Performance of dual-searcher mobiles in hotspot scenarios

1. Introduction

Third Generation Partnership Project (3GPP) High Speed Packet Access (HSPA) Release 8 specifications introduced the RRC signaling flag "*Adjacent Frequency measurements without compressed mode*". When this flag is set to "TRUE" by a User Equipment (UE), it does not require Compressed Mode (CM) to perform Common-Pilot Channel (C-PICH) measurements on a frequency that is adjacent (i.e., within 5 MHz) to the anchor frequency. We refer to such a UE as a ***dual-searcher UE***. A UE, on the other hand, that does not support this feature requires Compressed Mode to measure on the adjacent frequency: we refer to such a UE as a ***single-searcher UE***. Note that Compressed Mode requires the UE to tune-away to measure the other frequency during pre-configured slots: this degrades throughput on the serving frequency.

We implemented the dual-searcher UE functionality in a prototype, and compared its performance with that of a single-searcher UE. In our tests, both types of UEs are Dual-Cell HSDPA (DC-HSDPA) capable, i.e., they can receive downlink data on two adjacent carriers. The evaluation focused on so-called ***hotspot scenarios***, i.e., scenarios where a single NodeB or a group of NodeBs, referred to as ***hotspot NodeBs***, in a given area support two frequencies (and the dual-cell HSDPA feature), while the other NodeBs support a single frequency. The frequency supported by all NodeBs is the universal frequency, while the other frequency, supported only by the hotspot NodeBs (or hotspots), is the hotspot frequency.

Results from our prototype show that a dual-searcher UE, by being able to detect and measure the hotspot frequency over a wider geographic area than a single-searcher UE, can be served by two carriers over a larger area. Moreover, a dual-searcher UE does not require CM to perform such measurements, unlike a single-searcher UE. This translates to throughput gains over a single-searcher UE. Note that dual-searcher capability requires additional searcher resources at the UE, compared to single-searcher capability.

This report is organized as follows. In Section 2, we describe the two hotspot-related scenarios that our testing focused on. The inter-frequency handover (IFHO) call flows for single-searcher and dual-searcher UEs are reviewed in Section 3. Our prototype setup and OTA coverage is discussed in Section 4, while Section 5 describes results of our testing. Finally, we present conclusions in Section 6.

2. Hotspot Deployments

Our evaluation focused on heterogeneous deployments similar to that shown in Figure 1, where one NodeB, NodeB B, supports the universal and hotspot carriers, while the other NodeB, NodeB A, supports only the universal carrier. Such hotspot NodeBs may typically be deployed in areas where user density

and consequently, traffic intensity is significantly higher than in other parts of the network. Note that Figure 1 shows only a simplified example of a hotspot deployment, and real hotspot deployments may consist of more than one of each type of NodeB.

As Figure 1 shows, the signal from the hotspot NodeB, NodeB B, on the hotspot carrier does not see much interference and its signal quality remains high over a large coverage area. This means that NodeB B is the preferred serving NodeB (i.e., it can provide higher throughput) for a DC-HSDPA UE over a large coverage area compared to NodeB A.

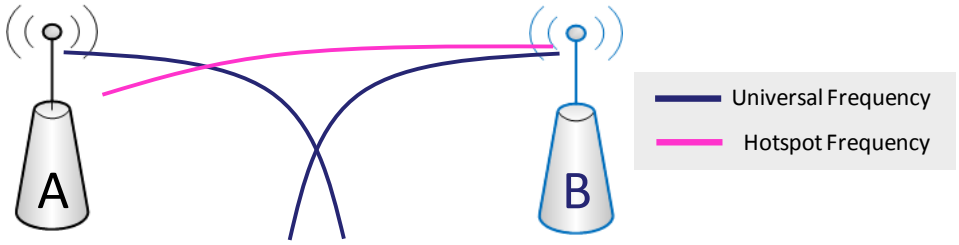

Figure 1: C-PICH E_c/No profile in a heterogeneous deployment scenario

In such a scenario, we consider dual-searcher and single-searcher UEs moving *into the coverage of* and *away from the coverage of* the hotspot NodeB. We look at the mobility events for each type of UE, and compare throughputs seen by each.

2.1 Scenario 1: UE moving towards hotspot NodeB

Scenario 1 involves the UEs moving towards the hotspot NodeB, as shown in Figure 2. We use the blue curve to denote the C-PICH Ec/No of the universal carriers and the magenta curve to denote the C-PICH Ec/No profile of the hotspot carrier.[1] In addition, we use bold lines to denote the serving cell(s).

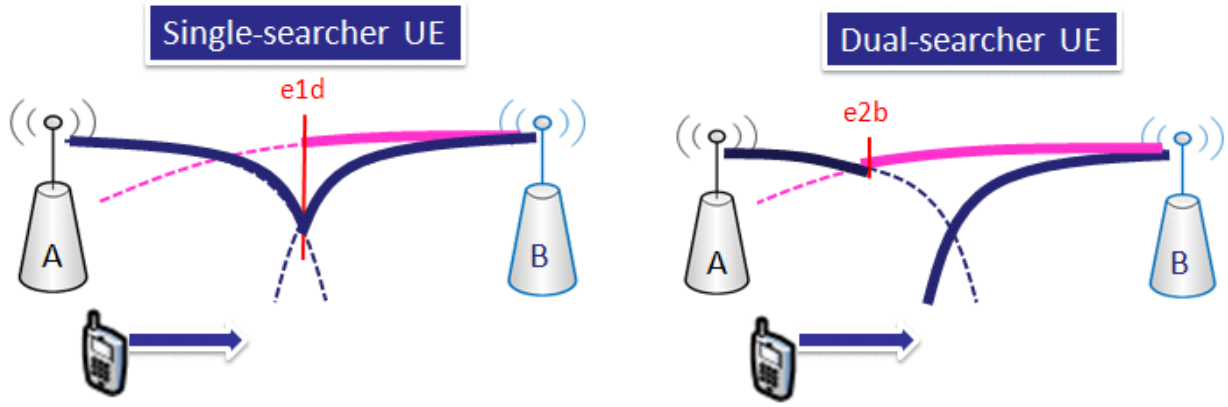

Figure 2: Scenario 1 – UE moving into the hotspot

Both the single-searcher and the dual-searcher UEs are initially served on the universal carrier of NodeB A. The single-searcher UE relies on intra-frequency handover triggered by Event 1d[2] to switch to the

[1] Note that C-PICH Ec/No is one of the quantities that can trigger mobility related events.

[2] Mobility events are described in Appendix 1.

Hotspot NodeB (i.e., NodeB B) as its serving cell(s). After Event 1d, the single-searcher UE starts dual-cell downlink reception from the hotspot NodeB.

The mobility procedure is different for the dual-searcher UE. With the capability of searching without CM, the dual-searcher UE can perform measurements on the hotspot carrier without requiring CM. Since the hotspot carrier is subject to less interference compared to the universal carrier, it can provide higher throughput. Therefore, when the dual-searcher UE triggers an Event 2b measurement report, indicating that the hotspot carrier is stronger than the universal carrier, the network initiates an IFHO to the hotspot NodeB, i.e., NodeB B. After IFHO, the dual-searcher UE starts downlink DC-HSDPA reception from NodeB B. At this point, it is likely that the universal carrier from NodeB B may be weak (due to interference from NodeB A), and the hotspot carrier provides most of the throughput. Due to the universal carrier from NodeB B being weak, the hotspot carrier also becomes the anchor carrier, i.e., it carries the uplink channels.

Comparing the two UEs, we expect throughput gain for the dual-searcher UE since it can receive data from the hotspot NodeB over a wider coverage area.

2.2 Scenario 2: UE moving out of hotspot NodeB

In scenario 2, we consider the case in which the UEs are moving out of the hotspot, as shown in Figure 3. The UEs are initially served by NodeB B with the hotspot carrier as their anchor carrier. Note that the reason for the hotspot carrier to be the anchor is to allow for load balancing of the uplink. In the absence of such load balancing, all UEs served by NodeB B would have the universal carrier as their anchor, and the hotspot carrier would go unused on the uplink.

As the UEs move out of the coverage of the hotspot carrier, they need to perform an IFHO to the universal carrier. In the case of the single-searcher UE, CM is required to measure the quality of the universal carrier. The sequence of events is the following: (a) UE triggers Event 2d when the hotspot carrier goes below a threshold, (b) RNC configures: CM gaps, Event 2b, and the neighbor list on the universal carrier, (c) UE triggers Event 2b when the hotspot carrier is below a threshold and the universal carrier is above another threshold and (d) RNC sends a reconfiguration message, upon receiving it the UE does an IFHO to the universal carrier.

For the dual-searcher UE, on the other hand, the RNC can configure Event 2b directly (i.e., when the hotspot carrier on NodeB B becomes the UE's serving carrier): this bypasses steps (a) and (b) in the previous paragraph. The sequence of events is the following: (a) UE triggers Event 2b when the hotspot carrier is below a threshold and the universal carrier is above another threshold (note that the UE does not require CM gaps to perform measurements for this event) and (b) RNC sends a reconfiguration message, upon receiving it the UE does an IFHO to the universal carrier.

The IFHO procedure for the dual-searcher UE has the following benefits compared to that for the single-searcher UE:

- There is no throughput loss due to CM tune-away gaps.

- There is no potential degradation in CQI, as may be seen by the single-searcher UE, when CM is enabled. Note that CM operation may have some detrimental impact on the UE's physical layer performance, e.g., on time/frequency tracking loops as well as CQI.
- The time to identify and measure the universal carrier is shorter, since the universal carrier can be measured all the time, rather than only in CM gaps. This allows setting of Event 2b thresholds that maximize coverage of the hotspot, i.e., allows the hotspot carrier to be the UE's serving carrier for a longer time without impacting call reliability.

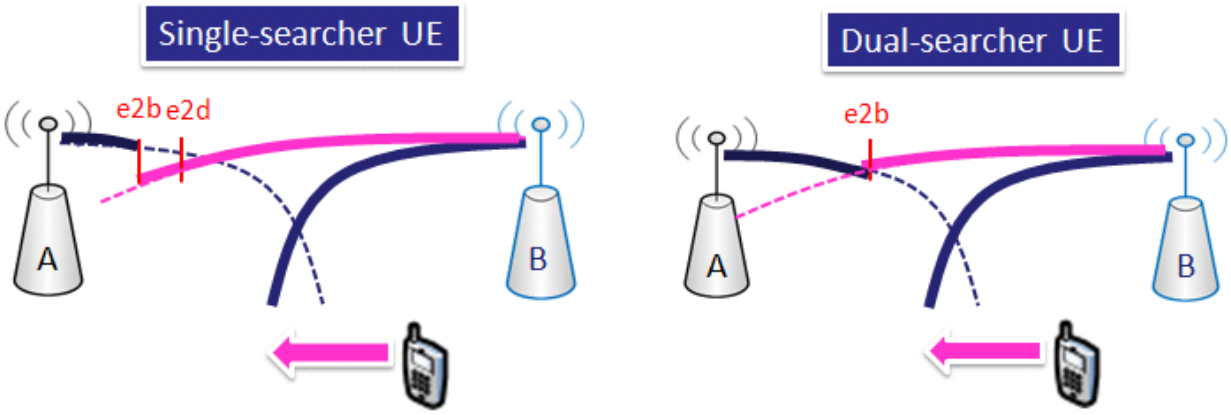

Figure 3: Scenario 2 – UE moving out of the hotspot

3. IFHO Overview

In this section, we describe IFHO procedures for single-searcher and dual-searcher UEs. The reader is referred to Appendix 1 for a summary of IFHO-related mobility events.

3.1 IFHO for single-searcher UE

The call flow of the IFHO procedure for a single-searcher UE is shown in Figure 4.

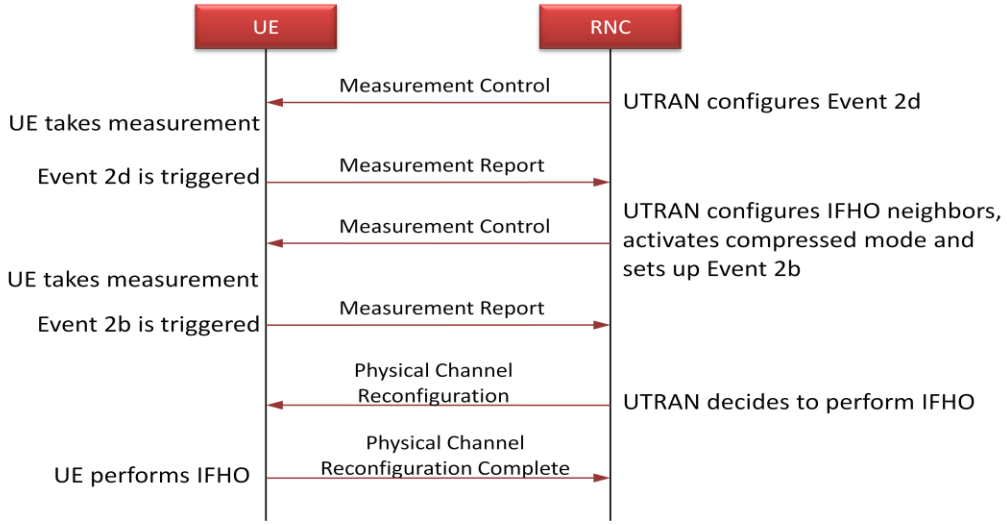

Figure 4: Call flow of IFHO for a single-searcher UE

The following are the key steps:

1. RNC configures Event 2d (with C-PICH Ec/No as the triggering quantity) when a UE enters a cell.
2. The UE sends an Event 2d measurement report to the network when the current frequency quality goes below a threshold.
3. Upon receiving the Event 2d report from the UE, the network configures the inter-frequency neighbor list, activates CM (including configuration of transmissions gaps), and configures Event 2b.
4. When thresholds for Event 2b are met, indicating that the current frequency quality is below a first threshold and the other frequency quality is above a second threshold, the UE sends an Event 2b report to the network. In response, the network sends an RRC message to re-configure the serving frequency of the UE. In our testing, the Physical Channel Reconfiguration (PCR) message is used to reconfigure the serving frequency. On finishing reconfiguration, the UE responds to the RNC with a Physical Channel Reconfiguration Complete (PCRC) message. This completes the IFHO procedure.

Compressed mode

As shown in Figure 4, a single-searcher UE relies on CM operation to perform inter-frequency measurements. During CM gaps, the UE tunes away to the other frequency during slots that are known to the serving NodeB. Figure 5 shows the CM configuration used in our study.

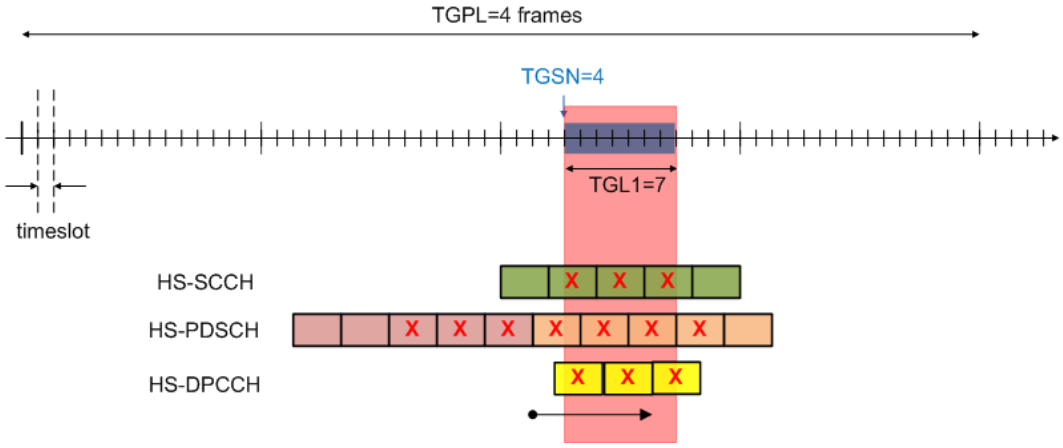

Figure 5: CM configuration

TGPL (Transmission Gap Pattern Length) denotes the periodicity of the CM gap (in 10 ms frames). TGSN (Transmission Gap Starting Slot Number) specifies the starting timeslot of the gap, and TGL1 (Transmission Gap Length 1) is the length of the CM gap (in slots). In the configuration shown in Figure 5, 7 timeslots out of every 4 frames are configured for CM.

Although the CM gaps occupy 7 out of every 60 slots in the above configuration, networks typically do not schedule the UE whenever (1) at least a part of HS-SCCH, or (2) at least a part of HS-PDSCH, or (3) at least a part of HS-DPCCH falls in a CM gap. Following these rules, we show the TTIs that the UE cannot

be scheduled by "X" in Figure 5. As seen in Figure 5, the UE cannot be scheduled for 7 out of 20 TTIs, ~ 35% of the TTIs.

3.2 IFHO for dual-searcher UE

The call flow of the IFHO procedure for a dual-searcher UE is shown in Figure 6.

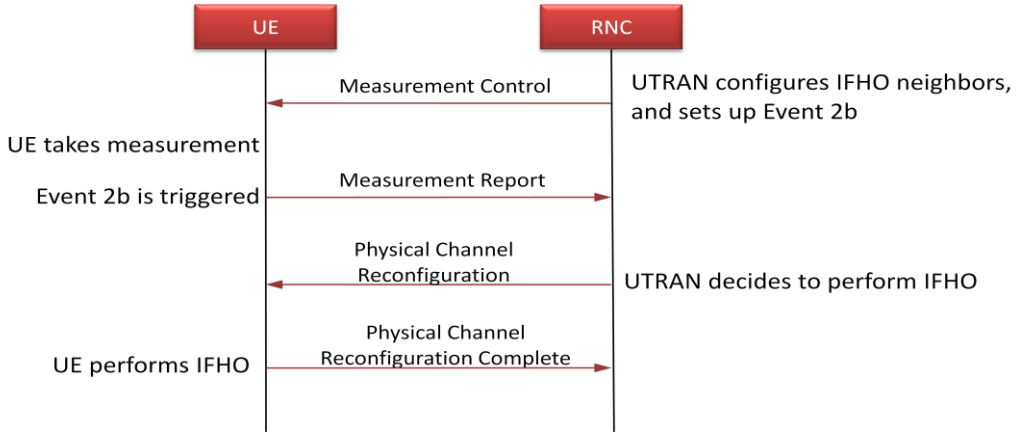

Figure 6: Call flow of IFHO for a dual-searcher UE

Comparing Figure 6 to Figure 4, the call flow for a dual-searcher UE is considerably simpler than that for a single-searcher UE. Also, the absence of Event 2d in Figure 6 means less parameters need to be optimized. Furthermore, as mentioned earlier, the time to identify and measure the "inter-frequency" carrier is shorter. This leads to more responsive searching, which has robustness benefits in challenging radio environments.

4. Details of prototype testing

The UEs used for this study were 3GPP HSPA Release 8 compliant and in particular DC-HSDPA capable, enhanced with the functionality to search on the adjacent frequency without compressed mode. The UEs can be configured either as single-searcher or as dual-searcher UEs. In the latter case and when configured to do so, the UE's physical layer performs measurements on the adjacent frequency (in addition to the anchor frequency) and the UE's RRC layer uses these measurements in evaluating IFHO. The RNC and NodeB implementations used for this study supported two different IFHO call flows (as described in Section 3) for single-searcher and dual-searcher UEs respectively.

The following are further details of our test setup:

- The UEs had single receive antennas.
- Testing for the single-searcher and dual-searcher UEs is done simultaneously. The two UEs receive signals from the same set of antennas.
- To load the neighboring cells (i.e., cells that are not serving any of the two UEs), OCNS is used to fill the transmission power to 80% of the cell power.

- The NodeBs have a round-robin scheduler.
- Throughput is measured by performing an FTP file download.

5. OTA tests

In this section, we describe our OTA environment, followed by the OTA test results.

5.1 OTA environment

Our OTA network consists of NodeBs A, B and C in the Qualcomm San Diego campus. As shown in Figure 1, NodeB A supports two sectors, NodeB B supports one sector and NodeB C supports 3 sectors (Figure 1 also shows the orientations of the sectors). Furthermore, NodeB B is the hotspot and supports two carriers, while NodeBs A and C support one carrier per sector.

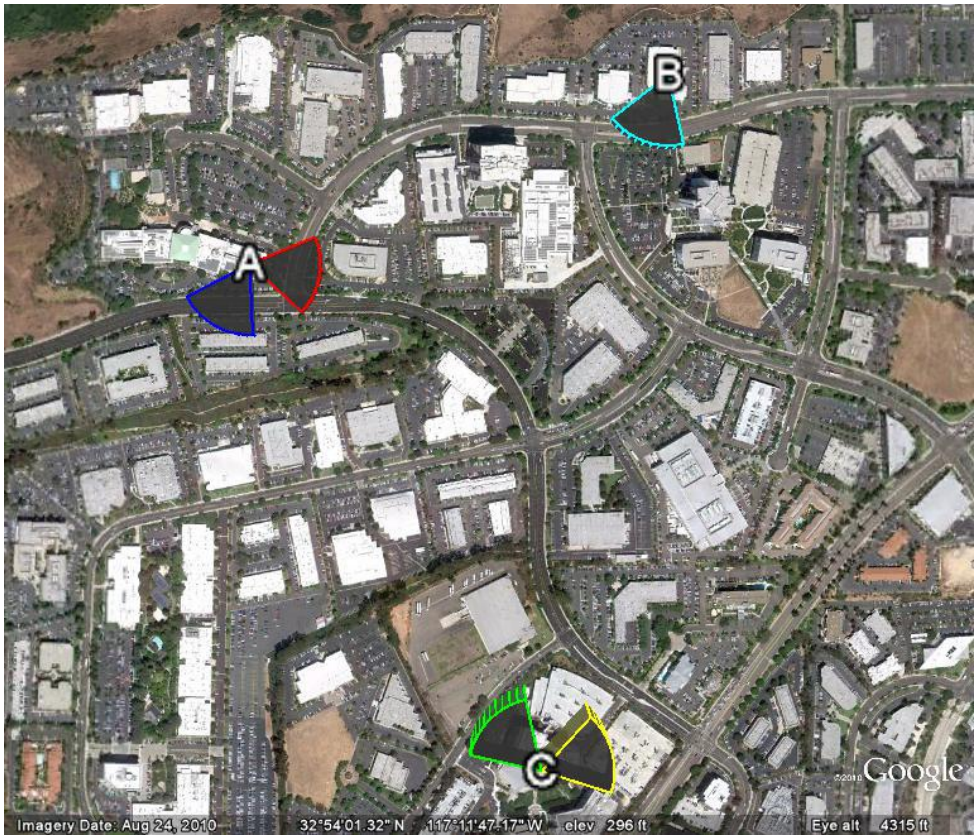

Figure 1: OTA map of NodeBs (Image generated using Google Earth™)

In our OTA tests, we drive on the route between NodeB A and NodeB B, i.e., Scenario 1 involves driving from NodeB A to B, and Scenario 2 involves driving from NodeB B to A.

5.2 Scenario 1 tests

In Scenario 1, the two UEs move towards the hotspot NodeB. For the dual-searcher UE, Event 2b is configured with the parameters: usedFreqThreshold = -10 dB and nonUsedFreqThreshold = -10 dB.

These thresholds were chosen to correspond to locations where the hotspot carrier provides higher throughput than the universal carrier.

Figure 2 shows the throughput of the two UEs over a period of time, during which the two UEs have different serving NodeBs.

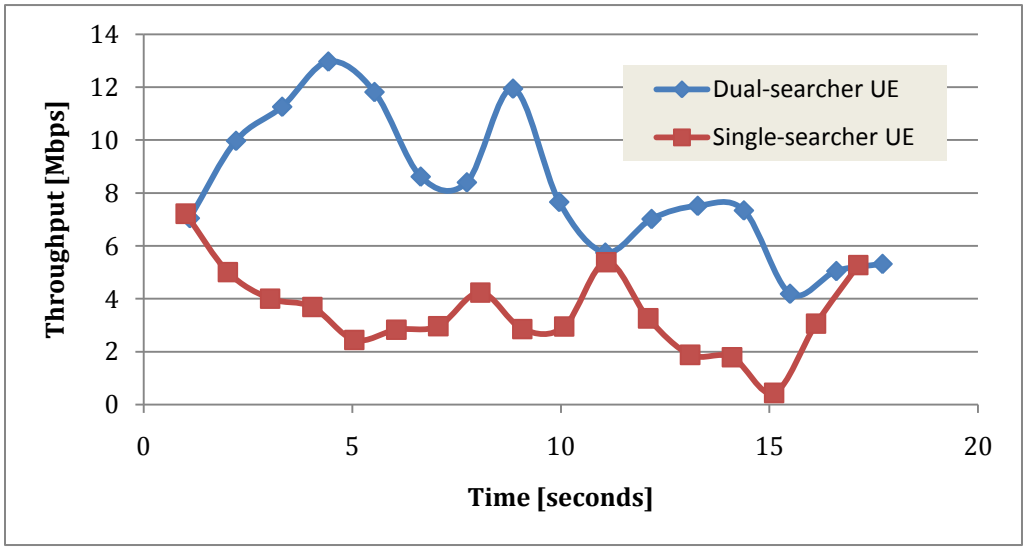

Figure 2: Throughput comparison during period where the two UEs have different serving NodeBs

The left end of Figure 2 corresponds to the location where the dual-searcher UE finishes a Event 2b triggered IFHO (with NodeB B as the new serving NodeB) and starts receiving service from both the carriers. The single-searcher UE, on the other hand, is still served by NodeB A on the universal carrier until the right end of Figure 2, upon which it performs an Event 1d triggered serving cell change to NodeB B. Thus, the time period shown in Figure 2 is the region where a dual-searcher UE has an advantage over a single-searcher UE. Note that this time period could be bigger or smaller, depending upon the particular route chosen.

The throughput gains of a dual-searcher UE over a single-searcher UE, for 6 test runs, are shown in Table 1. In the table, throughput gains are shown during (1) the period where the two UEs have different serving NodeBs and (2) the entire route (i.e, from NodeB A to NodeB B). The former period consists of ~15 seconds out of the entire drive route of 80 seconds.

Test Case	Throughput Gain during period where the two UEs have different serving NodeBs [%]	Throughput Gain over Entire Route [%]
RUN 1	272	12
RUN 2	206	16
RUN 3	271	9
RUN4	228	19
RUN5	205	22
RUN6	260	23
Average	**240**	**17**

Table 1: OTA test results for Scenario 1

We see an average of 240% throughput gain for a dual-searcher UE during the period where the two UEs have different serving NodeBs. Stationary UEs in locations where the two types of UEs have different serving NodeBs would see such throughput gain. The throughput gain during the entire route is reduced by the remainder of the drive route, during which the two UEs see similar throughput.

5.3 Scenario 2 tests

In scenario 2, the two UEs move away from the hotspot NodeB. For the dual-searcher UE, the parameters configured for Event 2b were the same as in Scenario 1. For the single-searcher UE, the parameters configured for Event 2d and Event 2b were:

- Event 2d: usedFreqThreshold = -11 dB
- Event 2b: usedFreqThreshold = -11 dB, nonUsedFreqThreshold = -10 dB

The parameters were chosen to maximize coverage of the hotspot carrier, while at the same time preventing the UEs from running out of coverage on the hotspot carrier.

Error! Reference source not found. shows a part of the drive route, containing IFHO-related mobility events for the two UEs. The magenta lines apply to the dual-searcher UE, and the blue lines apply to the single-searcher UE (the height of the lines in Figure 9 is proportional to the throughput). The reduced throughput seen by the dual-searcher UE from point 1 to point 2 is an artifact of our RNC implementation, which reduces the rate at which packets are forwarded to the NodeB for a particular UE, from the time a PCR is generated to the completion of the reconfiguration.

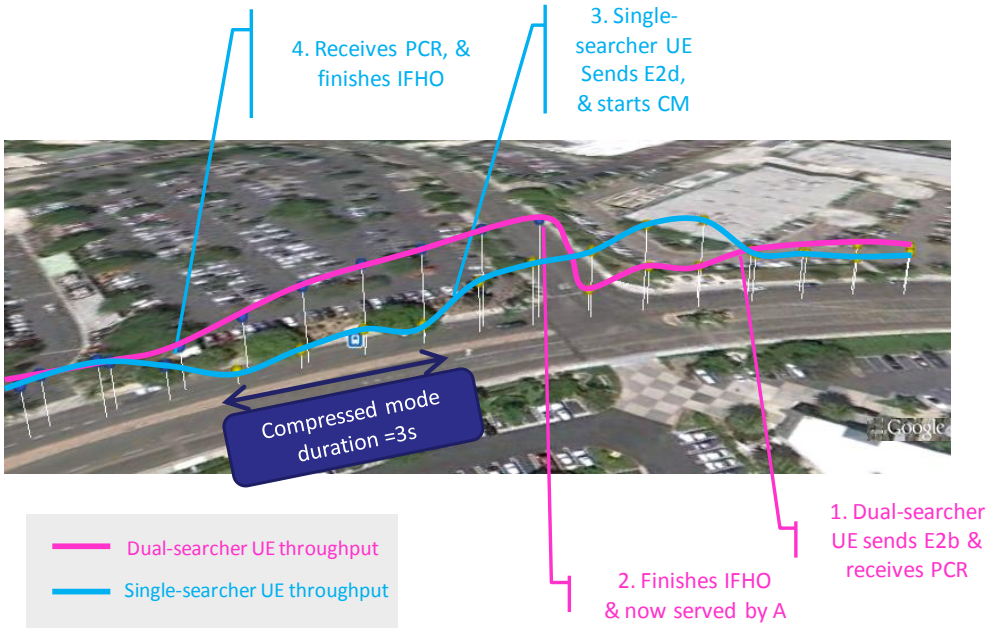

Figure 3: Part of drive route showing IFHO-related mobility events for Scenario 2 (Image generated using Google Earth™)

The throughput gains of a dual-searcher UE over a single-searcher UE, for 6 test runs of Scenario 2, are shown in Table 2.

Test Case	Throughput Gain during part of drive route shown in Figure 9 [%]	Throughput Gain over Entire Route [%]
RUN 1	198	3
RUN 2	158	5
RUN3	102	5
RUN4	92	7
RUN5	108	6
Average	**132**	**6**

Table 2: OTA test results for Scenario 2

During the part of the drive route shown in Figure 9, which is roughly the duration from Event 2b of the dual-searcher UE to the single-searcher UE receiving PCR, we observed an average of ~130% throughput gain. The gain comes from two reasons: (1) the single-searcher UE loses some TTIs of data scheduling

due to Compressed Mode, and (2) the single-searcher UE shows slightly lower average CQI (when Compressed Mode is ongoing) compared to dual-searcher UE. Similar to scenario 1, the throughput gain over the entire route (i.e, from NodeB B to NodeB A) is reduced due to the fact that for a significant part of the test duration, the two UEs have similar throughput.

6. Conclusions

In this work, we conducted a prototype test of the HSPA Release 8 feature "Adjacent Frequency measurements without compressed mode." We compared the performance of a UE that supports this feature, i.e., a dual-searcher UE, with that of a UE that does not support this feature, i.e., a single-searcher UE, under a hotspot deployment.

When the hotspot frequency is adjacent to the universal frequency, our results show that a dual-searcher UE can expand the range of a hotspot NodeB, leading to improved throughput. Under such deployment, a dual-searcher UE also does not need to rely on Compressed Mode to find the universal frequency when moving out of the coverage of a hotspot NodeB. Compressed Mode can reduce the TTIs available for a UE to be scheduled, and may have some detrimental impact on the CQI as well. Additional side benefits of a dual-searcher UE are a simplified call flow for the RNC, less signaling during mobility events and a smaller number of parameters to optimize in the case of IFHO. Overall, we see this Release 8 feature as an attractive option for UEs that support DC-HSDPA.

Appendix 1: Inter-frequency handover mobility events

The IFHO events, used in our study, are summarized in Table 3.

Parameter Name	Description
Event 2b	Current frequency quality below a first threshold *and* other frequency quality above a second threshold
Event 2d	Current frequency quality below a threshold

Table 3: Summary of IFHO events