2007-05-21	PC8	Complete scenario based reorganization
2007-06-23	C	Reorganized the paper based on individual deployment scenarios

1.4 Acronyms

3GPP	3rd Generation Partnership Project
CPICH	Common Pilot Channel
GERAN	GSM GPRS EDGE Radio Access Network
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HCS	Hierarchical Cell Structure
HSDPA	High Speed Downlink Packet Data
IFHO	Inter-Frequency Handover
LAC	Location Area Code
LAU	Location Area Update
MO	Mobile Originated
MT	Mobile Terminated
OVSF	Orthogonal Variable Spreading Factor
RAB	Radio Access Bearer
RAT	Radio Access Technology
RF	Radio Frequency
RSCP	Received Signal Code Power
UARFCN	UMTS Absolute Radio Frequency Channel Number
UE	User Equipment

UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

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2 Overview of Multi-Carrier Deployment Strategies

Depending on business considerations, many different multi-carrier strategies can be considered for expending or deploying a WCDMA network. Each approach has its own pros and cons. This section lists three basic (and often discussed) types of strategies, the hierarchical configuration for a balanced mobility and capacity support, the capacity expansion for handling high traffic volumes, and service separation for improving system efficiencies.

Network operators may choose a particular strategy approach or a combination based on their own business objectives and environments. The selection decision can be affected by (and not limited to) technical, financial, environmental, political, or any combinations of these factors.

This section provides an overview of the different multi-carrier strategies and its associated field deployment scenarios. Sections 3-5 provide some initial inter-frequency reselection and handover parameters' recommendations and trade-off analysis.

2.1 Hierarchical Cell Configuration

The hierarchical configuration strategy, also referred to as hierarchical cell structure (HCS), was introduced during the development of the UMTS standard. The addition of inter-frequency handover functionality in the standard was also partially due to the need of supporting HCS. The main objective of the HCS design is to efficiently support both high mobility and high capacity within a single network. A typical HCS network consists of several types of cells (or layers), such as macro cells, micro cells, and pico cells on different frequencies. While the macro cell, given its large cell coverage, provides good mobility management for high speed mobiles, the pico cell, covering hot spots, can provide high capacity support. Since different carriers are assigned to different layers, the inter-frequency handover and cell reselection are used to move active and idle users between the layers. An example of HCS deployment strategy is shown in Figure 1, where a layer of pico cells is overlaid on top of two layers of macro cells.

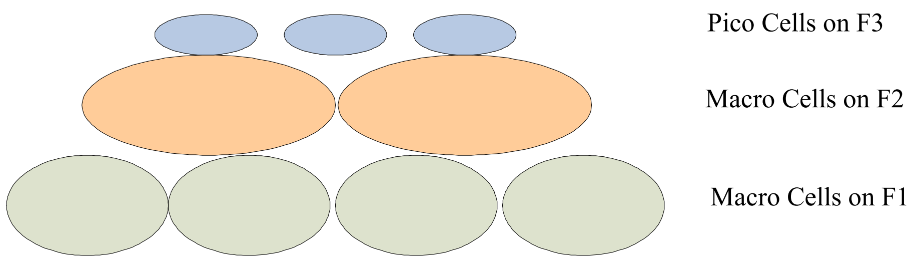

Figure 1: A HCS deployment with 2 layers of macro cells and 1 layer of pico cells

Although the HCS is a very good concept, and there have been a lot of studies and research devoted to it [2][3], the network design, network planning and network operation of an HCS system are often quite complex due to the difficulties in good mobility detection and efficient resource management to provide good mobility and capacity support at the same time. The high cost of coverage planning, network planning and tuning are also part of the disadvantages of this type of deployment. In addition to the generic inter-frequency cell reselection and handover mechanism, the 3GPP standards provide additional controls and parameters for handling the HCS systems. Optimizing these controls and parameters, especially network wide, is challenging and requires significant amount of effort. As a result, there have not been many commercial networks being deployed with large scale HCS systems. For a small area, however, for instance in recent development of indoor coverage of WCDMA systems, the HCS has found suitable applications due to the introduction of the high speed downlink packet data (HSDPA) support [4][5][6].

Given the amount of studies that have been done with respect to HCS, and given the complexity of the HCS system optimization, it would be necessary to have a separate overview of the design and optimization of HCS systems alone. Hence, for the rest of the paper, we will mainly focus on the discussion of multi-carrier deployment cases that are not specific to HCS, but use HCS concepts only for the multi-band deployment case. Carriers controlling multiple frequency bands have been considering an HCS deployment due to the natural cell coverage difference between different frequency bands. For instance, the cell coverage on the 850/900 MHz frequency band is at least 30 percent larger than the cell coverage on the 1900/2100 MHz frequency band. Potentially, the operator can deploy a system with 1900/2100 MHz cells supporting large traffic and with 850/900 MHz cell supporting high mobility. The inter-frequency handover and cell reselection configuration in such a multi-band deployment is discussed later on in this paper.

2.2 Capacity Expansion Strategies

As wireless traffic increases a single-carrier deployment may become insufficient and enforce network operators consider adding additional carriers to increase air interface capacity to attend the larger traffic demand. Depending on network planning, potential traffic increase distribution, and financial planning, the deployment strategy of the second or third carrier varies. In general, there are two types of deployments of the additional carriers to accommodate capacity expansions

- *Hot spot deployment*
- *One-to-one overlay deployment*

2.2.1 Hotspot Deployment

When the budgeted amount of initial expansion is limited, which is more often the case; operators may consider selectively adding the second carrier at hot spots where capacity increase is most needed. As the traffic in the network increases, the second carrier coverage is then expanded gradually. The topology of such a deployment is like a wedding cake as shown in Figure 2.

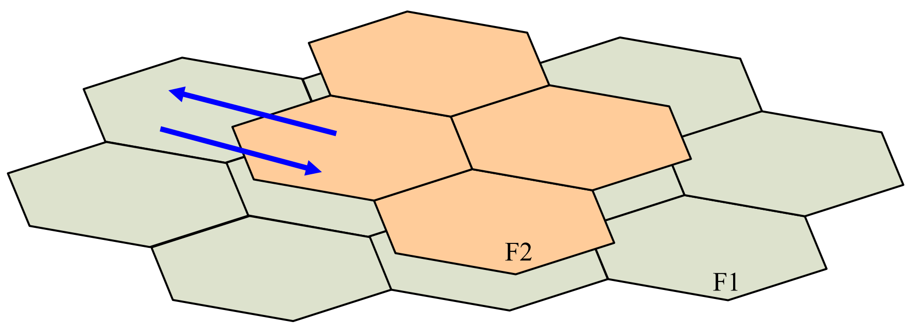

Figure 2: Hotspot Addition of the Second Carrier

Observe from Figure 2 that for hot spot deployments the main goals are:

- Mobility support at the coverage edge of the secondary carrier:
    - It requires service continuity for call origination/termination while idle state mobiles leave or enter the multi-carrier area. This is usually provided through inter-frequency cell reselection mechanisms as described in Section 3.1.1 and Appendix 7Appendix A.
    - It requires call continuity to support for mobile units leaving and entering the multi-carrier area while in Cell_DCH state. This is usually provided through inter-frequency handovers as described in Section 3.1.2 and Appendix 7Appendix B.
- A secondary goal is load balancing and traffic type distributions among the different carriers inside the hot spot deployment area (see Section 3.2 and Section 2.3 for more details).

Details covering idle and connected mode operation at the secondary carrier as well as load balancing and traffic distribution in this type of hot spot deployment are covered in Section 3 of this document. The Fundamentals of inter-frequency cell reselection and inter-frequency handover operation as well a succinct description of their corresponding associated parameters can be found in Appendix 7Appendix A and Appendix 7Appendix B, respectively.

2.2.2 One-on-one Overlay deployment

When financial funding is not limited and additional bandwidth is available within the band throughout the network coverage, the simplest and most expensive deployment scheme is to add the second carrier covering the entire network in a one-to-one cell overlay scheme. Figure 3 illustrates such a blanket rollout deployment. By adding the second carrier at each cell site and with the same deployment parameters, such as power rating and antenna configuration, etc., the coverage behavior of the second carrier is going to be approximately the same as the first carrier when operating in the same band.

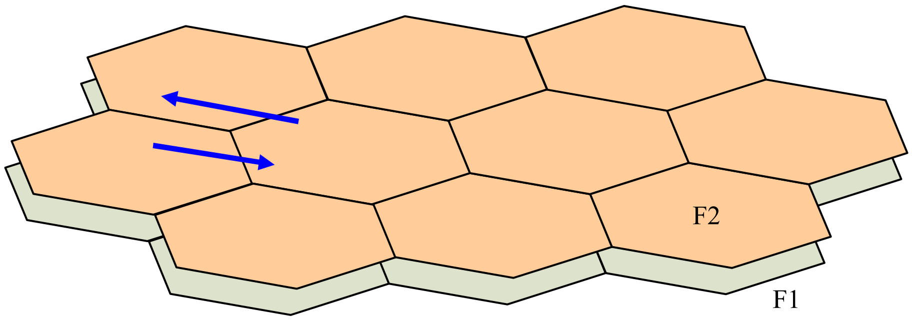

Figure 3: Blanket Rollout with One-to-One Cell Overlay

Observe from Figure 3 that for fully-overlapped one-on-one deployments, the goals are rather different than the ones described for hot spot deployments shown in Figure 2. In particular:

- Since there is coverage continuity in both frequencies, inter-carrier mobility management is not the main concern any more except in the border areas of both WCDMA carriers or in coverage holes affecting one or another carrier (See Section 0).
- The main goal instead, is proper idle and DCH-State mobile load balancing among the deployed carriers as discussed in section 4.1.1 and 4.1.2, respectively.
- Also traffic type distribution among the primary and secondary carriers as described in Section 2.3 and Section 4.2 should be taken into consideration.

Details covering idle and connected mode operation at the secondary carrier as well as load balancing and traffic distribution in this type of fully-overlapped One-on-one deployment are covered in Section 4 of this document. The Fundamentals of inter-frequency cell reselection and inter-frequency handover operation as well a succinct description of their corresponding associated parameters can be found in Appendix 7Appendix A and Appendix 7Appendix B, respectively.

2.3 Multi-carrier traffic type separation strategies

Considering the availability of HSDPA/HSUPA (a.k.a. HSPA) support in Rel-5/Rel-6, some network operators may consider an additional strategy of using the multiple frequency deployment to separate different traffic types in a per-carrier basis. In particular, the following multi-carrier traffic type separation strategies are expected:

- *HSPA (F2) overlaid on R99 (F1)*
- *HSPA+R99 (F2) overlaid on R99 (F1)*
- *HSPA (F2) overlaid on HSPA +R99 (F1)*

Per-carrier traffic separation strategies can be applied to both capacity expansion schemes (One-on-one and hot spot) discussed in the previous section.

NOTE: In the following sub-sections, illustrative figures show only the case of Hot spot deployment

2.3.1 HSPA (F2) overlaid on R99 (F1)

Consider Figure 4 for this multi-carrier deployment strategy. In that figure and the rest of the document, Cell(FX,Y) should be understood as a WCDMA cell operating at carrier Frequency X with PSC Y. In this particular case, the primary or ubiquitous carrier provides basic Rel-99 CS and PS services (such as AMR voice and R99 PS data) and the second carrier, with HSPA capability, provides high speed PS services and supports the applications that can benefit from the high efficiency of HSPA.

The advantage of this approach is the ease of radio resource management. Given the difference in traffic and radio resource management between HSPA and R99 separating the two types of services on two different carriers allows the operators and infrastructure vendors to fine tune the resource management algorithm for each of the traffic service types. Hence, it makes resource management more efficient and easy to optimize. For instance, given the efficiency of HSPA in supporting high speed packet data, the operator can significantly improve the overall resource utilization by moving packet data to the HSPA carrier and putting all circuit switched connections on the Rel-99 carrier so that the OVSF code and power resource management of HSPA can be more effective.

Another advantage of this approach is to allow the operators to introduce new services with less impact on the existing services. By introducing a new services on one carrier, the services on the other carrier will not be affected, hence, makes the introduction of the new service smoother.

This approach, however, limits the total number of CS users to the first carrier capacity and still requires careful attention when supporting multiple RABs (a single user having both voice and high speed data services active at the same time) which will be confined to F1.

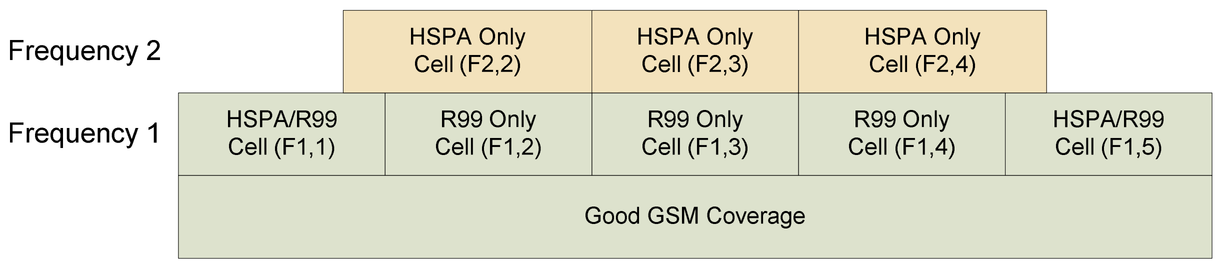

Figure 4: HSPA Overlaid on R99

2.3.2 HSPA+R99 CS (F2) overlaid on R99 (F1)

The approach described in the previous section, is not effective if R99 voice or CS/PS data traffic in the underlay carrier increases beyond the capacity of a single carrier. This can be the case in regions where voice traffic and R99 data traffic are the vast majority. To address capacity expansion, in this case, the network operator can consider the configuration of Rel-99 services on the first carrier and Rel-99+HSPA on the second carrier. In this case, however, it is recommended to leave R99 PS data services on F1 to avoid code resource exhaustion on F2. This allows for flexibility to handle additional voice users in the second carrier when the voice capacity of the first carrier is not enough. The Rel-99+HSPA configuration on the second carrier is also needed to handle multiple RAB applications, where a single user can have both CS voice and HS data services active at the same time.

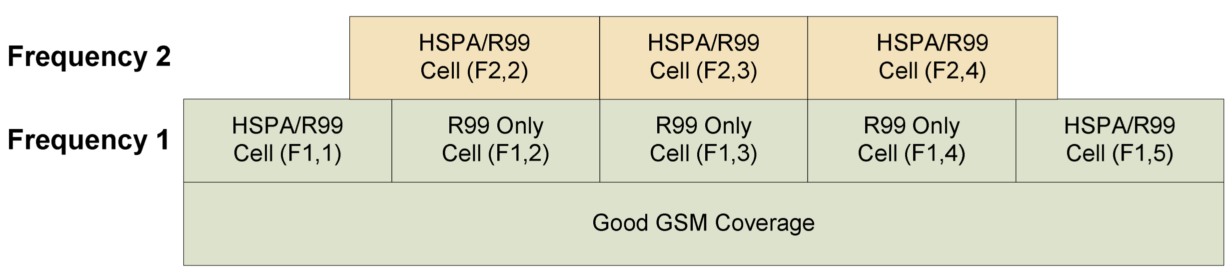

Figure 5: HSPA+R99 CS Overlaid on R99

2.3.3 HSPA (F2) overlaid on HSPA + R99 (F1)

For regions with significant data penetration, the configuration Rel-99+HSPA on the first carrier and HSPA only on the second carrier can be used (Figure 6). As wireless data traffic increases in the coming years [1], we may see more of such configurations being deployed.

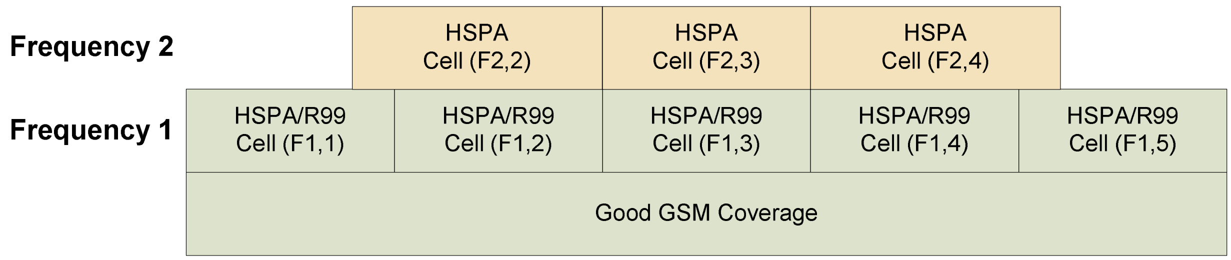

Figure 6: HSPA overlaid on HSPA PS+R99 CS

Since CS voice and high speed PS data services have different characteristics, the load variation on carriers carrying voice and carriers carrying data is also different and load balancing between HSPA and Rel-99 carriers through parameter settings become less significant (still load control is required though). Hence, in this document, whenever traffic separation is deployed, the inter-frequency cell reselection and handover parameter settings mostly focus on mobility management.

2.4 Multiple Band Support

Besides the multi-frequency deployment strategies discussed in the previous sections, some operators also face the issue of providing wireless services over multiple frequency bands. The reason of having a multiple band network could be simply due to the result of industry consolidation, or could be due to the operator's desire to extend 3G services with larger cell coverage in rural areas or better building penetration. Recent developments in UMTS standards allow operators to deploy WCDMA in 900MHz band. Comparing with the 2100MHz frequency band that is currently used by many UMTS operators, the 900MHz system has larger cell radius and higher building penetration.

For multiple band deployments, the emphasis is normally at coverage continuity, instead of load balancing because propagation characteristics at different bands are different. Given the cell coverage difference between frequency bands, the hierarchy deployment can be considered. Then, the emphasis of managing such a network becomes how to effectively balance mobility and capacity, instead of simply focusing in load balancing.

From the inter-frequency cell reselection and handover point of view, there will be a challenge. This configuration, not only requires parameter settings to satisfy mobility and capacity management at the same time, but also requires adequate configuration to avoid ping-pong cell reselections and handovers due to asymmetric RF behaviors between the frequency bands. Fortunately, the standard provides some signaling support in addition to the conventional handover and cell reselection mechanisms, which is intended for managing HCS systems and which needs to be fine tuned during the network optimization.

Details covering idle mode and connection mode operation in multi-band deployments are covered in Section 6.

2.5 General observations and assumptions

In practice, the multi-carrier deployment is not necessary only one of the typical scenarios listed above. Instead, it is often a combination of the above three types of deployments strategies. Even for a typical scenario, there can be many different variations. For instance, instead of separating carriers based on traffic type, one can also chose to distribute users among the carriers based on their UE capabilities, or based on agreed data rates etc. All these variations in scenarios add even more complexity in the network deployment and bring challenges in system optimization, in particular, with regards inter-frequency cell reselection and handover operation.

When configuring the inter-frequency cell reselection and handover parameters, depending on the implementation of infrastructure vendors, some parameters can be configured on a per cell basis, while other parameters can only be changed on the per node-B basis or per-RNC basis. In the inter-frequency cell reselection and handover examples discussed in the following sections, it is assumed that the parameters can be configured in a per-cell basis. Cautious adjustments are needed in real network applications when the parameters can only be configured on per- node B or per-RNC basis.

This document, in general, does not include HCS related parameter recommendations. In particular, the setting of $S_{searchHCS}$ is not covered in the current revision of the paper, but it will be included in future revisions since $S_{searchHCS}$ can be used in Rel 5 UEs regardless of HCS usage and also can be used in R99 UEs in case HCS is configured to "be used", though no other HCS specific settings as priority levels, UE speed Parameters, etc. are configured.

Release 5 Treselection scaling factor for inter-frequency operation is also not considered in this version of this document.

3 Hot Spot Overlay Deployment Scenario

3.1 Hot spot deployment without traffic separation

In this approach, operators selectively add a second carrier at hot spots where the capacity increase is most needed (Figure 2). As the traffic in the network increases, the second carrier coverage is then expanded gradually; possible up to a fully-overlapped network as described in Section 4.

The challenge of such a hot spot deployment is the complexity of network planning. Since the second carrier cell surrounding environment is different from that of the first carrier, the RF characteristics at the two layers are different. Correspondingly, the coverage on the two layers will be different. Load balancing is needed to reduce the call blocking probability because the traffic will not be evenly distributed between carriers partially due to the unbalanced cell coverage. At the same time, mobility management and inter-frequency handover are required to maintain the service continuity as the UE moves into or out-of the second carrier coverage.

Hence, both inter-frequency cell reselection and inter-frequency handover will be needed for the users to maintain the continuous connection within the network. Comparing with the one-to-one overlay scheme (described in Section 4), the parameter setting will focus more on mobility management. Balancing the load, in general, will be a secondary goal in most of the cases.

3.1.1 Inter-Frequency Cell Reselection in hot spot overlay deployment

Consider the deployment of a second carrier in hot spot areas as shown in Figure 7. Such a kind of deployment is mainly for the purpose of increasing the capacity to support the high traffic volume in the hot spot area. The coverage provided by the network at Frequency 1 is assumed to be sufficiently good. Hence, the setting of the inter-frequency cell reselection parameters will be focused on dealing with increased capacity in the hot spot areas and maintaining the service continuation as the UE moves out of the hot spot areas.

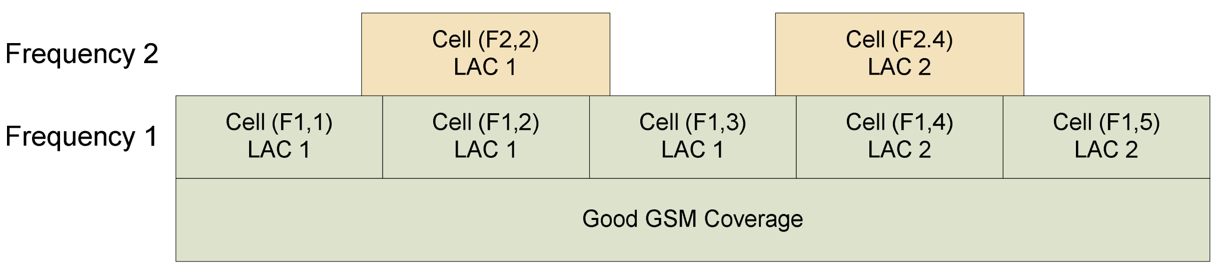

Figure 7: Hot spot deployment case

An example of inter-frequency cell reselection parameter setting is given in Table 1

Table 1: Parameter setting for hot spot deployment case

	Frequency 1	**Frequency 2**
FDD-quality-measure	RSCP or E_c/N_o	RSCP or E_c/N_o
$S_{intrasearch}$	12 dB	12 dB
$S_{intersearch}$	8 dB	6 dB
$S_{searchRAT}$	4 dB	4 dB
Q_{hyst1}	2 dB	2 dB
Q_{hyst2}	2 dB	2 dB
$T_{reselection}$	1 second	1 second

Neighbor List	Include Frequency 2 cells	Include Frequency 1 cells
$Q_{offset1,s,n}$	3 dB	1 dB
$Q_{offset2,s,n}$	3 dB	1 dB

In the example in Table 1, $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$ are set to 3 dB on Frequency 1 to provide the needed hysteresis. On Frequency 2, $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$ are set relative smaller compared with the setting on Frequency 1. The smaller setting is due to the fact that Frequency 2 coverage is not continuous. A UE camped on Frequency 2 needs to be switched to Frequency 1 as it moves out of the Frequency 2 coverage area. Setting the offsets smaller allows faster Frequency 2 to Frequency 1 cell reselection in order to maintain the service continuity.

Notice the value of $S_{intersearch}$ is higher on Frequency 1 comparing with Frequency 2. Thus, for Frequency 1, the inter-frequency cell reselection takes place early, which can result in more frequent inter-frequency cell switches into Frequency 2. The objective is to shift the idle UEs (hence the potential traffic loads) to Frequency 2 in the hot spot area whenever the signal quality on Frequency 2 is sufficiently good. On the other direction, the UE will not be moved to Frequency 1 unless it reaches the cell edge. Since the purpose of shifting UE from F2 to F1 to balancing the load, $S_{intersearch}$ is configured lower to avoid frequent switches as well as maintaining adequate loads on Frequency 2.

As mentioned in Appendix 7Appendix A, inter-frequency measurement bears extra cost compared with the intra-frequency measurement[2]. In particular, the UE takes longer time (and consumes more power) to search for inter-frequency cells than to search for intra-frequency cells. Hence, frequent search for inter-frequency cells should be avoided to preserve the UE battery life. Therefore, $S_{intersearch}$ should not be set too high, at least not higher than $S_{intrasearch}$ as illustrated in the example in Table 1. The operator has to make a tradeoff between achieving better signal quality (hence better system efficiency and performance) and better UE battery life.

In this example, both values of FDD-quality-measure are suggested. The discussion comparing RSCP vs EcNo in Section 7A.4 with the pros and cons of selecting each type of measurement is applicable here.

3.1.2 Inter-Frequency Handover (IFHO) in hot spot overlay deployment

Consider again the deployment of a second carrier in hot spot areas as shown in Figure 7. Since the coverage provided by Frequency 2 is not continuous, the inter-frequency handover is needed for maintaining the service continuity in the Cell_DCH state. In addition, the inter-frequency handover may also be used with a secondary goal of balancing the load between the two frequencies.

As mentioned in the appendix Section 7B.6, call redirection during cell setup or after soft handover can also help balancing the load between frequencies. Depending on the implementation of the infrastructure vendor, this call redirection feature may or may not be available to the network operator. If call redirection can be used, the inter-frequency handover parameter setting for load balancing can be more or less relaxed. If call redirection is not available, however, the inter-frequency handover parameter setting needs to be fine tuned in order to adequately support load balancing.

In the following, we will consider the following 3 different scenarios of inter-frequency handover parameter setting.

- Inter-frequency handover for the coverage purpose only (i.e., provide call continuity only)
- Inter-frequency handover for coverage and load balancing without call redirection
- Inter-frequency handover for coverage and load balancing with call redirection

3.1.2.1 IFHO for Coverage

Table 2 shows the example of inter-frequency handover parameter settings for maintaining service continuity as the UE moves out of the Frequency 2 coverage area (in Cell (F2, 2) or Cell (F2, 4)). The RSCP based measurement is used in the example (as explained in the appendix Section B.3.1). Here, we assume that inter-frequency handover from Frequency 1 to Frequency 2 is not needed since both frequencies are providing the same services[3] and the

[2] Depending on the hardware implementation, the extra cost can be different for different vendors.

[3] The discussion for the case in which different services are provided by different frequencies will be given in the next subsection.

operator chooses not to use inter-frequency handover to balance the load between carriers[4]. Hence, only one-way handover (from Frequency 2 to Frequency 1) needs to be configured. Such a configuration is stable since the ping-pong behavior is avoided.

Table 2: Inter-frequency handover parameter setting for coverage in hot-spot area (RSCP)

	Frequency 1	Frequency 2
Event 2d	Not configured	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Not configured	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Not configured	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Not configured	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2a	Not configured	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2b	Not configured	Threshold Used: -96 dBm Threshold non-Used: -98 dBm FC: 3 W: 1.0 TTT: 0 ms

In Table 2, the Event 2d and Event 2f triggering thresholds are set to -100dBm and -96dBm, respectively. These thresholds are configured to maximize the coverage (hence the utilization) of Frequency 2. The hysteresis is set to 4 dB given the relative large randomness of RSCP measurements[5].

Since the inter-frequency handover is only configured from Frequency 2 to Frequency 1, the setting of the handover triggering thresholds for Event 2a and/or Event 2b can be relaxed. The hysteresis for Event 2a is set to 4 dB, so the report will be generated when the RSCP measurement on Frequency 1 is 2 dB higher than that on Frequency 2. The thresholds for Event 2b are set to -96dBm for the used frequency and -98dBm for the non-used frequency. The strategy here should be to let the UE handover to Frequency 1 as long as the RSCP measurement on Frequency 1 is good enough (such as higher than -98dBm). Hence, the used frequency threshold should be set high enough, such as -96 dBm or higher, so the condition on the used frequency can be easily satisfied.

In the example here, both Event 2a and Event 2b are listed for triggering the inter-frequency handover. However, the handover behavior based on Event 2a and Event 2b are different. Event 2a is triggered based on the relative measurement difference, and an inter-frequency handover can only when the target frequency is better than the serving frequency. For instance, Event 2a will not trigger handover when the used frequency RSCP is -96.5dBm

[4] Instead, the operator may simply rely on call redirection and cell reselection to achieve the load balancing goal.

[5] Proper filter coefficient tuning is needed to remove the noise in the RSCP measurement.

and the non-used frequency RSCP is -97.5dBm. To certain extend, Event 2a prolongs the usage of the serving frequency by delaying the handover only to the point when the target frequency is clearly better than the serving frequency as illustrated in Figure 8. This approach, however, may increase the probability of handover failures.

On the other hand, the inter-frequency handover will occur if Event 2b is used as the trigger. With Event 2b, the target frequency quality (RSCP) is guaranteed so that the handover failures can be contained. In the example, the handover is triggered since the target frequency has RSCP higher than -98dBm, even though the serving frequency RSCP is still relatively good as illustrated in Figure 8. When configuring Event 2b thresholds, it is important to have the threshold for the used frequency higher than the threshold for the non-used frequency. Setting the threshold otherwise can delay the handover and resulting in increased handover failure rate.

To promote fast and reliable handover, we suggest setting the threshold for the used frequency high enough so that condition on the used frequency is always satisfied. Then, as long as the target frequency RSCP is above the non-used frequency threshold, the handover will be triggered immediately. This approach may result in reduced coverage on the serving frequency since the serving frequency RSCP may still be good at the time of handover. To alleviate this, the compressed mode triggering (Event 2d and/or Event 1f) thresholds should be set low so that the inter-frequency measurement (and hence handover) will only occur when the serving frequency is getting deteriorated[6].

Since the goal of inter-frequency handover here is to maintain the coverage and service continuity, we recommend Event 2b over Event 2a as the handover trigger for the more reliable handover.

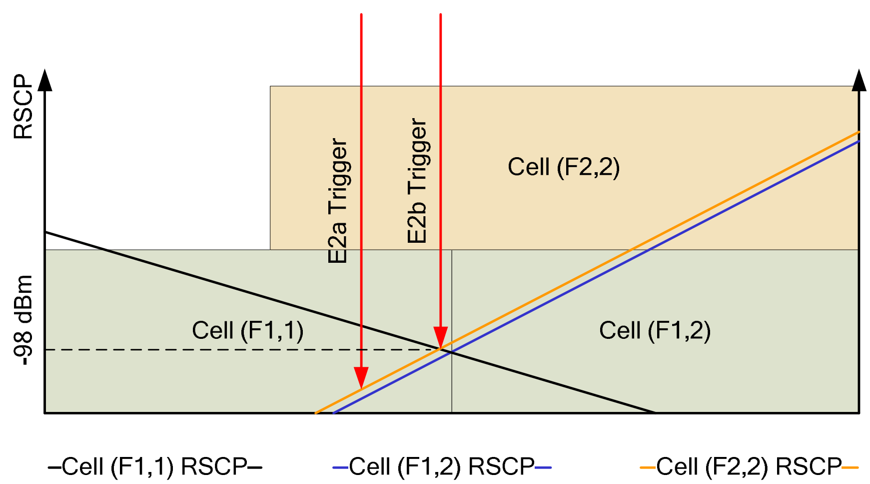

Figure 8: Event 2a and Event 2b reports in hot-spot coverage scenario as the UE moves left towards Cell (F1,1)

Although the operator may also consider configuring compressed mode activation and inter-frequency handover based on the E_c/N_o based measurement, we, in general, recommend RSCP based configuration as the primary mechanism unless special circumstances call for it. Since the E_c/N_o based measurement reflects the load of the cell, the inter-frequency handover region can be largely affected by the load differences between the two carriers. From the handover neighbor cell list management perspective, using the RSCP based handover can simplifies the neighbor cell list optimization since the handover region (hence neighbors) is not changed as the loads of the cells change.

As explained in Section 7B.4.2, in real networks, however, the operator can still choose to configure both RSCP and E_c/N_o based handover to improve the handover reliability in various circumstances.

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[6] Hence, taking values of Event 2d and Event 1f into account, assuming stable RF environment at the time Event 2d (or Event 1f) is triggered, both Event 2b and Event 2a will happen resulting in inter-frequency handover. That is, if the Event 2d (Event 1f) value is considered in Figure 8, both Event 2a and Event 2b will occur at the same place when Event 2d (Event 1f) is triggered. This, in fact, is the intention of the parameter design.

3.1.2.2 IFHO for Coverage and Load balancing (without Call Redirection support)

The setting of the inter-frequency handover parameters becomes tricky when the load balancing is considered and call redirection is not enabled in the network. Here the handover goes in both directions and potentially ping-pong handover can occur with improper configurations. Again, here we assume the coverage provided by F1 is sufficiently good and the same type of traffic is carried on both frequencies. A general approach in this case is to configure the F2 to F1 handover to provide call continuity as the UE moves out of the F2 coverage, and configure the F1 to F2 handover to shift loads from F1 to F2 when the UE enters the F2 coverage.

Table 3 shows an example of inter-frequency handover parameter setting. The configuration for F2 to F1 handover is the same as in the previous section (for the coverage only case). The configuration for F1 to F2 handover is similar to the setting in Section 4.1.2 for load balancing in the one-to-one overlaying carrier situation. The inter-frequency handover is based on the E_c/N_o measurement instead of RSCP because RSCP measure based handover is not effective for load balancing.

Notice in Table 3 that Event 2d and Event 2f thresholds for F2 are offset by 2 dB with respect to the thresholds for F1. This offset serves two purposes: 1) to initiate early handover from F1 to F2 for a better load balancing performance and 2) to prevent early F2 to F1 handover. The example settings for triggering handover via E2A and E2B are also given in the table. For E2A, the ping-pong handover can be prevented by configuring the right amount of hysteresis. For E2B, the ping-pong handover is prevented by the threshold difference. Specifically, at F1, the non-used frequency threshold is set to -8 dB, while at F2, the non-used frequency threshold is set to -10 dB[7]

Table 3: Inter-frequency handover parameter setting for coverage in hot-spot area (E_c/N_o)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -11 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -7 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 2a	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2b	Threshold used: -8 dB Threshold non-used: -8 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -10 dB Threshold non-used: -10 dB FC: 3 W: 1.0 TTT: 0 ms

In theory, it is possible to configure F2 to F1 handover based on the RSCP measurement and configure the F1 to F2 handover based on the E_c/N_o measurement since RSCP measurement reflects the path loss while the E_c/N_o measurement reflects the system load. However, cautious should be taken to avoid potential ping-pong handover since the two types of measurements are often not aligned.

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[7] Unfortunately, this setting has the drawback that can affect the system performance as well as call performance. As soon as the UE completes the F2 to F1 handover, a CM can be activated due to the higher triggering threshold. It affects system downlink power consumption (hence the capacity) and the BLER of the call (hence the call performance). It is possible that infrastructure vendors can provide some controls to prevent immediate CM activation after inter-frequency handover so that the impact on the system capacity and call performance is limited. In any case, the setting here has to be fine tuned by the operator for the desired result.

An example of ping-pong handover due to the mismatch of RSCP and E_c/N_o measurements is shown in Figure 9, where the F1 to F2 handover (for load balancing) is based on the E_c/N_o measurement and F2 to F1 handover (for call continuity) is based on the RSCP measurement. Assume that a UE originally in Cell (F1,1) moves right towards Cell (F1,2). Approaching the boundary of Cell (F1,1) and Cell (F1,2), the UE sees good E_c/N_o from Cell (F2,2) and performs the F1 to F2 handover. However, immediately after the handover, the UE obtains bad RSCP measurements in Cell (F2,2) and sees good RSCP in Cell (F1,1). This triggers the UE to perform another handover from F2 back to F1, resulting in a ping-pong handover. Through proper parameter setting, such a ping-pong handover can be avoided. For instance, configuring the F1 to F2 handover only when Cell (F1,2) becomes the dominant cell in the active set based on the Event 1d report.

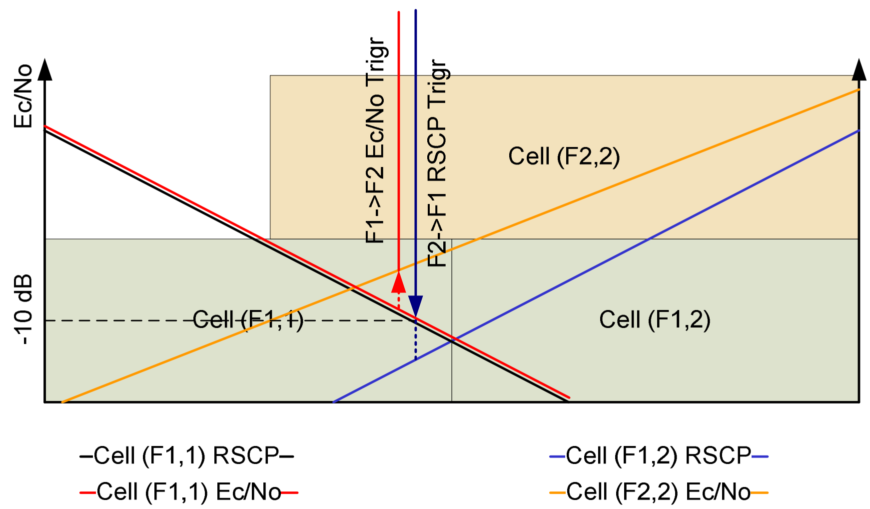

Figure 9: Ping-pong handover due to mismatch of RSCP and Ec/No measures

In addition to the inter-frequency handover, the inter-frequency cell reselection should also be configured properly. In particular, the cell reselection should also be configured taking load balancing into account. Since call redirection is not implemented, the operator may configure the cell reselection so that more UEs will select F2 instead of F1. As a result, more UEs will setup calls on F2, which increases the load on F2. Again ping-pong behavior should be avoided and this can be minimized by making the handover boundary align with the cell reselection boundary.

3.1.2.3 IFHO for Coverage and Load balancing (with Call Redirection support)

When the network supports call redirection at call setup or after soft handover for load balancing, most of the load balancing goal can be achieved by properly configuring the call redirection function[8]. Hence, the requirement on inter-frequency handover to perform the load balancing can be relaxed. The inter-frequency handover can be configured to mainly handle the mobility (i.e., the service continuity).

Table 4 shows an example of inter-frequency handover parameter setting. Comparing with the settings given in Table 3, the thresholds for E2d and E2f are lowered on F1. This reduces load balance effectiveness of inter-frequency handover. However, this loss is compensated by the call redirection function. With the lower thresholds, the impact of CM on system capacity is reduced, which results in overall system performance improvement.

Table 4: Inter-frequency handover parameter setting for coverage in hot-spot area (E_c/N_o)

	Frequency 1	Frequency 2
Event 2d	Threshold: -11 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -11 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms

[8] The call redirection function is infrastructure vendor proprietary and the configuration will be different for different vendors.

Event 2f	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 2a	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2b	Threshold used: -8 dB Threshold non-used: -8dB FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -10 dB Threshold non-used: -10 dB FC: 3 W: 1.0 TTT: 0 ms

Since the load balancing can be realized by proper call redirection, IFHO based load balancing may not be necessary and the RSCP based handover configuration can also be used here. Also, the operator can choose to configure both RSCP and E_c/N_o based handover to further improve the handover reliability as pointed out in Section 7B.4.

3.2 Hot spot deployment with traffic separation

When upgrading the network to support HSPA, it can be convenient deploying HSPA capability on the second carrier while keeping the first carrier for Rel-99 traffic only (Figure 4). As voice traffic load in the primary carrier grows a better configuration would be HSPA+R99 CS over R99 (Figure 5), but if data traffic penetration increases at a faster speed, then HSPA over HSPA+R99 (Figure 6) could be a suitable combination before VoIP is massively deployed and HSPA only over HSPA only becomes the most common scenario. Since, at the time of writing of this document, most multi-carrier WCDMA deployments are at the early stage, we will only focus on the first scenario. The traffic carried on the two carriers, in this case, will be different, and this difference should be reflected in the proper setting of inter-frequency cell reselection and inter-frequency handover parameters.

3.2.1 Inter-Frequency Cell Reselection for Hot spot deployments with Traffic Separation

When the second carrier is deployed as a HSPA dedicated carrier (see Figure 10), there are two possible approaches to distribute idle UEs among the two carriers: 1) Inter-Carrier Balancing of Idle UEs and 2) All Idle mode UEs camped on the primary carrier

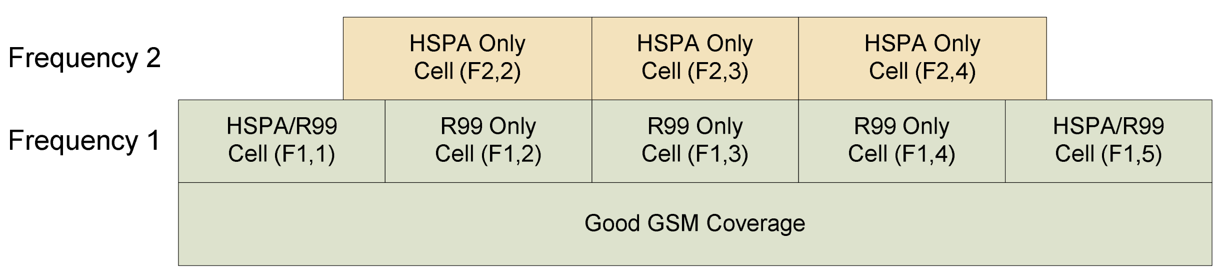

Figure 10: HSPA PS Overlaid on R99 CS

While these two approaches for Idle UE distributions are also possible in multi-carrier deployments without traffic separations, in the case of traffic separation with HSPA overlaid on R99, the second approach is of special interest since it may allow improved power utilization on the HSPA only carrier.

3.2.1.1 Inter-carrier balancing of Idle UEs

For a given WCDMA cell, the paging channel capacity is determined by the capacity of the SCCPCH(s) on the cell, which, in turn, depends on the system configuration on the cell, such as number of SCCPCHs and their corresponding data rates. When the SCCPCH capacity on the cell is reached, paging messages can be dropped or delayed resulting in a call access failure. Note that SCCPCH overloading probability is highly correlated with the number of idle UEs camped in a single location area.

Similarly, when the random access channel (RACH) is congested, access attempts of UEs may collide leading to call setup delays or failures. The loading on both PCH/FACH and RACH is highly correlated with the number of idle UEs camped on a cell/frequency. To reduce the overloading probability, the operator should avoid having too many idle UEs camped in a single location area or a single cell.

So, by distributing the Idle UEs across multiple frequencies and LACs, the call setup failure rates can potentially be reduced. The possible Cell reselection configurations for this approach are similar to the ones presented for the One-on-one overlay deployment in Section 4.1.1.

The advantage of balancing Idle UEs among the serving carrier is that the load on the paging and random access channels can be distributed and hence avoid SCCPCH congestion. The disadvantage is that at least one SCCPCH is setup in each carrier possibly not using efficiently power resources in the overlaid carriers.

Also HSPA data calls originated in F1 need to be redirected to F2 and voice calls originated in F2 need to be redirected to F1.

3.2.1.2 All Idle UEs camped on the primary carrier

With this approach the goal is to have the UEs camped on only the primary carrier. When the UEs initiate a call, they can either be serviced on the primary frequency itself or redirected to the secondary frequency. In this way the network can be configured for no SCCPCH transmission on Frequency 2 and all the paging, FACH and RACH operations are carried only in Frequency 1. The power saved on the SCCPCH of the second carrier can be applied to HSDPA to further improve system capacity.

The trade-off would be, in idle mode, the decreased overall WCDMA coverage due to higher probability to reselect GSM from Frequency 1. Not supporting paging, FACH and RACH operations on Frequency 2 can also impact the call access performance in some cases when the UE happens to camp on Frequency 2, e.g. as the result of initial cell selection or due to some temporary WCDMA degradation of Frequency 1 (if GSM is not reselected first) or due to call drops or call releases on Frequency 2[9], the UE will not be able to get any services. Hence, the operator should make sure proper inter-frequency cell reselection configuration is installed; similar to the one provided in Section 4.2.1 for the One-on-one deployments.

Call Redirection functionality is also required with this approach for deploying the second carrier as HSPA carrier. In a typical scenario at the initial call setup, the UTRAN assigns the UE a Rel-99 DCH on Frequency 1 using *RRC Connection Setup* message and as the network detects the UE supports HSPA, it redirects it to Frequency 2 and moves the UE traffic from DCH to HS-DSCH. More details are given in Section B.6.

3.2.2 Inter-Frequency Handover (IFHO) for Hot spot deployments with Traffic Separation

Here, we consider the hot spot deployment as depicted in Figure 10. Differently from the deployment scenarios described in Section 3.1.2 without traffic separation, the cells on Frequency 2 are dedicated to HSPA for packet data traffic. With such a deployment, the strategy of traffic separation is to push packet data traffic to F2 whenever there is sufficient coverage to utilize the high efficiency of HSPA and the UE is capable of HSPA. At the same time, the inter-frequency handover will be responsible for maintaining the service continuity when the UE moves out of the F2 coverage.

We assume that the inter-frequency cell reselection is configured to have all the idle UEs on Frequency 1 as described in Section 3.2.1.2. Hence, all the calls are originated from Frequency 1 and only PS data calls of HSPA capable UEs are handed over (or redirected) to Frequency 2.

Same as we have seen in Section 3.1.2, the inter-frequency handover parameter configuration depends on whether or not call redirection is supported by the infrastructure vendor. Two configuration examples are discussed in the following subsections. Section 3.2.2.1 provides a configuration example when there is no call redirection support, while Section 3.2.2.2 illustrates a configuration example with the support of call redirection.

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[9] When a call is dropped or released on Frequency 2, it will come back on Frequency 2 first during the system acquisition after the call drop or call release.

3.2.2.1 IFHO for Traffic Separation without Call Redirection

For a traffic separation deployment, E2A based handover trigger will not be appropriate. Instead, E2B or E2C should be the handover trigger. With E2A, the target frequency has to be stronger than the used frequency, which does not fit the objective of pushing HSPA packet data traffic to F2.

An example of inter-frequency handover parameter setting is given in Table 5. Notice that the handover parameters are only configured for packet data calls on Frequency 1 since voice calls on F1 will not be moved to F2. For E2D, E2F (similarly E1F, E1E) the effective triggering thresholds are set to -13 dB and -8 dB respectively on Frequency 2. The reason for such a setting is the handover from F2 to F1 should only occur when the UE is moving out of the F2 coverage. Hence, there is no need to trigger the compressed mode for inter-frequency search early. Correspondingly, the handover can be triggered via E2B. For E2B, the used frequency threshold is set to -12 dB while the target frequency threshold is set to -10 dB. Such a setting emphasizes the philosophy that F2 to F1 handover should not occur when the source frequency is still strong enough to provide the data service. The setting also takes into account that PS data calls are more tolerant to handover failures.

Table 5: Inter-frequency Handover Parameter Setting for Deploying HSPA Hot Spots (E_c/N_o)

	Frequency 1 (PS of Rel5/6 UEs Only)	**Frequency 2**
Event 2d	Threshold: -7 dB Hysteresis: 2dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -12 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold:-5 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -5 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -7 dB Hysteresis: 2dB FC: 3 TTT: 320 ms	Threshold: -12 dB Hysteresis: 2 dB FC: 3 TTT: 320 ms
Event 2b	Threshold Used: 0 dB Threshold non-used: -10 dB FC:3 W: 1.0 TTT: 0 ms	Threshold Used: -12 dB Threshold non-used: -10 dB FC:3 W: 1.0 TTT: 0 ms

On Frequency 1, the effective triggering thresholds for E2D and E2F (similarly E1F, E1E) are set to -8 dB and -4 dB, respectively. With such a setting the compressed mode will be triggered almost immediately when a call enters F1. The reason for such as aggressive setting is to move packet data to F2 as early as possible[10]. In particular, a UE that sees a strong RF on F1 often sees a strong RF on the vertical neighbor on F2. Hence by moving it to F2, the UE can greatly enjoy the high efficiency of HSPA.

This aggressive setting, however, can cause frequent activation of the compressed mode and impact the system capacity and the overall call performance as we have discussed in earlier deployment scenarios. Hence, the operator has to find tune the parameter to balance the aggressiveness (hence gain on F2) and the loss of capacity on F1. Some infrastructure vendors may also offer features for controlling the compressed mode activation such as

[10] Of course, the UE has to be HSPA capable first.

activating compressed mode only in cells that have vertical neighbors on F2, or limiting the number of simultaneous compressed mode activations in a cell, or limiting the duration and frequency of compressed mode activation, or prohibiting UE going into compressed mode immediately after it is handed over from F2, or allowing compressed mode activation only after the initial call setup. With these network features available, the operator can be even more aggressive in setting the handover parameters on F1. In such as case, for instance, the effective triggering thresholds for E2D and E2F are -3dB and 0 dB, respectively.

Another impact of such a parameter configuration is the potential ping-pong behavior. Since the setting on F1 is more aggressive compared with the setting on F2, it is possible that the UE enters the compressed mode immediately after the handover from F2 to F1. Another handover can be triggered if the condition is satisfied. To minimize such ping-pong events, the operator, again, needs to fine tune the parameters balancing the ping-pong impact and the capacity gain on F2. For instance, in Table 5, the E2B "threshold non-used" for F1 to F2 handover is set to -10 dB, 2 dB higher than the used-frequency threshold set on Frequency 2. This 2 dB hysteresis prevents the frequent ping-pong handovers at the expense of delaying the packet data call handover from F1 to F2. Again, the features provided by the infrastructure vendors, such as preventing immediate CM activation after F2 to F1 handover, can also help reducing the ping-pong behavior.

The RSCP based inter-frequency handover can also be configured for such a deployment scenario. An example is given in Table 6 and the principle behind such a configuration is the same as we have seen in Table 5.

Also, the operator can choose to configure both RSCP and E_c/N_o based handover, especially on Frequency 2, for improving handover reliability.

Table 6: Inter-frequency Handover Parameter Setting for Deploying HSPA Hot Spots (RSCP)

	Frequency 1 (PS of Rel5/6 UEs Only)	**Frequency 2**
Event 2d	Threshold: -60 dBm Hysteresis: 4dB FC: 3 W: 0 TTT: 320 ms	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 320 ms
Event 2f	Threshold:-56 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 640 ms	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 640 ms
Event 1e	Threshold: -56 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -60 dBm Hysteresis: 4dB FC: 3 TTT: 320 ms	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2b	Threshold Used: -58 dBm Threshold non-used: -95 dBm FC: 3 W: 0 TTT: 0 ms	Threshold Used: -102 dBm Threshold non-used: -98 dBm FC: 3 W: 0 TTT: 0 ms

3.2.2.2 IFHO for Traffic Separation with Call Redirection

When call redirection is supported at the call setup or after handovers, the inter-frequency handover configuration can be simplified since the objective of the inter-frequency handover, pushing packet data to F2 for better efficiency can be handled by the call redirection function. As a result, the inter-frequency handover will only be responsible for maintaining the mobility management and service continuity.

Keeping in mind that we still want to keep the packet data on F2 whenever there is sufficient coverage on the frequency, we configure the inter-frequency handover as in Table 7. Here, RSCP based measurement is considered. The same principle behind this configuration can also be applied to the E_c/N_o based configuration. And again, the operator may choose to configure both for improving handover reliability.

Table 7 Inter-frequency Handover Parameter Setting for Deploying HSPA Hot Spots (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Not configured	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 320 ms
Event 2f	Not configured	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 640 ms
Event 1e	Not configured	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Not configured	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2b	Not configured	Threshold Used: -102 dBm Threshold non-used: -98 dBm FC: 3 W: 0 TTT: 0 ms

3.2.2.3 IFHO for Voice Traffic Spill Over

Consider again the deployment scenario depicted in Figure 5 (copied here as Figure 11) where the Release 99 traffic is also supported on the second carrier. This scenario is necessary when the capacity on Frequency 1 is not sufficient to support the large amount of voice (and Release 99 PS) traffic, for instance, during busy hours. As the traffic volume on Frequency 1 increases, the operator can move some Release 99 traffic to Frequency 2, provided there is resources there.

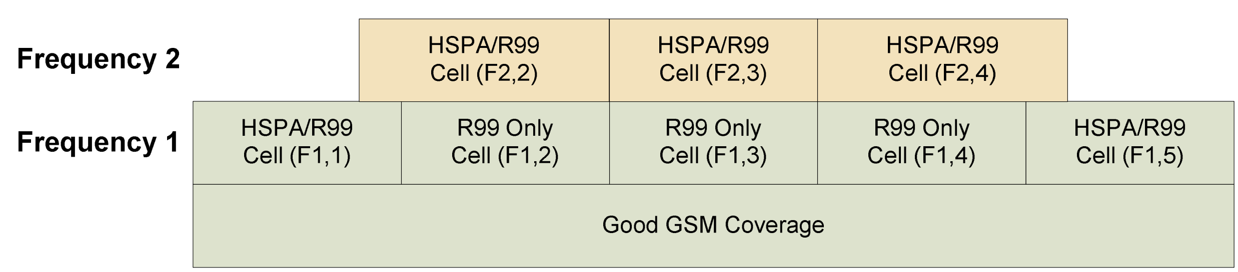

Figure 11: HSPA+R99 CS Overlaid on R99

Depending on the infrastructure implementation, there could be different ways of shedding traffic from Frequency 1 to Frequency 2, and the operator may utilize one or more approaches at the same time depending on the network operating criteria, traffic behavior, and cost consideration, etc.

One simple approach, for example, is to redirect all the new Release 99 calls to Frequency 2 at the call setup when the traffic load on Frequency 1 reaches a certain threshold. An example of the call flow for call redirection during call setup is given below in Figure 12. After the initial RRC connection setup, the network instructs the UE to start compressed mode for inter-frequency measurement and performs the inter-frequency handover when the signal quality strength on Frequency 2 is sufficiently good. Otherwise, the call setup proceeds on Frequency 1. The recommended thresholds for Event 2b reporting is given in Table 8 and Table 9.

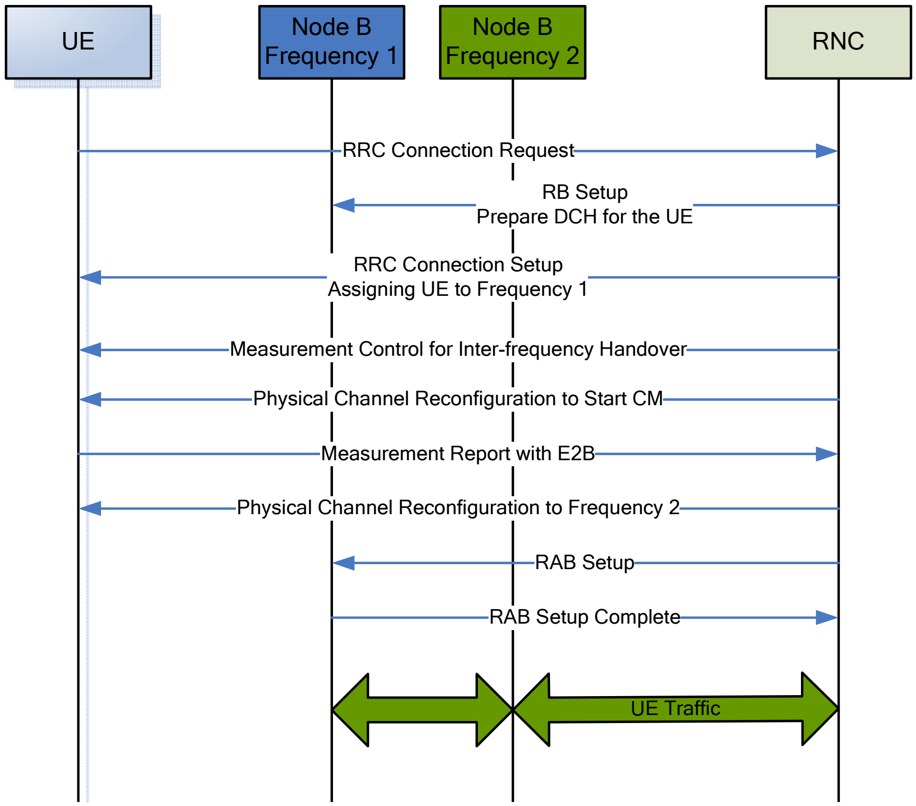

Figure 12 Release 99 Call Redirection at the Call Setup

Table 8 Thresholds for Call Redirection and Handover (E_c/N_o)

	Frequency 1	**Frequency 2**
Event 2d	Not configured	Threshold: -12 dBm Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Not configured	Threshold: -9 dBm Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Not configured	Threshold: -9 dBm Hysteresis: 2 dB FC: 3 TTT: 640 ms
Event 1f	Not configured	Threshold: -12 dBm Hysteresis: 2 dB FC: 3

		TTT: 320 ms
Event 2b	Threshold Used: 0 dBm Threshold not-used: -10 dBm FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -12 dBm Threshold not-used: -10 dBm FC: 3 W: 1.0 TTT: 0 ms

Table 9 Thresholds for Call Redirection and Handover (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Not configured	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 320 ms
Event 2f	Not configured	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 W: 0 TTT: 640 ms
Event 1e	Not configured	Threshold: -98 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Not configured	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2b	Threshold Used: -50 dBm Threshold not-used: -98 dBm FC: 3 W: 0 TTT: 0 ms	Threshold Used: -102 dBm Threshold non-used: -98 dBm FC: 3 W: 0 TTT: 0 ms

When the UE moves out of the Frequency 2 coverage, inter-frequency handover is performed for maintaining the call continuity and the same handover parameters in Section 3.2.2.2 can be applied here. For easy comparison, these handover parameters are also included in Table 8 and Table 9. To prevent potential ping-pong behavior, the triggering threshold for Event 2b for call redirection needs to be set higher than the triggering threshold for Event 2b for handover on Frequency 2. As shown in Table 8 and Table 9, 2dB and 4dB thresholds are given in for E_c/N_o and RSCP based triggers, respectively.

Besides call redirection at the call setup, the network can also move Release 99 traffic to Frequency 2 during the call. For instance, the network can start moving Release 99 UEs to Frequency 2 when it sees significant uplink interference causing random access channel failures. In such a case, the network can activate compressed mode for individual UEs to measure Frequency 2 signals and inter-frequency handover can occur upon Event 2b reports.

To limit the impact of compressed mode on the capacity on Frequency 1, the operator needs to pay attention on how often the compressed mode is activated for individual users and how many simultaneous compressed mode activations in the system. To many compressed mode activations will have negative impact on system capacity.

4 One-on-One overlay deployment scenario

4.1 One-on-One overlay deployment without traffic separation

In this deployment, the second carrier is deployed covering the entire network in a one-to-one cell overlay scheme. The main advantage of this deployment scheme is its simplicity. If the second carrier is in the same frequency band, there is little need for network planning of the second carrier. The network operation can also be made simpler by disabling the inter-frequency handover and inter-frequency cell reselection at the price of relatively lower system capacity. Given the fact the coverage is almost the same between the two carriers, there is no need to perform inter-frequency handover or cell reselection for the purpose of maintaining the coverage continuity. For load sharing (or load balancing), the operator can rely on uniformly distributed users between the two carriers and hope the traffic load will be balanced on the two carriers (at least statistically)[11]. Or, more proactively, the operator can further rely on redirection at the call setup to further balance load[12].

The main drawback of this type of deployment is, of course, the initial cost of such a deployment. The operator needs to commit a significant initial investment for the hardware of the additional second carrier. At least, downlink maximum transmit power is doubled for each cell in the network, which is often the biggest part of the investment given the high cost of power amplifiers. For the remaining of network elements, depending on the infrastructure implementation, the operator may have some flexibility to scale the investment based on the traffic distribution within the network. For instance, for low traffic volume cells (areas), the operator may be able configure the existing backhaul to support both carriers, hence avoiding the cost of adding backhaul bandwidth. Similar dimensioning may also be possible for the number of channel elements (or channel cards) within each node-B.

When inter-frequency cell reselection and inter-frequency handover are indeed enabled in this scenario, the focus is more on capacity management instead of mobility management. That is, the objective of inter-frequency cell reselection and handover is to maintain the same amount of traffic between carriers instead of increasing the coverage of the network, although the coverage is often improved due to balanced load.

4.1.1 Inter-Frequency Cell Reselection in One-on-one overlay deployments

Consider a deployment with one-on-one overlaying of the second carrier on top of the first carrier as shown in Figure 13. In that figure, Cell(FX,Y) should be understood as a WCDMA cell operating at carrier Frequency X with PSC Y. The main objective of the inter-frequency cell reselection operation in this case is to reduce the call origination or call termination failure rate due to system resource (or capacity) limitations. Three capacity limitations can occur while the UE is in idle state or random access state: 1) paging channel capacity, 2) random access channel capacity, and 3) dedicated connection capacity.

For a given WCDMA cell, the paging channel capacity is determined by the number of SCCPCH(s) and the corresponding data rates of each SCCPCH(s) in the cell. When the SCCPCH(s) capacity in the cell is reached, paging messages can be dropped or delayed resulting in call access or termination failures, since the page message or the RRC connection setup message cannot reach the UE in time. Note that SCCPCH overloading probability is highly correlated with the number of idle UEs camped in a single location area or carrier. To reduce the overloading probability, the operator should avoid having too many idle UEs camped in a single location area or same carrier frequency.

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[11] WCDMA system does not have a mechanism to randomly (or uniformly) assign idle users among different frequencies. If the inter-frequency cell reselection is disabled, the UE will simply camp on the frequency that was last used by the UE. Hence, in an ideal situation, if initially all the UEs are evenly distributed between the frequencies; this balanced distribution will be kept in the system.

[12] The behavior of call redirection depends on the proprietary implementation of each infrastructure vendor. Only properly designed call redirection (as a function of system load) can be used for load balancing.

Similarly, the random access channel capacity depends on the configuration of RACH on the cell, and the probability of RACH overloading is also highly correlated with the number of idle UEs in the cell. Therefore, the network operator should avoid having too many idle UEs camped on a single cell.

Hence, in the scenario shown in Figure 13, the idle UEs should be evenly distributed between the two location areas (LAC1 and LAC2) and between the two frequencies (F1 and F2). In general, it would be difficult to design LACs covering around the same number of idle UEs due to support for mobility, so the common approach is evenly distributing them among the serving carriers. For this objective, two approaches are foreseen:

- Inter-Carrier Balancing of Idle UEs without Call Redirection
- Inter-Carrier Balancing of Idle UEs with Call Redirection

Frequency 2	Cell (F2,1) LAC 1	Cell (F2,2) LAC 1	Cell (F2,3) LAC 1	Cell (F2,4) LAC 2	Cell (F2,5) LAC 2
Frequency 1	Cell (F1,1) LAC 1	Cell (F1,2) LAC 1	Cell (F1,3) LAC 1	Cell (F1,4) LAC 2	Cell (F1,5) LAC 2
	Good GSM Coverage				

Figure 13: Fully overlapped 2-carrier network

The goal is to have the UEs camped on both frequencies somewhat evenly. The advantage is that the load on the paging and random access channels can be distributed and hence avoid congestion. The possible Cell reselection configurations for this approach depend on whether the Call Redirection functionality is supported or not.

4.1.1.1 Inter-Carrier balancing of Idle UEs (without Call Redirection)

When the call redirection at call setup is not supported by the network, having a balanced idle UE distribution between the two frequencies is very important. For most WCDMA networks, the paging channel capacity and the random access channel capacity are much larger than the dedicated channel capacity. Not supporting call redirection implies the dedicated resources are not pooled between the two frequencies. Hence, an access attempt to the network on Frequency 1 can be blocked due to the lack of dedicated resources on that frequency, even though there are available resources on Frequency 2. The call attempt blocking probability is minimized when a balanced idle UE distribution is achieved. (*Strictly speaking, the call attempt blocking probability depends on the distribution of call attempts, not the distribution of idle UEs. However, unless the call patterns of individual users are known, the network operator should assume the same call behavior among all the UEs. Then, balancing the idle UE distribution is equivalent to balancing the call attempt distribution. In some cases, especially during the initial network expansion on Frequency 2, the dedicated channel capacity on Frequency 2 may not be the same as the capacity on Frequency 1. Then, idle UE distribution between the two frequencies needs to be weighted with respect to the capacities of the two frequencies*)

Unfortunately, in WCDMA systems, the network does not have a direct control on assigning individual UEs to different frequencies within a LAC. The UE autonomously performs inter-frequency cell reselection purely based the RF measurements on neighboring cells. As a result, the network has no way of guaranteeing a uniform distribution of idle UEs among all the carriers.

What the network can do is to make "all frequencies appear statistically equal to the UE" during the cell reselection process. For instance, the operator can set the inter-frequency cell reselection parameters symmetric between the vertical neighbors (vertical neighbors are collocated cells using same PSC, but different carrier frequency). The operator can also set *FDD-quality-measure* to RSCP since the RF propagation characteristics are similar for frequencies within the same signal band[13]. To be more aggressive, the operator can further configure low hysteresis to make the cell reselection frequent.

From the physical layer implementation point of view, however, the inter-frequency cell reselection may require more UE signal processing effort since the UE has to tune to a different frequency to search for the neighbor cells. This extra effort costs extra battery consumption. Hence, the operator may not want to have too frequent inter-

[13] Of course, for carriers from different signal bands, this attempt won't help.

frequency cell reselections. With this approach, there is a clear tradeoffs between the idle distribution balance and battery life reduction when setting $S_{intersearch}$ and hysteresis parameters[14].

An example of inter-frequency cell reselection parameter setting is given in Table 10 (with respect to the deployment in Figure 13). The FDD-quality-measure is set to E_c/N_o for detecting the load differences. The $Q_{offset2,s,n}$ is aggressively set to 1 dB resulting in a low hysteresis for frequent inter-frequency cell reselections. With increased amount of inter-frequency cell reselections, the operator needs to closely monitor the probability of missing pages and increase the hysteresis if the paging failure rate is high.

Table 10: Parameter settings to evenly distribute idle UEs

	Frequency 1	Frequency 2
FDD-quality-measure	E_c/N_o	E_c/N_o
$S_{intrasearch}$	10 dB	10 dB
$S_{intersearch}$	7 dB	7 dB
$S_{searchRAT}$	4 dB	4 dB
Q_{hyst2}	2 dB	2 dB
$T_{reselection}$	1 second	1 second
Neighbor List	Include Frequency 2 cells	Include Frequency 1 cells
$Q_{offset2,s,n}$	1 dB	1 dB

4.1.1.2 Inter-Carrier balancing of Idle UEs (with Call Redirection)

When call redirection at call setup is supported[15], the dedicated resources at the two carriers are pooled together. A call attempt to the network will not be blocked as long as there are resources available on at least one of the carriers. Then, the requirement of balancing idle UEs, although still needed to prevent possible PCH or RACH congestion, can be relaxed.

An example of cell reselection parameter settings is given in Table 11 for the one-to-one overlay deployment scenario in Figure 13. This table assumes that call redirection is supported in the network. Since the call redirection is supported, the operator can set FDD-quality-measure to E_c/N_o to provide a better network coverage as discussed in Section A.4. The parameters $S_{intrasearch}$ and $S_{searchRAT}$ are included to show the preference among the intra-frequency, inter-frequency and inter-RAT cell reselections. Notice the $Q_{offset2,s,n}$ is set to 3 dB to provide sufficient hysteresis as suggested in Section A.2.1 and A.4. Lowering these offset values can result in faster and more frequent inter-frequency cell reselections and potentially more balanced idle UE distribution among the carriers, provided the network is able to effectively balance the connected mode traffic. The benefit, however, could not be significant for the two-carrier network when PCH and RACH capacity is sufficiently large.

Table 11: Parameter settings to evenly distribute idle UEs

	Frequency 1	Frequency 2
FDD-quality-measure	E_c/N_o	E_c/N_o
$S_{intrasearch}$	10 dB	10 dB
$S_{intersearch}$	7 dB	7 dB
$S_{searchRAT}$	4 dB	4 dB
Q_{hyst2}	2 dB	2 dB
$T_{reselection}$	1 second	1 second
Neighbor List	Include Frequency 2 cells	Include Frequency 1 cells
$Q_{offset2,s,n}$	3 dB	3 dB

[14] Here, we assume that vertical neighbors have the same LAC. For the case vertical neighbors belong to different location area, the inter-frequency cell reselection latency needs also to be considered.

15 More and more infrastructure vendors are supporting call redirection now. However, the redirection algorithms are proprietary.

4.1.2 Inter-frequency Handovers in One-to-one overlay deployment

Consider a deployment with one-to-one overlaying of the second carrier on top of the first carrier as shown Figure 13. The GSM coverage is also available. In the Cell_DCH state, the intra-frequency soft/softer handover can significantly improve the radio link reliability at cell boundaries. In such a network, the inter-frequency handover, if enabled, should be tuned to optimize the load balancing to improve system capacity.

An example of inter-frequency handover parameter setting is given in Table 12. In this example, the inter-frequency handover is enabled for balancing the load between the carriers. Hence, the triggering conditions for starting the measurement and for sending the measurement report are configured based on E_c/N_o, instead of RSCP. Also, for the same reason, the parameters are set symmetrically between the two carriers[16].

Table 12: Parameter settings for the fully overlapped 2-carrier network (E_c/N_o)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -9 dB Hysteresis: 2dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -7 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -7 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -7 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms	Threshold: -7 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -9 dB Hysteresis: 2dB FC: 3 TTT: 320 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 TTT: 320 ms
Event 2a	Hysteresis: 4dB FC: 3 W: 1.0 TTT: 320 ms	Hysteresis: 4dB FC: 3 W: 1.0 TTT: 320 ms
Event 2b	Threshold Used: -9 dB Threshold non-used: -7 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold Used: -9 dB Threshold non-used: -7 dB FC: 3 W: 1.0 TTT: 320 ms

As discussed in Appendix 7Appendix B, Event 2d and Event 2f can be used to trigger the activation and deactivation of the compressed mode for inter-frequency measurements. In the example above, the Event 2d and Event 2f are triggered at -10 dB and -6 dB respectively[17]. Note that -10dB and -6dB are referred to as the absolute threshold for actually triggering the Event 2d and Event 2f reports, respectively. They are determined as follows:

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[16] As discussed in Section B.3.2, other mechanisms, if available, can be used for activating the compressed mode for load sharing. The example here assumes that these mechanisms are not available. If the infrastructure vendors do provide such mechanisms, the operator should adjust the thresholds for Event 2d, 2f, 1e and 1f, accordingly.

[17] For the load balancing purpose, the triggering thresholds are normally set higher than the values for maintaining the coverage continuity. This may affect the system capacity since there will be more users in the compressed mode

E2D absolute threshold = E2D Threshold - ½ E2D Hysteresis

E2F absolute threshold = E2F Threshold + ½ E2F Hysteresis

The non-zero hysteresis is needed to reduce signaling.

In addition to Event 2d and Event 2f, the Event 1f and Event 1e can also be used for triggering (and de-triggering) the inter-frequency measurement. The example triggering thresholds in Table 12 for these events are -9 dB for Event 1f and -7 dB for Event 1e, respectively. Given that Event 1e and Event 1f are the measurements with respect to a given cell instead of a given active set, the compressed mode for inter-frequency should be triggered only if all the cells in the active set have reported Event 1f.

For triggering the inter-frequency measurement report (and hence the inter-frequency handover), two reports are given in the example in Table 12. One report is Event 2a. Event 2a reports the change of the best frequency as the non-best frequency E_c/N_o becomes Δ dB higher than the best frequency E_c/N_o. Here, Δ is one-half of the hysteresis. Hence, with the hysteresis setting of 4 dB, the Event 2a report is triggered when the frequency is 2 dB better than the best frequency. In the load balancing case, the best frequency should also be the used frequency. Hence, the Event 2a report will result the inter-frequency handover.

Another report is Event 2b. Event 2b report is triggered when the used frequency is below a certain threshold and a non-used frequency is above a certain threshold. The thresholds in the example are -9 dB for the used frequency and -7 dB for the non-used frequency.

Different from Event 2a for which the report is triggered by the relative difference, Event 2b is triggered by the absolute measurement. This difference results in different system behavior. For the load balancing purpose, Event 2a based handover is better. In particular, when the inter-frequency handover is triggered by Event 2a, the load difference between the two frequencies is approximately 2 dB or smaller, because the UE is handed over to the low load frequency whenever the E_c/N_o difference between the two frequencies is larger than 2 dB. On the other hand, when the inter-frequency handover is triggered by Event 2b, the load difference between two frequencies is not bounded. For instance, the inter-frequency handover will not be triggered even when the used frequency is -12 dB but the non-used frequency is -7.5 dB. However, for a different deployment scenario, the Event 2b still has its application. We will illustrate this further in Section 4.2.2.

One concern with using inter-frequency handover for load balancing is the potential ping-pong behavior. With Event 2a as the handover trigger, the UE can handover back-and-forth between Frequency 1 and Frequency 2 as the load on the two frequencies oscillates. Different from the handover for coverage continuity situation, the ping-pong handover is a desired behavior for load balancing, so that the traffic can be moved to the lower load carrier. Hence, frequent handover is needed to achieve accurate load balancing. However, frequent inter-frequency handover can result in call drop probability increase. It can also cause increased air interface and network signaling and network resource management complexities. Hence, the operator should be careful in setting the inter-frequency handover parameters for load balancing. In particular, the hysteresis for Event 2a should not set too small or too large. There may also be proprietary solutions from infrastructure vendors available for achieving the optimal tradeoff between the load balancing gain and the ping-pong handover impact. For instance, to prevent too frequent handover, the network can delay the activation of the compressed mode for UEs that have performed inter-frequency handover within the past X seconds.

Note that the symmetrical parameter setting between the two carriers in Table 12 is due to the condition that both carriers have exactly the same RF coverage footprint and both carriers see the same traffic type distribution. When these conditions are not satisfied, the inter-frequency handover parameter setting will not be symmetrical. In particular, when the operator designates a carrier to HSPA, the parameter settings in Table 12 must be changed accordingly. Such a setting is discussed further in Section 4.2.2.

4.2 One-on-One overlay deployments with traffic separation

When upgrading the network to support HSPA, it can be convenient deploying HSPA capability on the second carrier while keeping the first carrier for Rel-99 traffic only (Figure 4). As voice traffic load in the primary carrier

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(CM) and the expected CM duration can also be longer. Hence, the operator needs to check if the infrastructure vendor has any solution for this issue. For instance, the infrastructure vendor may implement an algorithm to limit the duration of each CM, limit the interval between consecutive CMs, and/or limit the maximum number of simultaneous CMs in a cell.

grows a better configuration would be HSPA+R99 CS over R99 (Figure 5), but if data traffic penetration increases at a faster speed, then HSPA over HSPA+R99 (Figure 6) could be a suitable combination before VoIP is massively deployed and HSPA only over HSPA only becomes the most common scenario. Since, at the time of writing of this document, most multi-carrier WCDMA deployments are at the early stage, we will only focus on the first scenario. The traffic carried on the two carriers, in this case, will be different, and this difference should be reflected in the proper setting of inter-frequency cell reselection and inter-frequency handover parameters.

4.2.1 Inter-Frequency Cell Reselection for One-on-one deployments with Traffic Separation

Idle mobility support for the inner cells is taken care of through conventional Intra-Frequency Cell Reselection settings. On the other hand, at the WCDMA coverage edge, proper inter-frequency cell reselection parameters, as explained in Section 4.3 should be set for each border cell.

If the second carrier (F2) is deployed as an HSPA dedicated carrier as shown in Figure 14, differently than in the case where there is no traffic separation (Section 4.1.1), the operator may consider having all the idle UEs camped on a single carrier (F1).

Frequency 2	Cell (F2,1) HSPA Only	Cell (F2,2) HSPA Only	Cell (F2,3) HSPA Only	Cell (F2,4) HSPA Only	Cell (F2,5) HSPA Only
Frequency 1	Cell (F1,1) R99 Only	Cell (F1,2) R99 Only	Cell (F1,3) R99 Only	Cell (F1,4) R99 Only	Cell (F1,5) R99 Only
	Good GSM Coverage				

Figure 14 Second carrier dedicated to HSPA

With this approach the goal is to have the UEs camped on only the primary ubiquitous carrier. When the UEs initiate a call, they can either be serviced on the primary frequency itself or redirected to the secondary frequency. In this way the network can be configured for no SCCPCH transmission on Frequency 2 (i.e., the power on the SCCPCH can be zero Watt), since all the paging, FACH and RACH operations will be only in Frequency 1. The power saved on SCCPCH could be applied to HSDPA in traffic separation schemes or to support additional voice call and further improve system capacity while provide higher utilization indexes to the primary SCCPCH.

The trade-off would be, in idle mode, the decreased overall WCDMA coverage due to higher probability to reselect GSM from Frequency 1. Also, not supporting paging, FACH and RACH operations on Frequency 2 can impact the call access performance because, when the UE happens to camp on Frequency 2, e.g. as the result of initial cell selection or due to some temporary WCDMA degradation of Frequency 1 (if GSM is not reselected first) or due to call drops or call releases on Frequency 2[18], the UE will not be able to get any services. Hence, the operator should make sure proper inter-frequency cell reselection configuration is installed (as given the examples below), so that such risks are minimized.

Since with this approach all the UEs originate or terminate calls on the primary carrier, Call redirection is a required feature to redirect and establish the call on the secondary carrier. With this approach, at the initial call setup, the UTRAN assigns the UE a Rel-99 DCH on Frequency 1 using *RRC Connection Setup* message. As the network detects needs of the UE to use HSPA or the load reaches a certain level in the primary frequency, it redirects the UE to Frequency 2 and moves the UE traffic from DCH to HS-DSCH if applicable. More details are given in Section B.6.

In terms of parameter settings, there are several different approaches to move all the idle UEs to the ubiquitous Frequency 1. Two typical examples are given below.

[18] When a call is dropped or released on Frequency 2, it will come back on Frequency 2 first during the system acquisition after the call drop or call release.

4.2.1.1 Moving Idle UEs to primary carrier (through Parameter Settings)

In this approach, the operator sets the cell reselection parameters so that cells on Frequency 1 are always selected. During the idle state, the UE frequently checks if there are other "better" cells in the neighborhood and performs cell switch if it finds such a cell. By properly setting the hysteresis parameters, the operator can make the cells on Frequency 1 appears better than cells on Frequency 2. Hence, the UE will always pick the Frequency 1 cells during the inter-frequency cell reselection.

Table 13 shows a configuration example. By setting the $S_{intersearch}$ to a negative value on Frequency 1, the inter-frequency cell reselection is essentially disabled. The UE, while camping on Frequency 1, will not search for better cells on Frequency 2 to perform inter-frequency cell reselection. There are other approaches to prevent the reselection to frequency 2. For instance, on Frequency 1, the broadcasted neighbor list will contain only cells from Frequency 1. Then, the network does not need to broadcast $S_{intersearch}$ and can save a few bits on PCCPCH. The values of hysteresis on Frequency 1 will not affect the behavior of the cell reselection due to the particular setting of $S_{intersearch}$. The same is true for $T_{reselection}$.

Regarding the settings on Frequency 2, the $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$ are set to negative values (e.g. -50dB, respectively) for cells on Frequency 1. Then, if the UE happens to camp on Frequency 2, during the inter-frequency cell reselection, cells on Frequency 1 will be ranked higher than the source cell and the UE will be triggered to select a cell on Frequency 1. Also, by setting the neighbor list to include only Frequency 1 cells, we can speed up the inter-frequency cell reselection since the UE won't spend time to search any neighbor cells on Frequency 2.

As for the GSM neighbors, they should not be included in the neighbor list either to make sure that the UE will always land on a Frequency 1 cell. If the operator does need to include GSM cells in the neighbor list, proper offsets can be set for the Frequency 1 cells to favor UMTS over GSM systems.

Table 13: Parameter settings to select Frequency 1 cells

	Frequency 1	Frequency 2
PCCPCH Power	10% of HPA power	10% of HPA power
SCCPCH Power	10% of HPA power	10% of HPA power
Cell Barred	Not barred	Not barred
FDD-quality-measure	RSCP or E_c/N_o	RSCP or E_c/N_o
$S_{intersearch}$	< 0 dB (or not sent)	> $(-Q_{qualmin})$ dB
Q_{hyst1}	N/A	2 dB
Q_{hyst2}	N/A	2 dB
$T_{reselection}$	N/A	1 second
Neighbor List	Exclude Frequency 2 cells	Include Frequency 1 cells
$Q_{offset1,s,n}$	N/A	-50 dB
$Q_{offset2,s,n}$	N/A	-50 dB

This approach, however, does not guarantee to put all the UEs on Frequency 1, though the probability for a UE to camp Frequency 2 would be very low. When the UE happens to camp on Frequency 2 as the result of initial cell reselection or due to temporary WCDMA degradation on Frequency 1 (if GSM is not selected first) or after the call drops or call releases on Frequency 2, the UE will not be able to access the system on Frequency 2 unless paging and RACH are supported on Frequency 2. As a result, the UE is forced to perform a cell reselection again and move to Frequency 1, and during this period there is a probability (although not very high) that the UE misses the pages (which can result mobile terminated call failures). Also, the UE cannot immediately make mobile originated calls until it camps on Frequency 1.

As mentioned in Section 3.2.1.2, the operator also has an option of setting the SCCPCH power to zero on Frequency 2. Although this will benefit the downlink capacity, the impacts mentioned in that section should also be carefully evaluated.

4.2.1.2 Moving Idle UEs to primary carrier (through Cell Access Restriction)

In this approach, the operator sets the *Cell Access Restriction* information element to prevent the UE from camping on the cell. The *Cell Access Restriction* information element (IE) is included in SIB3. For the cells on Frequency 2, the operator can set the field *Cell Barred* to "*barred*" to prevent any UE from camping on these cells. According to the standard, the UE removes the cell from the list of cells for cell initial selection or reselection if the cell is identified as "*barred*" by the *Cell Barred* information element. As a result, the UE will select a different cell. If the "*Intra-frequency cell re-selection indicator*" IE is set to "*not allowed*" the UE shall not re-select a cell on the same frequency as the barred cell. In this case, the UE has to find a cell on Frequency 1 to camp on. This is a cleaner approach compared with the previous one because it restricts the UE from selecting Frequency 2.

Table 14 shows an example configuration. By setting the $S_{intersearch}$ to a negative value, the inter-frequency cell searching threshold is set below $Q_{qualmin}$ on Frequency 1, and the inter-frequency cell reselection is essentially disabled. The UE, while camping on Frequency 1, will not search for better cells on Frequency 2 to perform inter-frequency cell reselection. The values of hysteresis on Frequency 1 will not affect the behavior of the cell reselection due to the particular setting of $S_{intersearch}$. The same is true for $T_{reselection}$. Alternatively, by excluding Frequency 2 cells from the neighbor list on Frequency 1, the UE will not search any inter-frequency cells and there is no need to send $S_{intersearch}$ in SIB3.

Table 14: Parameter settings with cell access restriction on Frequency 2 cells

	Frequency 1	**Frequency 2**
PCCPCH Power	10% of HPA power	10% of HPA power
SCCPCH Power	10% of HPA power	0% of HPA power
Cell Barred	Not barred	barred
FDD-quality-measure	RSCP or E_c/N_o	RSCP or E_c/N_o
$S_{intersearch}$	< 0 dB	N/A
Q_{hyst1}	N/A	N/A
Q_{hyst2}	N/A	N/A
$T_{reselection}$	N/A	N/A
Neighbor List	Exclude Frequency 2 cells	Include Frequency 1 cell only
$Q_{offset1,s,n}$	N/A	-50 dB for Frequency 1 cells
$Q_{offset2,s,n}$	N/A	-50 dB for Frequency 1 cells

With this scheme, however, the UE may experience a delay to acquire the system after a call terminates on Frequency 2. When a call is terminated on Frequency 2, the UE will first try to camp on a cell that belongs to the active set just before the call is terminated. After finding the cell is barred, the UE starts search for other candidates based on the frequency information stored in the UE. One the barred cell, the operator can configure the "*Intra-frequency cell re-selection indicator*" IE is set to "*not allowed*", so that the UE will not re-select a cell on the same frequency as the barred cell. Then, the UE will start search for Frequency 1 cells. Before it camped on a cell, the UE has no access to the network, cannot make a call or receive paging messages.

The SCCPCH power is set to zero here for improving the downlink capacity. However, the operator should also pay attention to the impact of such a setting as discussed in Section 3.2.1.2.

4.2.2 Inter-Frequency Handover for One-on-one deployments with Traffic Separation

Consider again the network deployment in Figure 14. Assume that inter-frequency cell reselection scheme in Section 4.1.1 is employed. Assume that all cells on Frequency 2 are equipped with the HSPA capability. Assume that the operator would like to push packet data traffic to Frequency 2 as much as possible for HSPA capable UEs and to move all the voice calls to Frequency 1 so that efficient radio resource management of HSPA can be fully realized. In such a scenario the parameter setting given in Table 12 will not be suitable. Instead, the inter-frequency handover parameter setting will be focused on the operation strategy of separating voice and data traffic and at the same time maintaining the desired quality of service requirements.

Under such a traffic segregation scheme, the traffic load distributions on the two carriers will be very different. On one hand, the downlink load on Frequency 2 cells is often close to 100% due to the support of HSPA, which tries to use all the available down link power whenever there are enough data to send. On the other hand, the loads on

Frequency 1 cells fluctuate and seldom reach 100%. The fluctuation is caused by the power control on Release 99 dedicated channels, dedicated channel addition or deletion, and voice (or traffic) activities. The load behavior differences should be taken into account in the inter-frequency handover parameter settings. In particular, if the E_c/N_o based measurement is used, the Event 2a based handover trigger is not appropriate anymore and Event 2b should be used instead.

Table 15 shows an example of the parameter setting for this HSPA deployment scenario. The E_c/N_o based measurements are considered in this example. Notice that the purpose of inter-frequency handover here is to segregate different types of traffic for a better radio resource management. The handover parameter settings are configured for CS calls (or voice calls) and PS calls of Rel99 UEs only on Frequency 2 and PS calls of Rel5/6 UEs only on Frequency 1. That is, the voice calls already on Frequency 1 will not receive the measurement control message for inter-frequency measurement, nor will the packet data calls of Rel5/6 UEs already on Frequency 2. Only the PS calls on HSPA capable UEs are instructed to perform inter-frequency handover to Frequency 2, and the network will send the measurement control message for inter-frequency handover only to the UEs with the HSPA capability. Rel-99 PS calls will be instructed to handover to Frequency 2.

Table 15: Parameter settings for the fully overlaying HSPA on Release 99 network (E_c/N_o)

	Frequency 1 (Applied to PS of Rel5/6 UEs Only)	**Frequency 2 (Applied to CS and PS of Rel99 UEs Only)**
Event 2d	Threshold: 0 dB Hysteresis: 2dB FC: 3 W: 1.0 TTT: 0 ms	Threshold: 0 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2f	Threshold: 0 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: 0 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: 0 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms	Threshold: 0 dB Hysteresis: 2 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -0 dB Hysteresis: 2dB FC: 3 TTT: 0 ms	Threshold: -0 dB Hysteresis: 2 dB FC: 3 TTT: 0 ms
Event 2b	Threshold Used: 0 dB Threshold non-used: -16 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: 0 dB Threshold non-used: -16 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2c	Threshold non-used: -16 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold non-used: -16 dB FC: 3 W: 1.0 TTT: 0 ms

Note that the thresholds for Event 2d and Event 1f are set to zero. The objective is to activate the compressed mode as soon as possible after the network detects the need of handing over the UE to a different frequency. The compressed mode activation will be independent of the CPICH E_c/N_o value. Due to the same objective, the configuration of Event 2f and Event 1e becomes redundant (since Event 2f and Event 1e will never be triggered). Hence, the configuration is grayed in the table indicating that the operator can choose not to configure them.

The thresholds in Table 15 are set in such a way that a voice call will immediately be handed over from Frequency 2 to Frequency 1 as soon as the call is detected on Frequency 2 and the CPICH quality (E_c/N_o) on Frequency 1 is above -16 dB. In particular, the threshold for the used frequency is set to 0 dB. Such a setting is used when operators focus on separating the voice and data traffic with less consideration on the quality of the calls or handover successful rates. In such a case, the operator can also configure Event 2c, instead of Event 2b, for triggering the handover. In addition, two other approaches can also be used to serve the same purpose and yet may simplify the control.

- Blind inter-frequency or call redirection at call setup: If the RF environment on the target frequency can be predicted based on the measurements from the serving frequency (such as RSCP and/or E_c/N_o) and the network information (such as load measurements), the operator may consider using the blind handover instead of activating the compressed mode for target frequency measurement. With the blind handover, there is no compressed mode activation and the system capacity reduction due to the compressed mode activation can be eliminated.
- Inter-frequency handover at the call setup or after soft handover: Instead of triggering the compressed mode based on the E2D or E1F measurements, the network can also activate the compressed mode as soon as the UE establishes the radio link(s) during call setup or after soft handover. With this approach, the network does not need to configure E2D or E1F, hence it saves some signaling messages. Since the target frequency is still measured and reported, the handover success rate is expected to be better than the simple blind handover.

When the operators have concerns about potential call drops due to inter-frequency handover, the parameter settings in Table 15 can be adjusted to be less aggressive. In particular, the setting of Event 2b (Event 2c) thresholds for the non-used frequency (i.e., the target frequency) should be raised as shown below (Table 16). The threshold for the target frequency for CS call handover is increased to -11 dB to reduce the possible call drops due handover failures, whilst the less increase is given to the threshold for the target frequency for PS call handover due to the fact that PS call drop is more tolerable than the CS call drop.

Table 16: Modified Event 2b Setting for Table 15 to Reduce Call Drop Rates

	Frequency 1 (PS of Rel5/6 UEs)	**Frequency 2 (CS and PS of Rel99 UEs)**
Event 2b	Threshold Used: 0 dB Threshold non-used: -14 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: 0 dB Threshold non-used: -11 dB FC: 3 W: 1.0 TTT: 0 ms
Event 2c	Threshold non-used: -14 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold non-used: -11 dB FC: 3 W: 1.0 TTT: 0 ms

The RSCP based measurements can also be used for triggering the inter-frequency handover. Since the RSCP measurements from vertical cells are highly correlated and the RSCP measurements are independent of the cell loading, the RSCP based inter-frequency handover has an advantage in handing over PS calls from Frequency 1 to Frequency 2 where the loading could always be very high when the data traffic is high. Here is an example of the Event 2b (Event 2c) setting using RSCP measurements.

Table 17: Modified Event 2b Setting (for Table 15) Using RSCP Measurements

	Frequency 1 (PS of Rel5/6 UEs)	**Frequency 2 (CS and PS of Rel99 UEs)**
Event 2b	Threshold Used: -25 dBm Threshold non-used: -100 dBm FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -25 dBm Threshold non-used: -100 dBm FC: 3 W: 1.0 TTT: 0 ms

Event 2c	Threshold non-used: -100 dBm FC: 3 W: 1.0 TTT: 0 ms	Threshold non-used: -100 dBm FC: 3 W: 1.0 TTT: 0 ms

In the scenario discussed here, there is no ping-pong event for the inter-frequency handover. Hence, the operator can choose different triggering measurement at different frequency. For instance, the operator can use the Ec/No based measurement for the Frequency 2 to Frequency 1 handover (for voice calls) and RSCP based measurement for the Frequency 1 to Frequency 2 handover (for data calls). Or, the operator can choose to configure both at the same time.

Note the example given in Table 15 is with respect to the simple traffic separation and inter-frequency cell reselection scenario described at the beginning of this section. In real networks, the operator may add many different variations to handle traffic separation on top of what is given in the example. Then, the handover parameter setting discussed in Table 15 should be adjusted accordingly. For instance, for networks that have significant voice traffic, the operator will let voice calls stay on Frequency 2 when the voice call load on Frequency 1 is high. Another example, for multi-RAB scenarios such as when the UE makes concurrent voice and data calls, the operator many choose to handover the UE to a single frequency or leave the UE at its current frequency. The parameter setting for multi-RAB scenarios, not explored in the example here, needs to be carefully tuned based on the principles in Table 15.

4.3 Operation at WCDMA Boundary of One-on-one deployments

An interesting inevitable scenario for One-on-one deployments (also possible for hot spot deployments) is the operation at the WCDMA coverage edge as shown in Figure 15. Observe that the border cells (Cell (F1,3) and Cell (F2,3)) in this case have, essentially, same coverage and a decision needs to be made for idle and connected mode mobiles leaving F2 in the sense of camping or handing over to the primary cell or directly proceeding towards GSM coverage.

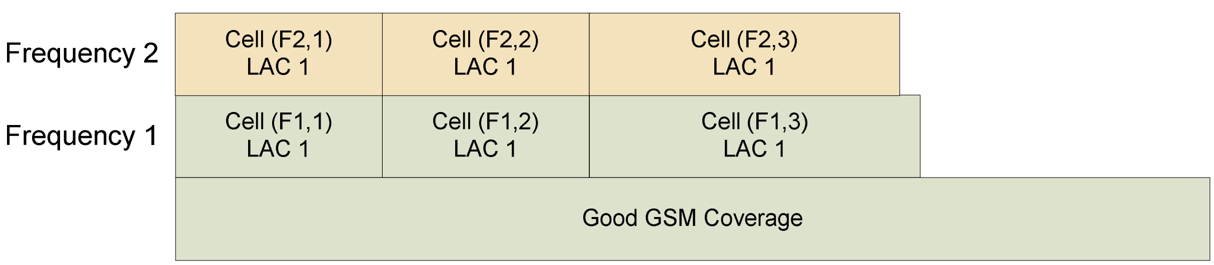

Figure 15: Same coverage boundary on both frequencies

4.3.1 Inter-Frequency Cell Reselection at WCDMA Boundary

When the coverage boundaries of Frequency 1 and Frequency 2 are essentially the same, as the boundary of Cell (F1,3) and Cell (F2,3) shown in Figure 15, the WCDMA inter-frequency cell reselection may be avoided as the UE moves towards the edge of the WCDMA coverage. In particular, as a UE in Cell (F2,3) moves towards right, it will start inter-frequency cell reselection if the signal E_c/N_o on Cell (F1,3) is higher. However, as the UE continues moving right, the RF signal on Cell (F1,3) also degrades, and the UE has to perform the inter-RAT cell reselection soon after it camped on Cell (F1,3).

From the idle performance perspective, given that UE cannot receive paging messages during the cell switching, performing an inter-RAT cell reselection directly from Cell (F2,3) is beneficial since the UE will experience only one cell switching instead of two. From the WCDMA coverage point of view, by-passing the inter-frequency cell switch may reduce the WCDMA coverage since the UE goes to the GSM system earlier. Hence, the operator should set the inter-frequency reselection and inter-RAT cell reselection parameter together to obtain the best tradeoffs between maintaining the WCDMA coverage and a good idle performance.

Table 18 shows an example of setting for the coverage boundary case. In this example, the purpose of inter-frequency cell reselection is essentially the same as the inter-RAT cell reselection: to maintain the service continuity. Hence, $S_{intersearch}$ and $S_{searchRAT}$ are set to the same value here. The UE will then perform inter-frequency or inter-RAT cell reselection depending purely on the ranking result. With $S_{intersearch}$ set at 4dB, the UE is already reaching the WCDMA coverage of the corresponding cell. Unless the signal quality at the other frequency is significantly better, there is little benefit to perform inter-frequency cell reselection. Note in this example, we do not distinguish Q_{offset} for inter-frequency and Q_{offset} for inter-RAT. The operator, however, can always fine tune these parameters. For instance, by setting Q_{offset} for inter-frequency higher, we can emphasis on avoiding unnecessary inter-frequency cell reselection, i.e., the inter-frequency cell reselection can only happen when the other frequency is significantly better.

Observe that RSCP based measurement is used in this example to make it consistent with the inter-RAT cell reselection operation.

Table 18: Parameter setting for the WCDMA boundary case

	Frequency 1	**Frequency 2**
FDD-quality-measure	RSCP	RSCP
$S_{intrasearch}$	12 dB	12 dB
$S_{intersearch}$	4 dB	4 dB
$S_{searchRAT}$	4 dB	4 dB
Q_{hyst1}	2 dB (default)	2 dB (default)
Q_{hyst2}	2 dB (default)	2 dB (default)
$T_{reselection}$	1 second (default)	1 second (default)
Neighbor List	Include Frequency 2 cells	Include Frequency 1 cells
$Q_{offset1,s,n}$	3 dB	3 dB
$Q_{offset2,s,n}$	3 dB	3 dB

4.3.2 Inter-Frequency Handovers at WCDMA Boundary

At the coverage boundaries, the focus of inter-frequency handover parameter setting should be maintaining the service continuation or mobility management. The load balancing, if considered, is only a secondary goal here. From the mobility management point of view, when the coverage boundaries of Frequency 1 and Frequency 2 are essentially the same, as the boundaries of Cell (F1,3) and Cell (F2,3) shown in Figure 15, the inter-frequency handover may need be conservative as the UE moves towards the edge of the WCDMA coverage. In particular, as a UE in Cell (F2,3) moves towards right, it may start inter-frequency handover to Frequency 1 if the signal quality (E_c/N_o or RSCP) on Cell (F1,3) is higher. However, as the UE continues moving right, the RF signal on Cell (F1,3) also degrades, and the UE has to perform the inter-RAT cell handover soon after it moves to Cell (F1,3).

Hence, the inter-frequency handover should only occur if the signal on the target frequency is significantly higher than the signal on the used frequency and the UE is expected to be able to stay there after the handover. An example of inter-frequency handover configuration for such a scenario is given in Table 19, in which RSCP based measurement is used. Note that the RSCP based measurement is consistent with the GSM measurement, which makes it easy for properly configuring inter-frequency and inter-RAT handover together to avoid unnecessary ping-pong handovers.

Table 19: Inter-frequency Handover Configuration at the WCDMA Boundary (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -96 dBm Hysteresis: 4 dB	Threshold: -96 dBm Hysteresis: 4 dB

	FC: 3 W: 1.0 TTT: 640 ms	FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2b	Threshold Used: -100 dBm Threshold non-used: -96 dBm FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -100 dBm Threshold non-used: -96 dBm FC: 3 W: 1.0 TTT: 0 ms

In Table 19 the E2D and E2F (similarly E1F, E1E) thresholds are configured low so that the compressed mode will be activated only at the boundaries. The reason behind this low setting is to maximize the usage of the serving frequency before moving to a different frequency, since load balancing is not the goal. When the target frequency RSCP is significantly higher than the RSCP of the used frequency, the inter-frequency handover will happen and the UE is expected to be able to stay on the target frequency for a while before the UE moves out of the coverage of the target frequency.

In the example in Table 19, the target frequency RSCP (due to E2A or E2B settings) has to be 4 dB higher than the used frequency value. Such a high handover triggering threshold prevents the UE from early inter-frequency handover when the target frequency RSCP is only slightly higher than that of the serving frequency. Otherwise, as the UE continues moving out the WCDMA coverage, it may need to perform an IRAT handover immediately following the inter-frequency handover. When the target frequency is not significantly better than the serving frequency and the UE is moving out of the WCMA coverage, the network should instruct the UE to search for other RAT candidates together with the inter-frequency search and let the UE perform the inter-RAT handover to the GSM system as it moves out of the WCDMA coverage. By doing so, we save one handover churn and reduce the potential call drop due to handover failure.

The E_c/N_o based inter-frequency handover configuration can also be used here. The operator may choose to configure both in order to get high inter-frequency handover reliabilities.

As mentioned earlier, the inter-RAT handover should be configured in consistent with the setting for the inter-frequency handover. Table 20 below is an example of inter-RAT handover configuration based on RSCP measurement. Notice that the E2D and E1F thresholds are set the same as in Table 19. Hence, the network will start inter-frequency measurement and IRAT measurement at the same time, and the UE can report either inter-frequency or IRAT measurement result depending on whether E2B or E3A is satisfied first. As a result, unnecessary redundant handovers can be avoided.

Table 20: Inter-RAT Handover Configuration at the WCDMA Boundary (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0

	TTT: 640 ms	TTT: 640 ms
Event 1e	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 3a	Threshold Own System: -102 dBm Threshold Other System: -96 dBm Hysteresis: 0 dB FC: 3 W: 1.0 TTT: 0 ms	Threshold Own System: -102 dBm Threshold Other System: -96 dBm Hysteresis: 0 dB FC: 3 W: 1.0 TTT: 0 ms

5 Disjoint carriers deployment

5.1 Deployment model

When the second carrier is deployed for the purpose of extending the coverage of the first carrier as shown in Figure 16, the objective of inter-frequency cell reselection and inter-frequency handover should be for maintaining the service continuity instead of balancing the UE distribution. This deployment scenario may be used also for inter-band deployment and/or indoor coverage solutions including the deployment of femto cells.

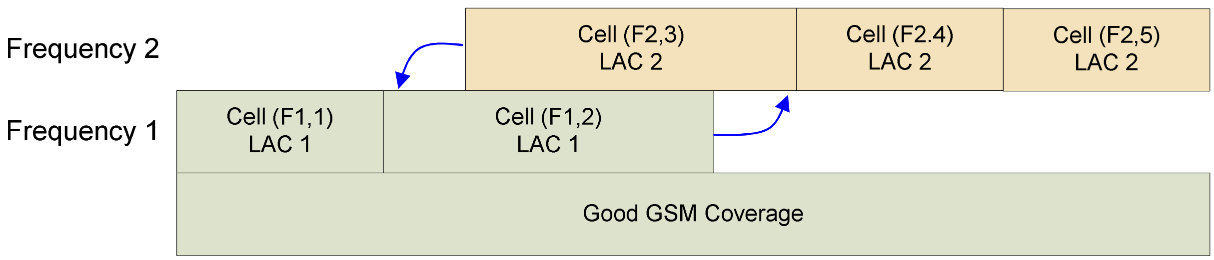

Figure 16: Carriers at different frequencies/bands covering different areas

5.2 Inter-Frequency Cell Reselection in Disjoint Carrier scenarios

In this scenario, it is assumed that the operator associates the two carriers with different LACs. From mobility management point of view, the inter-frequency cell reselection should be enabled only at the border cells (i.e., Cell (F1,2) and Cell (F2,3)) and only when the serving cell signal quality is low for maintaining the continuous service. This is because frequent inter-frequency cell reselection can result in mobile terminated call failure due to missed pages (and MO setup decreased performance) during the cell reselection and LAU. Also, there is no need to perform inter-frequency cell reselection when the signal quality is still good. The cell reselection hysteresis, offsets and reselection timer need also to be properly tuned to reduce the number of inter-frequency cell reselection and potential ping-pong behavior.

An example of cell reselection parameter settings for border cells Cell (F1,2) and Cell (F2,3) is given in Table 21.

Table 21 Parameter settings at frequency boundary cells

	Frequency 1: Cell (F1,2)	**Frequency 2: Cell (F2,3)**
FDD-quality-measure	RSCP or E_c/N_o	RSCP or E_c/N_o
$S_{intrasearch}$	10 dB	10 dB
$S_{intersearch}$	6 dB	6 dB
$S_{search,RAT}$	4 dB	4 dB
Q_{hyst1}	2 dB	2 dB
Q_{hyst2}	2 dB	2 dB
$T_{reselection}$	1 second	1 second
Neighbor List	Include Cell (F2,3)	Include Cell (F1,2)
$Q_{offset1,s,n}$	3 dB	3 dB
$Q_{offset2,s,n}$	3 dB	3 dB

Note in this example, the $S_{intersearch}$ is set close to $S_{searchRAT}$ and farther from $S_{intrasearch}$, compared to the earlier example One-on-One with call redirection support (Section 4.1.1.2). This is because both inter-frequency cell reselection and inter-RAT reselection serve the same purpose here: maintain service continuity. The $S_{intersearch}$ is, nevertheless, set higher than $S_{searchRAT}$ because the 3G service is still assumed to be preferred over the 2G service.

In this example, we recommend that RSCP being configured although both RSCP and E_c/N_o based cell reselection can be configured. Since the RSCP measurement does not change with respect to the load variation in the cell, the cell reselection boundary based on RSCP is more predictable than the cell reselection boundary based on E_c/N_o.

5.3 Inter-Frequency Hand over in Disjoint Carrier scenarios

When the second carrier is deployed for the purpose of extending the coverage of the first carrier as shown in Figure 16, the objective of inter-frequency handover should then be for maintaining the service continuity instead of balancing load of the traffic. In particular, as shown in Figure 16, the F2->F1 handover is needed when the user is on Frequency 2 and moving left. Similarly, the F1->F2 handover is to maintain the call continuity for UEs on Frequency 1 and moving right.

In this scenario, it is not necessary to perform the inter-frequency handover late at the coverage edge. In other words, the parameter setting should not focus on extending the coverage of each frequency. Instead, the inter-frequency handover setting should emphasize the handover reliability and preventing ping-pong handovers, provided good overlapped deployment exists.

Given such considerations, the inter-frequency handover is better to be based on RSCP and the Event 2b, instead of Event 2a, should be used. The handover parameters should be set as suggested in the following table (Table 23).

Table 22 Inter-Frequency Handover parameter setting for call continuity (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms	Threshold: -100 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2b	Threshold Used: -98 dBm Threshold non-used: -94 dBm FC: 3 W: 1.0 TTT: 0 ms	Threshold Used: -98 dBm Threshold non-used: -94 dBm FC: 3 W: 1.0 TTT: 0 ms

Notice that there is a 4 dB gap between the used frequency and the non-used frequency specified for Event 2b. It is intended to reduce possible ping-pong handovers in such a deployment scenario.

6 Inter-band Overlay Deployment

6.1 Deployment model

A multiple-band deployment scenario is shown in Figure 17. Here, the WCDMA network consists of two carriers from two different frequency bands in the UMTS 2100 MHz band and the UMTS 900 MHZ band, respectively. Different from the deployments we have discussed earlier, there are normally no vertical cells defined here. This is due to the fact that RF propagation behavior is significantly different for different frequency bands. The cell coverage on the 900 MHz band, for instance, is usually larger than the cell on the 2100 MHz band [11].

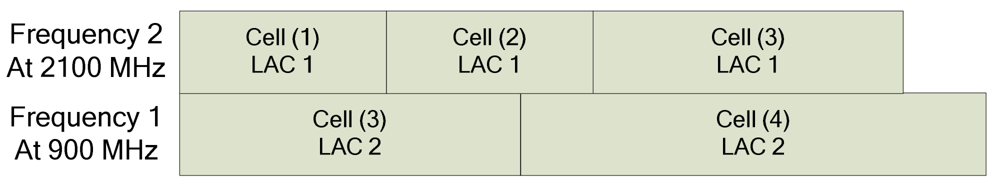

Figure 17: Multiple-Band Network Deployment

The multiple-band deployment is generally not for purposes of increasing the capacity. Instead, it is often due to the following possible factors:

- Government Spectrum Licensing: A network operator may want to provide services among different countries and border cities may require multiple band coverage support
- Cost Considerations: A network operator may want to use an additional lower frequency band for rural deployments (less number of NodeBs required) given the different capacity and coverage requirements between urban and rural areas
- Coverage Extensions: A network operator may require providing coverage extensions in a different frequency band for in-building and subway coverage requirements, etc.

Besides the coverage difference, it is also possible that the two carriers are controlled by different RNCs and are assigned with different LACs[19]. The operator or infrastructure vendor may choose such a LAC arrangement for operation or implementation simplicity. However, having different LACs for the vertically overlapping cells impacts inter-frequency performance due to the increased inter-frequency cell reselection latency. As a result, frequent inter-frequency cell reselection should be avoided.

6.2 Inter-Frequency Cell Reselection in Inter-band deployments

An example of the inter-frequency cell reselection parameter setting is given in Table 23. To avoid frequent inter-frequency cell reselections, $S_{intersearch}$ is set to quite low compared to $S_{intrasearch}$. The offsets $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$ are set to 4~5 dB. Setting the offsets this high can further reduce the inter-frequency cell switching and avoid cell switching ping-pong behavior.

Table 23: Inter-frequency cell reselection parameters for multiple-band deployment

	2100 MHz	900 MHz
FDD-quality-measure	RSCP or E_c/N_o	RSCP or E_c/N_o

[19] Since no vertical neighbors are defined, it is very hard in network planning to correlate cells on different bands with the same physical area. It is easier to simply assign cells on different bands to different LACs.

$S_{intrasearch}$	12 dB	12 dB
$S_{intersearch}$	6 dB	6 dB
$S_{searchRAT}$	4 dB	4 dB
Q_{hyst1}	2 dB (default)	2 dB (default)
Q_{hyst2}	2 dB (default)	2 dB (default)
$T_{reselection}$	1 second (default)	1 second (default)
Neighbor List	Include Frequency 2 cells	Include Frequency 1 cells
$Q_{offset1,s,n}$	4~5 dB	4~5 dB
$Q_{offset2,s,n}$	4~5 dB	4~5 dB

6.3 Inter-Frequency Hand over in Inter-band deployments

Consider the deployment scenario of Figure 17. The operator may consider fast moving UEs on the 900 MHz band so that UE experiences less frequent handovers due to the relatively large cell coverage. On the other hand, the operator can assign slow moving UEs to the 2100 MHz band where it can enjoy higher cell capacity. In such a scenario, the inter-frequency handover will not be used for load balancing since the load is managed based on the mobility characteristics of the UE. Hence, the inter-frequency handover is needed only if there is a need for maintaining service continuity.

The following tables show examples of inter-frequency handover parameter setting for the purpose of maintain the service coverage. In this example, both F1->F2 and F2->F1 handovers are configured conservatively. This is under the assumption that both frequency bands have continuous coverage and the UE is preferred to stay within the frequency band unless the signal quality is really bad.

Table 24: Inter-frequency handover parameter settings for continuity (RSCP)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms	Threshold: -96 dBm Hysteresis: 4 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms	Threshold: -102 dBm Hysteresis: 4 dB FC: 3 TTT: 320 ms
Event 2a	Hysteresis: 4dB FC: 3 W: 1.0 TTT: 320 ms	Hysteresis: 4dB FC: 3 W: 1.0 TTT: 320 ms

Table 25: Inter-frequency handover parameter settings for continuity (Ec/No)

	Frequency 1	**Frequency 2**
Event 2d	Threshold: -11 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms	Threshold: -11 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 320 ms
Event 2f	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms	Threshold: -9 dB Hysteresis: 2 dB FC: 3 W: 1.0 TTT: 640 ms
Event 1e	Threshold: -9 dBm Hysteresis: 2 dB FC: 3 TTT: 640 ms	Threshold: -9 dBm Hysteresis: 2 dB FC: 3 TTT: 640 ms
Event 1f	Threshold: -11 dBm Hysteresis: 2 dB FC: 3 TTT: 320 ms	Threshold: -11 dBm Hysteresis: 2 dB FC: 3 TTT: 320 ms
Event 2a	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms	Hysteresis: 4 dB FC: 3 W: 1.0 TTT: 0 ms

Notice that both RSCP and E_c/N_o based inter-frequency handover can be configured and the operator can use both of them to trigger the handover. The Event 2a handover triggering is used in the examples so that the UE is handed over to a different frequency band only if the signal on the used frequency is very bad and the signal on the other frequency is better.

Generally speaking, the inter-frequency handover should be configured in such as a way so that intra-band inter-frequency handover is preferred over inter-band inter-frequency handover due to the difference in RF propagation characteristics.

7 Conclusion

As the wireless industry continuously grows, more and more mobile applications and services are being introduced resulting in continuously increasing the wireless traffic volume and capacity demand. We will see more and more networks being expanded with multiple carriers. Hence, a thorough understanding of how to effectively configure the system with multiple frequencies is crucial in achieving high system efficiency and at the same time providing high quality of services in the network.

We looked at different multi-carrier deployment schemes, in particular

- Hot spot deployments
- One-to-one overlay
- Disjoint and Inter-band deployment
- Traffic Type separation among the deployed carriers

For each of the deployment scenarios, we then looked at how the inter-frequency handover and inter-frequency cell reselection can be configured as a function of different deployment objectives, such as:

- Coverage/Service continuity
- Load sharing
- HSPA/R99 traffic separation

For each combination of deployment scenarios and operation strategies, the paper provides recommended system parameters configuration for the inter-frequency cell reselection and inter-frequency handover and it explains the principles and reasoning behind the recommended settings.

It is important to point out that the examples shown in this paper do not represent all the possible deployment scenarios in practical networks. Each deployed network always has its unique characteristics due to geography differences, government regulations, and radio/core network infrastructure differences. Also, the network operation is unique due to operator strategies, service differentiation, business model differences, etc. As a result, the system configuration examples provided in the paper may not be directly applicable to the networks in the fields. The examples, however, serve as a guideline to the actual system configuration and following this guideline, the operator should be able to fine tune the system configuration based on the principles described for each case in the paper.

Appendix A Inter-Frequency Cell Reselection Fundamentals

Inter-frequency cell reselection allows the UE to change its camping cell at one frequency to a cell at a different frequency. By design, this operation improves the coverage of the network, hence improves the call setup and paging performances, by allowing the UE to switch a cell that has stronger signals.

During the inter-frequency cell reselection, the UE compares the serving frequency CPICH E_c/N_o (or RSCP) with the CPICH E_c/N_o (or RSCP) from other frequencies and changes the serving frequency as it deems meeting the network specified requirements.

Potentially, the inter-frequency cell reselection has the load balancing gain since the UE can always camp on the carrier with a stronger CPICH E_c/N_o. When the vertical neighbors carry the same type of traffic, a higher E_c/N_o indicates a lower load on the corresponding carrier. The operator can see better call setup performance when the UE camps on the lower load carrier. This load balancing gain, however, is limited due to the hysteresis specified to avoid frequent back-and-forth inter-frequency cell reselections, and the gain is not observed until the UE access the system. In addition, with the call redirection function at the call setup, which is supported by many infrastructure vendors, there is little need for using inter-frequency cell reselection to balance the load.

Also, there will not be load balancing gain, if different types of traffic are supported on different carriers, for example, in the case when the first carrier is configured as the Rel-99 system and the second carrier is configured as the R99+HSPA system.

Hence, the inter-frequency cell reselection optimization should be focused on aspects other than load balancing, such as reducing cell reselection delay, avoiding ping-pong events, and conserving UE battery consumption in idle mode. Frequent inter-frequency cell reselection should be avoided when the cell reselection delay is high, especially if a location area update (LAU) and/or routing area update (RAU) are needed after the cell reselection.

The operator needs also pay attention to the configuration of location area codes (LAC) and routing area codes (RAC) in a multi-carrier network. The UMTS system does not support IMSI hashing to assign idle UEs to different frequencies based on their IMSI within the same LAC. As a result, when paging a UE, the network has to send the page message on all the frequencies having the same LAC. This will impact the paging channel capacity. To improve the utilization of paging channel capacity, the operator can assign different frequencies with different LAC. However, this will increase the inter-frequency cell reselection latency since LAU and RAU are needed after the reselection.

For different operation objectives and network deployments, the corresponding cell reselection configuration is also different. Hence, instead of providing a one-size-for-all configuration guideline, it will more beneficial for us to discuss parameter configurations with respect to individual examples. In addition to the generic discussions that apply to most of the inter-frequency cell reselection configurations, the reasoning behind the particular setting in each particular example is also provided. Hence, the reader can have a good understanding of why a particular parameter is set at a certain value and how this parameter can be further fine tuned.

In the following, we will first describe inter-frequency cell reselection procedures and parameters defined in 3GPP standards and discuss common issues concerning inter-frequency cell reselection implementation. Then, we will dive into individual network deployment and operation scenarios and discuss the corresponding cell reselection configuration examples.

A.1 Parameters

The following parameters are defined in the 3GPP standard for inter-frequency cell reselection.

Table 26: Inter-frequency Cell Reselection Parameters

Parameter Name	Comments

Cell Barred	If set to true, idle UEs are not allowed to camp on the cell.
FDD-quality-measure	RSCP or E_c/N_o
$S_{intersearch}$[20]	The threshold below which the inter-frequency cell search starts
Q_{hyst1}[21]	The hysteresis used for ranking the serving cell (RSCP)
Q_{hyst2}	The hysteresis used for ranking the serving cell (E_c/N_o)
$T_{reselection}$	The cell ranking evaluation period before the UE changes the serving cell
$Q_{offsets1,s,n}$[22]	The offset used for ranking the non-serving cells (RSCP)
$Q_{offsets2,s,n}$	The offset used for ranking the non-serving cells (E_c/N_o)
Neighbor List	The potential candidates specified by the network for cell reselection
$Q_{rxlevmin}$	Minimum CPICH RSCP (minus $P_{compensation}$) for the cell to be suitable
$Q_{qualmin}$	Minimum CPICH E_c/N_o for the cell to be suitable

For inter-frequency cell reselection the neighbor list broadcasted on the overhead channel (in SIB11/SIB12 on PCCPCH) can consists of up to 32 inter-frequency cells on up to 2 other frequencies. UTRAN controls when the UE takes measurements of inter-frequency cells by setting the $S_{intersearch}$ threshold. In the paper, we assume $Q_{rxlevmin}$ and $Q_{qualmin}$ to be the same for both frequencies.

There are a few other parameters defined by the standard that can impact the inter-frequency cell reselection, such as the ones given in Table 27. They should be jointly considered when setting the inter-frequency cell reselection parameters.

Table 27: Inter-frequency Cell Reselection Parameters

Parameter Name	**Comments**
$S_{intrasearch}$	The threshold below which the intra-frequency cell search starts
$S_{searchRAT}$	The threshold below which the inter-RAT cell search starts
$S_{searchHCS}$	It specifies the limit of S_{rxlev} in the serving cell below which the UE shall initiate search of all neighboring cells for the serving cell (see Section A.2.

.

A.2 Cell Reselection Procedure

The UE performs measurements on its neighbor cells to determine when it is desirable to perform a cell reselection. The inter-frequency measurement requires the UE to tune to the target frequency. When the UE is in Idle, Cell_PCH, and URA_PCH states, it normally performs inter-frequency measurements during its wake up time. When the UE is in Cell_FACH state, it normally performs inter-frequency measurements during the interval determined by the FACH Measurement Occasion cycle length coefficient specified by the network[23]. During this interval, the UTRAN will not transmit any data to the UE on the FACH.

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[20] If the inter-frequency neighbor list is empty, the UE will not start inter-frequency search and the $S_{intersearch}$ parameter can omitted, i.e., not sent over the air.

[21] In the idle mode, the serving cell refers to the cell that the UE camps on. Non-serving cells are also referred to as other cells.

[22] The recommended settings for $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$ are respect to inter-frequency cells. They should not be applied to intra-frequency cells.

[23] This applies only to the UEs with only one receiver chain. For UEs with dual receiver chains, the inter-frequency measurement can be performed anytime.

During the cell reselection, the UE checks the suitability of each cell in the neighbor list and ranks the suitable neighbor cells, along with the serving cell, according to the ranking criteria specified by the standard. If a cell other than the current serving cell is the highest ranked cell, that cell is chosen for cell reselection. Before the UE chooses a new cell to camp on, that cell must be higher ranked than the serving cell for $T_{reselection}$ seconds. Also, the UE must have been camped on the current serving cell for at least one second.

A cell is determined to be suitable must satisfy the condition

$$S_{rxlev} > 0 \text{ and } S_{qual} > 0$$

where

$$S_{rxlev} = Q_{rxlevmeas} - Q_{rxlev\min} - P_{compensation}$$
$$S_{qual} = Q_{qualmeas} - Q_{qual\min}$$

$Q_{rxlevmeas}$ and $Q_{qualmeas}$ are the measured CPICH RSCP and CPICH E_c/N_o, respectively. $P_{compensation}$ is determined as max(UE_TX_PWR_MAX_RACH – P_MAX, 0). P_MAX is the maximum transmission power of the UE and UE_TX_PWR_MAX_RACH is the maximum allowed transmission power on PRACH.

In addition, for a cell to be suitable it must also:

- Belong to the currently registered PLMN
- Not be barred
- Not belong to a forbidden location area

This additional information is obtained by reading the system information messages on the target cell.

The UE starts taking inter-frequency measurements if $S_{qual} < S_{\text{intersearch}}$. For Release 5 (or later) UEs, the inter-frequency measurement will also start if $S_{rxlev} < S_{searchHCS}$ [24].

The UE computes the ranking of the serving cell as

$$R_s = Q_{meas,s} + Q_{hysts}.$$

The UE computes the ranking of the neighbor cell "n" as

$$R_n = Q_{meas,n} - Q_{offset,s,n}.$$

A.2.1 Typical RF Characteristics

From the inter-frequency cell reselection procedure specified in the 3GPP standard, we see that inter-frequency cells and intra-frequency cells are treated equal when the UE performs the cell ranking. Hence, conceptually the UE can simply treat vertical neighbor cells as horizontal neighbor cells and the operator can configure the inter-frequency cell reselection to be the same as the intra-frequency cell reselection, i.e., with the same parameter values.

In practice, however, the two types of cell reselection operations have their unique characteristics and they should be taken into account in the corresponding parameter configuration. For instance, the RF propagation characteristics are different between the environment for inter-frequency cell reselection and the environment for intra-frequency cell reselection.

Inter-frequency cell reselection normally occurs between vertical neighbors, while the intra-frequency cell reselection occurs between horizontal neighbors. Correspondingly, RF signal variation between the source and neighbor cells is different for the two types of cell reselections. Figure 18 illustrates the typical relative RF signal

[24] The recommendation on the setting of $S_{searchHCS}$ is not covered in the current revision of the paper. It will be included in the future revisions.

change between the intra-frequency neighbors and the inter-frequency neighbors[25]. The plot on the top is the RF variation between the intra-frequency (horizontal) neighbors. The relative RF change between the neighboring cells is mainly due to the geometry change as the UE moves. The plot on the bottom is the RF variation between inter-frequency (vertical) neighbors. The relative RF change between the cells is mainly due to the cell load change or local fading.

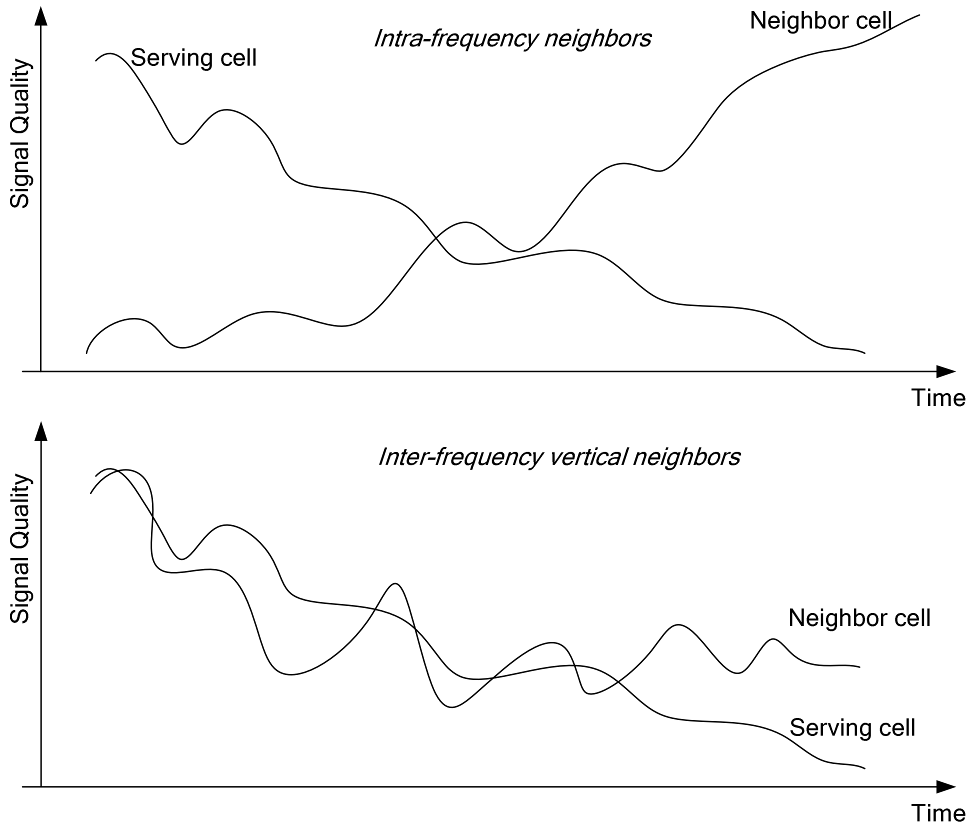

Figure 18: RF variation between the serving cell and neighbor cell

Since the RF variation due to load change and fading is faster than the RF change due to geometry, the inter-frequency cell reselection and ping-pong behavior can occur quite often if the hysteresis for cell reselection is not set properly, especially when the inter-frequency cell reselection is enabled for mobility management. This hysteresis is realized by properly setting the values of $Q_{offset1,s,n}$ and $Q_{offset2,s,n}$. Also, in this typical example, the trends of RF signal degradation between vertical neighbors are the same. In such a case, reselecting to a vertical cell does not serve the purpose of mobility management. Hence, a conservative (i.e., relatively high) hysteresis may be used for inter-frequency cell reselection between vertical neighbors with the same surrounding environment.

When the vertical neighbors do not have the same surrounding environment, such as in the hot-spot deployment case, the inter-frequency cell reselection need not to be conservative as the UE moves out of the hot-spot area. Also, in such as case, the inter-frequency cell reselection parameter setting will be asymmetric due to the asymmetric RF environments among different carriers. This point is further illustrated in later discussions.

[25] By "typical" we assume the same surrounding RF environment on each carrier. For instance, vertical cells are all embedded cells. The average loads on the vertical cells are about the same and the average load on the neighbor cells that are vertical to each other are also the same.

A.3 Inter-frequency Cell Reselection Latency

The inter-frequency cell reselection latency measures the duration from when the UE stops receiving broadcast and paging messages on the old frequency to when the UE start to receive broadcast and paging messages on the new frequency. During this period, the UE will not be able to receive any paging messages addressed to the UE. A well configured system should have low inter-frequency cell reselection latency.

Besides the inter-frequency cell reselection parameter setting, the cell reselection latency is also affect by the network configuration. In particular, if the network is configured to have different LAC on different carriers, inter-frequency cell reselection will result in LAU, which then results in long cell reselection latencies, thus increasing the mobile terminated (MT) call setup failure rate, due the fact that the UE is not able to receive paging messages. Hence, unless the PCH and RACH capacity is of concern, the operator should try to avoid such a situation by configuring vertical neighbors with the same LAC[26].

By assigning vertical neighbors to the same LAC, the network has to page UEs on all the frequencies within the location area. This increases the traffic on the PCH. For a two-carrier network, the paging traffic is doubled. For a three-carrier network, the paging traffic will be 3 times of what a single carrier network has. Operators may see paging capacity issue as they deploy 3 or more carrier networks. Proper PCH configuration, such as adding another S-CCPCH, and location area dimensioning will be needed to solve the problem.

In the examples discussed in the rest of the section, we assume vertical neighbors are assigned the same LAC, unless otherwise explicitly pointed out. The reader should, however, keep in mind that it is possible that vertical neighbors are assigned different LACs due to specific circumstances.

A.4 RSCP versus Ec/No

One parameter that requires careful consideration by the operator when configuring the inter-frequency cell reselection is *FDD-quality-measure*, which specifies whether RSCP or E_c/N_o based measurement should be used during inter-frequency cell reselection. Different from the intra-frequency cell reselection where *FDD-quality-measure* E_c/N_o and RSCP can be set interchangeably for cell reselection[27], the operator needs to set this parameter based on the network management objective. The RSCP based measurement is directly related to the signal propagation path loss and independent of the cell load. On the other hand the Ec/Io based measurement directly reflects the cell load and cell geometry but is less dependent on the path loss.

For instance, if the main objective is to maintain reliable service continuity as the UE moves out of the Frequency 2 coverage area, the RSCP based measurement may be considered. Figure 19 illustrates the normal cell reselection behavior when *FDD-quality-measure* is set to RSCP. On the one hand, as the UE in Cell (F2,2) moves to the left, it performs inter-frequency cell reselection when the signal quality of Cell (F1,1) becomes better. On the other hand, as the UE in Cell (F1,1) moves to the right, it may perform the intra-frequency cell reselection to Cell (F1,2) but may never switch to Cell (F2,2) because the RSCP measurements from Cell (F1,2) and Cell (F2,2) are the same. Inside Cell (F2,2) and Cell (F1,2), the inter-frequency cell reselection probability is also low given the same propagation behavior on the two frequencies[28]. Hence, overall there will be many UEs camped on Frequency 1 while there will not be many UEs camped on Frequency 2. From the service continuity point of view, however, setting *FDD-quality-measure* to RSCP meets the objective.

Setting *FDD-quality-measure* to RSCP provides reliable inter-frequency cell reselection, however, at the cost of reduced coverage, especially when the second carrier is under loaded. As shown in Figure 20, when the load on Cell (F2,2) is low, the RF signal E_c/N_o is generally better than that of Cell (F1,2) and part of Cell (F1,1), and yet, UEs in the Cell (F1,1) and Cell (F1,2) cannot benefit the better signal quality in Cell (F2,2) unless *FDD-quality-measure* is

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[26] In practice, this is feasible since the configuration is inline with the UTRAN architecture from most of the infrastructure vendors. For instance, vertical neighbors are often served by the same node-B (and may even share the same antenna), hence assigning vertical neighbor s (from the same node B) with the same LAC simplifies the network configuration.

[27] This is because E_c/N_o is RSCP divided by RSSI, which is the same for all the intra-frequency cells.

[28] Here, we assume Frequency 1 and Frequency 2 are within the same band class. The discussion with respect to the multiple carrier deployment using different signal bands is given in a different subsection.

set to E_c/N_o. By moving UE to cells or carriers with a better signal quality the call access performances, such as paging success rate, random access success rate, and random access latency, can be improved.

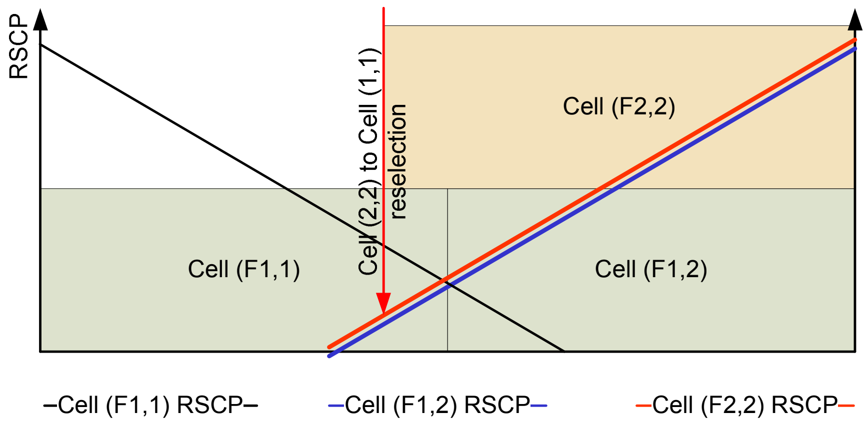

Figure 19: Cell reselection behavior based on RSCP measurement

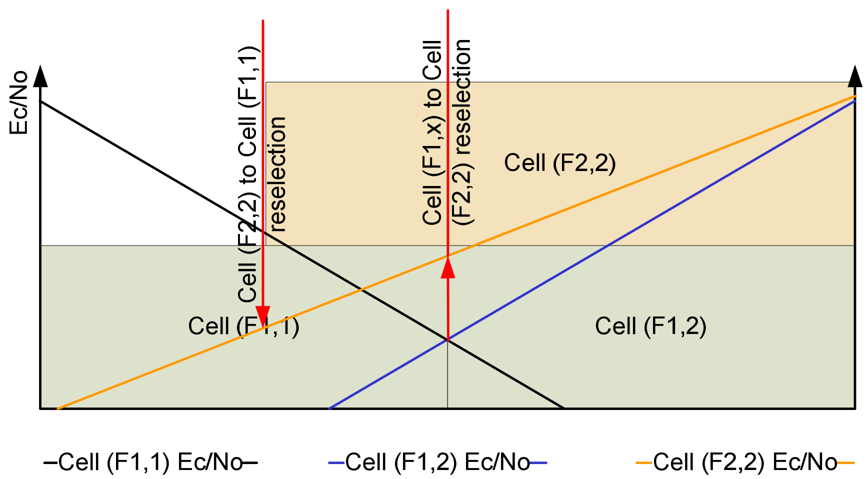

Figure 20: Cell reselection behavior based on Ec/No measurement

Figure 20 shows the inter-frequency reselection behavior when *FDD-quality-measure* is set to E_c/N_o. Here, we consider the situation when the load on Cell(F2,2) is smaller than the load on Cell(F1,2). We see two inter-frequency cell switches. The Cell(F2,2) to Cell(F1,1) reselection occurs when the UE moves out of the Frequency 2 coverage area, and the Cell(F1,X) to Cell(F2,2) reselection happens as the UE moves towards the cell boundary area on Frequency 1. The advantage of such a setting is the improved coverage quality, since the UE is allowed to move to a better cell with a stronger E_c/N_o. The disadvantage is the lower reliability of cell reselection transition compared with setting *FDD-quality-measure* to RSCP. As the UE moves left into the Cell(F1,1) coverage area, the E_c/N_o measurement on Cell(F2,2) may still be good in the low load situation but the RSCP signal has already degraded. Or, the E_c/N_o measurement on Cell(F2,2) may already degraded in the high load situation while the RSCP signal is still strong (not shown in the figure). As a result, the service failures can also occur due to paging failure, or access failure, or handover failure immediately after the UE entered the connected mode. To reduce the failure rates, the operator can make the cell reselection from Frequency 2 to Frequency 1 faster while making the cell reselection from the F1 to F2 conservative. More discussion is given in Section 3.1.1.

Appendix B Inter-Frequency Handover Fundamentals

Inter-frequency handover (IFHO) allows the UTRAN to switch the serving frequency of the UE during the Cell_DCH state. This operation is intended to serve two objectives.

- To maintain the desired service continuity or coverage continuity,
- To maintain the desired system capacity or load balance, and
- To provide the separation of application/traffic for better radio resource management

The service continuity measures the system performance from the UE's perspective and can be expressed by metrics such as call interruption duration during the handover, call drop rates due to the handover, and for packet data, the data throughput degradation due to the inter-frequency handover. The load balance between carriers measures the system performance from the UTRAN perspective and is expressed by the metrics such as average call blocking rate, the average downlink DPCH channel power, or the downlink cell power limiting duration, etc..

Like the inter-RAT handover, the inter-frequency handover procedure normally consists of two steps.

- The inter-frequency measurement[29] and
- The inter-frequency handover

The inter-frequency handover parameters can be configured to control the triggering of the inter-frequency measurement and the conditions of sending the measurement report, which essentially triggers the handover. The setting of the parameters depends on the network operation objective, network service configuration, the cluster configuration, the types of UEs in the network, and the traffic distribution in the network.

In this section, we look at a few examples with different combinations of network configuration, service configuration, and operation emphasis. Through the parameter setting discussion in these examples, we provide guidelines on the inter-frequency handover parameter configuration.

B.1 Parameters

The following parameters are specified by the 3GPP standard inter-frequency handover.

Parameter Name	Definitions of the Event Report	Comments
Event 2a (E2A) threshold	Change of the best frequency	Can be used to trigger inter-frequency handover for load sharing.
Event 2b (E2B) threshold	The estimated quality of the currently used frequency is below a certain threshold **and** the estimated quality of a non-used frequency is above a certain threshold	Can be used to trigger inter-frequency handover for load sharing or for a better coverage.
Event 2c (E2C) threshold	The estimated quality of a non-used frequency is above a certain threshold	Can be used to trigger inter-frequency handover for moving UE to HSPA capable frequencies.
Event 2d (E2D) threshold	The estimated quality of the currently used frequency is below a certain threshold	Can be used to activate the compressed mode for inter-frequency measurements.
Event 2f (E2F) threshold	The estimated quality of the currently used frequency is above a certain threshold	Can be used to deactivate the compressed mode due to E2D.
Event 1f (E1F)	A Primary CPICH becomes better than an	Can be used to activate the compressed

[29] This step is not needed for blind handover.

threshold	absolute threshold	mode for inter-frequency measurements.
Event 1e (E1E) threshold	A Primary CPICH becomes worse than an absolute threshold	Can be used to deactivate the compressed mode due to E1F.
Event 6a (E6A) threshold	The UE Tx power becomes higher than an absolute threshold	Can be used to activate the compressed mode for inter-frequency measurements.
Event 6b (E6B) threshold	The UE Tx power becomes less than an absolute threshold	Can be used to deactivate the compressed mode due to E6A.
CM triggering Period		Controls the compressed mode activation frequencies. May be used for load balancing related inter-frequency handover control.
CM duration		Controls the compressed mode activation duration. May be used for load balancing related inter-frequency handover control

Again, there are many other parameters that are used to control the inter-frequency handover but only observable from the network side. For instance, the network can trigger the inter-frequency handover for load sharing with a limit on the maximum number of simultaneous CM activated in the network. Also, the network may have an internal timer to decide how long a UE has to stay in the CM. These parameters are infrastructure implementation dependent and should be studied carefully before any configuration changes to the above thresholds are made in the field.

In addition, the setting of these thresholds for inter-frequency measurement using compressed mode and inter-frequency handover should be consistent with the threshold setting for inter-RAT measurements and inter-RAT handover. For instance, if the operator wants to keep the call within the UMTS system, the inter-frequency measurement should be activated earlier than the inter-RAT measurement. Hence, the corresponding E2D or E1F threshold will be higher the inter-frequency measurement than for the inter-RAT measurement.

B.2 Handover Procedure

For the deployment scenarios where inter-frequency handover is needed, the well designed and configured handover mechanism (or handover algorithm) is the key to achieve the deployment objectives. In particular, what information (or measurement) is used and when the handover is performed need to be fine tuned with respect to the deployment scenarios. In this section, we briefly summarize the inter-frequency handover mechanisms defined by the 3GPP standard.

B.3 Measurements

Although the standard defines basic mechanisms for inter-frequency handover, it does not dictate how the handover procedure should be implemented. It is the individual infrastructure vendor's responsibility to make it work. In the implementation, infrastructure vendors are free to use any measures to decide when and how the inter-frequency measurements are triggered.

Essentially, there are two types of information available to the network. One is the information reported by the UE, the other is the information directly collected by the network. The latter can be anything from power control measurements (transmission power, power control commands, and target SIR) to traffic flow measurements (number of bits, delays, and packet drops). There is no limit on which information to use and how the information is used from the standard point of view. Given the proprietary nature of infrastructure vendors' implementation, we will not discuss the usage of this information in this paper.

With the UE reported information, however, the network can have more accurate evaluation of the downlink radio frequency (RF) environment, in particular the measurements of the Ec/No and RSCP of both the serving and the non-serving frequencies. In addition, the UE can also report its uplink power consumption measurement to indicate the uplink condition. To measure the downlink RF of the non-serving frequency, the UE needs to be in the compressed mode[30], which can be triggered either by the Event 2d or Event 1f report from the UE, or based on the UE internal measurements (Event 6a), or by the network internal measurements or periodically. As for how and when the compressed mode (CM) should be triggered, it depends on deployment scenarios.

B.3.1 IFHO for Service and Coverage Continuity

In the hot-spot deployment scenario, the inter-frequency handover is needed for maintaining the call continuity as the UE moves out of the hot-spot coverage area and needs to be moved from the second frequency to the first frequency. In such a handover scenario, the triggering of the compressed mode can simply be based on the serving frequency CPICH quality, because the degradation of CPICH signal (RSCP or E_c/N_o) indicates that the UE is moving away from the hot spot. Therefore, the network may move the call into compressed mode when the UE reports an Event 2d or Event 1f.

For the two CPICH signal measures: RSCP and E_c/N_o, it is expected that RSCP based threshold is more suitable for triggering the compressed mode, because the RSCP does not changes with the load and provides a good coverage indication. This is the case for border cells. For embedded cells, the RSCP based measurement may not be good for triggering the compressed mode if pilot pollution is observed in the area.

The triggering of the compressed mode can also be based on uplink quality, which can be inferred from the UE transmission power. As the UE moves out of the hot spot coverage area, the uplink degradation causes the UE to transmit at its maximum power. In such a case, the UE can report Event 6a, which can be used to trigger the compressed mode by the network.

B.3.2 IFHO for Load Sharing

If the purpose of the inter-frequency handover is to balance the load between different frequencies, a UE may be moved from one frequency to another even if its serving frequency CPICH signal quality (RSCP or E_c/N_o) is still good.. In other words, different from the IFHO for service continuity, the UE being handed over to the other frequency is not necessarily located at the edge of the coverage area of its serving frequency and can be anywhere within a cell. As a result, the serving CPICH signal quality (RSCP and E_c/N_o) is not very suitable as a trigger of the compressed mode. Instead, the compressed mode may need to be started periodically for all the UEs in the multi-carrier coverage area [7] or be activated based on other information. For instance, the compressed mode for inter-frequency measurement can be activated immediately for new calls after the call setup when the network determines there is a need for moving the UE to a different carrier.

If the infrastructure vendor does not provide a mechanism to activate compressed mode based on the information other than the RSCP and E_c/N_o measurements, the operator should choose E_c/N_o based measurement for compressed mode activation. At least, E_c/N_o does contain the load information and we should not trigger CM on the carrier that has low load.

Since the compressed mode operation impacts power control and leads to the increase of interference [8], the network needs to carefully control the period of compressed activation for each UE, as well as how many UEs can be in compressed mode simultaneously as suggested in [7]. This is because too many UEs simultaneously in compressed mode can cause OVSF code blocking and significant capacity reduction. The control of periodic compressed mode, as well as the duration of the compressed mode activation, depends on the implementation of individual infrastructure vendors.

Although the compressed mode many not be triggered based on the E_c/N_o measurement, the inter-frequency handover needs to be triggered based on the E_c/N_o measurement. Using RSCP will achieve the load sharing objective, since it cannot guarantee always handing UE from the high load carrier to the low load carrier.

Another alternative is to perform blind handover. For instance, the network can perform blind handover to move user from one frequency to another upon the detection of the load imbalance between the carriers. In such a case, there is no need for compressed mode activation. However, the call drop rate may be affected as discussed in Section B.5.

[30] Compressed mode is needed for UEs that have one receive chain to make inter-frequency measurements. UEs with dual receive chains do not need to be in the compressed mode to take inter-frequency measurements.

B.3.3 IFHO for HSPA Support

Besides the coverage consideration and load sharing, the inter-frequency handover is also needed when the multi-carrier deployment is based on capability or application separations. For instance, the release 99 support is mainly deployed on one carrier, while the HSPA support is mainly carried on a second carrier. For such a deployment scenario, the inter-frequency handover is needed to move the PS data traffic of a HSPA capable UE into or out of the second frequency as the UE moves in or out of the multi-frequency area.

For such handover cases, both signal strength based triggering and periodic triggering are needed for activating the compressed mode, depending on whether the UE is entering or leaving the multi-frequency area. Or, the network can perform blind handover for UEs that are HSPA capable.

B.4 Inter-Frequency Handover impacts on System Performance

B.4.1 Compressed Mode Impact

In general, the compressed mode operation causes interference to increase in the system. Therefore, the operator needs to pay attention to the compressed mode performance for inter-frequency handover, such as the number of simultaneous and total CM activations, the CM success rate (i.e., the rate that a compressed mode leads to a successful inter-frequency handover) and the average CM duration.

For the case of load balancing where periodic compressed mode activation may be used, the operator also needs to check how often compressed mode is turned on and with what duration as a function of a load balancing target, as well as the average power consumption increase due to the CM activation. Note that frequent compressed mode activation may result in a better load balancing, but at the same time causes more reduction of the system capacity, which defeats the original objective of load balancing.

B.4.2 Handover Trigger Impact

Notice that the RSCP measurement does not change with respect to the network load, while the E_c/N_o measurement varies as the network load changes. It is expected that the performance of the two measurement based handovers will not be the same. Both RSCP and E_c/N_o based triggering mechanisms for inter-frequency handover have been discussed in literatures and their performances have also been reported. For instance, in [7], the authors reported that in a simulated one-to-one overlay scenario, the RSCP based inter-frequency handover performs better than the E_c/N_o based handover with lower call drop probability. However, the E_c/N_o based handover, in the same one-to-one overlaying deployment, performs better than RSCP based handover with lower call blocking probability due to load balancing effect. This is consistent with the report in [9], which shows the average load reduction when the E_c/N_o based inter-frequency handover for load balancing is used.

In real networks, the operator can choose to configure RSCP or E_c/N_o based handover, depending on whether the inter-frequency handover is for mobility management or load balancing or depending on the overall network performance as discussed above. However, no matter what handover approach is used, the call quality should not be degraded. For this reason, for mobility management, it is very often that both RSCP and E_c/N_o based handovers are configured. Since CPICH RSCP and E_c/N_o are both essential in maintaining good radio connections, inter-frequency handover should be initiated whenever either RSCP or E_c/N_o is degraded and the risk of call drops increases.

B.5 Blind Inter-Frequency Handovers

There are basically two types of inter-frequency handovers: the blind handover and non-blind handover.

The blind handover has essentially the same behavior of call redirection (see Section B.6). With the blind handover, the network does not need the UE to measure and report the downlink RF environment of the target frequency and makes the handover decision based on information collected directly by the network and the reported UE measurements on the serving frequency only. Comparing with non-blind handover, the blind handover does not require the UE to be in compressed mode, hence avoids the interference increase due to compressed mode activation. However, the call drop rate of blind inter-frequency handover is expected to be higher (hence low reliability) since the RF condition on the target frequency cell is not known at the time of handover.

The blind handover could be applied in the case where the cell deployments on different carriers are the same, such as the one-to-one overlay scenario, resulting in the same RF propagation characteristics on all the carriers. In such a case, the handover reliability can be improved provided the loading on each carrier is known to the network and is properly used by the network in determining the handover.

For non-blind handover, the target frequency RF measurement report from the UE is needed for the network to make the handover decision. The compressed mode needs to be activated for the UE to make the measurements. The triggering of the compressed mode has been discussed in the previous subsection.

For the simplest handover implementation, network makes handover decision solely based on the UE reports. For the IFHO for continuity case, the network can start the inter-frequency handover when the measurement report shows that the serving frequency is below a certain threshold and the target frequency signal quality (RSCP and/or E_c/N_o) is better than a certain threshold. For the IFHO for load sharing case, the network can start the inter-frequency handover when the measurement report shows the target frequency E_c/N_o is Δ dB higher than the serving frequency E_c/N_o. (For load sharing, the RSCP based handover triggering is not as good as the E_c/N_o based as reported in [8].) Therefore, event based reporting (such as Event 2a or Event 2b reports) will be sufficient for the network to trigger handover.

For the IFHO for HSPA support case, the operator may want to move the traffic of a HSPA capable UE to the HSPA frequency as early as possible to take advantage of the high spectrum efficiency of the HSPA system. In such a case, the network will trigger inter-frequency handover as long as the target frequency signal quality (RSCP and/or E_c/N_o) is above a certain threshold. Therefore, the event based reporting of Event 2c can be used to trigger the handover.

B.6 Call Redirection

Although inter-frequency cell reselection has the potential of balancing the loads between carriers, load balancing can be more effectively realized using call redirection and/or inter-frequency handover.

In addition, call redirection is also needed to support the *application separation* deployment scenarios with the first carrier supporting Rel-99 and the second carrier supporting Rel-99+HSPA. For such a deployment scenario, a typical call redirection scenario looks like this. At the initial call setup, the UTRAN assigns the UE a Rel-99 DCH on Frequency 1 using *RRC Connection Setup* message. As the network detects needs of the UE to use HSPA, it redirects the UE to Frequency 2 and moves the UE traffic from DCH to HS-DSCH. A simplified call flow in Figure 21 illustrates this scenario.

Depending on the implementation of individual infrastructure vendors, call redirection can also occur at other stages of a call. For instance, the UTRAN can directly assign the UE to a carrier different from the origination carrier in the *RRC Connection Setup* message, provided the UTRAN knows that the UE is HSPA capable and the UE is originating a PS call. This possible for Release 6 UEs who can send *RRC Connection Request* messages with the *UE Capability Indication* to inform the UTRAN their capabilities of supporting HSPA. The UTRAN can also initiate a *Physical Channel Reconfiguration* to move a PS call to Frequency 2 after the UE enters the HSPA coverage area. The UTRAN determines that a UE is in the HSPA coverage area if, after soft handover, all the cells in the active set have HSPA capable vertical neighbors.

From Figure 21 we see that distinction of inter-frequency handover and call redirection is not significant. Looking at the call flow in the figure, it is essentially a blind inter-frequency handover. Hence, in the rest of the paper, we will interchangeably use call redirection and blind handover[31]. Depending on the context, some places we use the term “blind handover” and in other places we use “call redirection”. Not supporting call direction will mean not supporting blind handover.

[31] One can also argue that inter-frequency measurement steps may also be included in the call redirection call flow in Figure 21. For the naming simplicity, we will refer that as the inter-frequency handover, instead of call redirection.

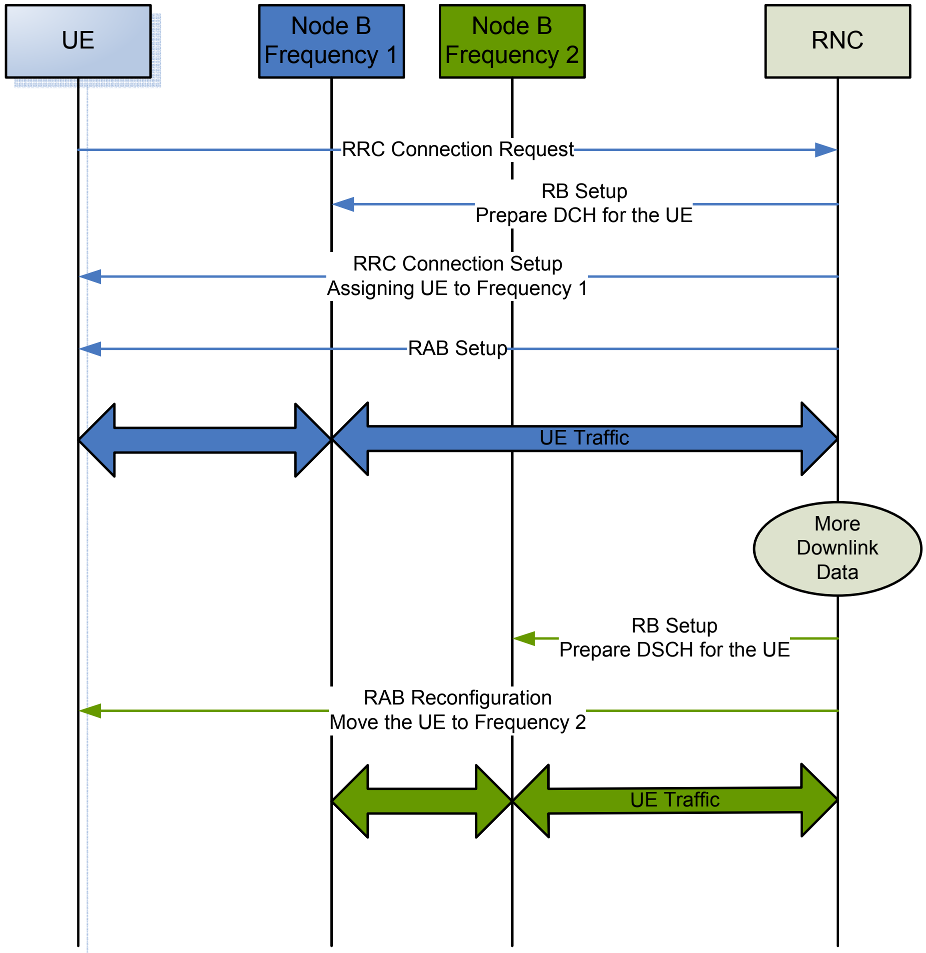

Figure 21: A simplified call redirection call flow