

Enhanced HSDPA Mobility Performance: Quality and Robustness for VoIP Service

Abstract

3GPP has standardized CDMA-based packet-switched air interfaces for downlink and uplink, called High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) respectively. Significant voice capacity gains are possible by carrying voice (in the form of Voice over IP or Circuit Switched Voice) over HSDPA/HSUPA compared to circuit-switched Dedicated Channels (DCH). The key difference between HSDPA and DCH is that data is transmitted from a single “serving cell” in HSDPA, compared to all cells in the so-called “Active Set” in DCH. This presence of soft handover in DCH allows signaling radio bearers (SRBs) to be received reliably even under tough scenarios. When SRBs are mapped over HSDPA, on the other hand, a rapidly deteriorating serving cell may prevent SRBs from being received reliably under some extreme scenarios (e.g., Urban Canyon-like scenarios where serving cell signal strength degrades significantly in a short period of time), when using the legacy serving cell change (SCC) procedures defined pre-Release 8. To address this issue, 3GPP has standardized a new SCC procedure called the enhanced SCC procedure for HSDPA in Release 8 that is designed to be robust even under challenging scenarios. In this paper, we compare the performance of the legacy and enhanced SCC procedures both through simulations as well as lab testing. We conclude that the enhanced SCC procedure provides significantly improved performance both in terms of reduced call drops as well as reduced packet losses during a serving cell change.

1 Introduction

3rd Generation Partnership Project (3GPP) has standardized CDMA-based packet-switched air interfaces for downlink and uplink, called High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) respectively. One key difference on the downlink between HSDPA (standardized in Release 5 onwards of the WCDMA specifications) and the previously standardized circuit-switched air-interface (standardized in Release 99 of the WCDMA specifications), is the absence of soft-handover in HSDPA. This means that data is transmitted to the User Equipment (UE) or mobile from a single cell called the HSDPA serving cell. As the user moves, the HSDPA serving cell changes. In Release 99 channels, on the other hand, the UE receives data on dedicated channels (DCH) from all cells in its so-called Active Set (which is updated as the user moves), also referred to as macro diversity. This key difference has implications on the reliability with which signalling messages can be received at the UE.

According to mobility procedures defined Release 5 of 25.331 [1], the Radio Resource Control (RRC) signalling messages for changing the HSDPA serving cell are transmitted from the current HSDPA serving cell (called the source cell in this paper), and not the cell that the UE reports as being the stronger cell (called the target cell in this paper). This means that under conditions where the signal strength of the source cell deteriorates rapidly, the reliability with which these RRC signalling messages are received at the UE may be reduced. Further, in a radio condition environment where the source cell is degrading, repetition (in the form of Hybrid Repeat Request (HARQ)) from the source cell is not very helpful.

In Release 8 of 25.331 [1], an enhanced mobility procedure was standardized in 3GPP, where the UE can receive signalling from the target cell for the purposes of serving cell change. We refer to the Release 5 and Release 8 mobility procedures as legacy and enhanced mobility procedures respectively; these procedures are discussed in further detail in Section 2.

It should be noted that RRC signaling for a VoIP or a circuit-switched (CS) call over HSPA call can be made reliable by carrying Signaling Radio Bearers (SRBs) on a Dedicated Channel (DCH), since DCH can be soft combined from multiple cells. However, due to the code space occupied by DCH, this leads to a significant loss of capacity for VoIP over HSDPA (our simulations indicate ~40% capacity loss) as well as loss of spare capacity for Best Effort for a given number of VoIP calls. Thus, to achieve high voice capacity, the appropriate configuration for VoIP over HSDPA is to carry SRBs on High Speed-Downlink Shared Channel (HS-DSCH), while configuring Fractional-Dedicated Physical Channel (F-DPCH) to carry power control bits, as was intended when F-DPCH was included in the standard.

In this paper, we focus on the serving cell change performance when SRBs are mapped on HS-DSCH, which as discussed above is the high-capacity configuration for VoIP over HSDPA. We specifically focus on the performance of HS-DSCH serving cell change (SCC) under environments where the serving cell signal strength shows sudden degradation. Examples of such “Urban Canyon” environments [2] [3] are dense urban areas, such as downtown areas of many cities. Simulation results are shown using real traces from downtown areas of two cities. The focus application is voice, which has tight requirements for service outage, in terms of call drops, during cell change. For VoIP to be a successful service, it must meet the same level of quality and reliability requirements as circuit-switched voice carried on dedicated channels which enjoy the benefits of macro diversity.

The key performance metrics that our simulations and lab tests focus on are the reliability and performance of the current SCC procedures under Urban Canyon conditions. As discussed earlier, under conditions where the signal strength on the

source cell is rapidly deteriorating, it may not be possible for the UE to reliably decode the SCC RRC message from the source cell, leading to a call drop. Logs taken in multiple dense urban areas confirm that fast changing path loss conditions do indeed exist, where path loss may increase by 25 dB or more in less than a second. Thus, for efficient utilization of resources under Urban Canyon conditions, i.e., for high voice or spare Best Effort capacity, the robustness of the serving cell change procedure needs to be evaluated when SRBs are mapped on to HS channels. This high capacity configuration is the focus of our simulations and lab testing.

Section 2 provides an overview of the legacy and enhanced serving cell change procedures. Section 3 describes details of traces obtained from downtown areas of two cities and provides serving cell change simulation results using these traces. Section 4 provides a description of our prototype system as well as the VoIP features it supports. Section 5 shows serving cell change results obtained from testing under lab conditions. Conclusions are presented in Section 6.

2 Serving Cell Change Procedures

2.1 Description of Legacy SCC Procedure

The key characteristic of the legacy SCC procedure is that the SCC RRC message is received from the source cell. According to legacy RRC procedures (defined in Release 5 of HSPA), HS-DSCH serving cell change can be either synchronized or unsynchronized.

For the synchronized procedure, the network indicates the activation time at which the UE will perform the serving cell change. Since the network does not know either how long it will take the RRC reconfiguration message (such as Physical Channel Reconfiguration (PCR)/Transport Channel Reconfiguration (TCR)/Radio Bearer Reconfiguration (RBR)) to be transmitted over the source cell or how long the UE will take to reconfigure on receiving the message, it has to assume the worst-case. Another consideration for the network is that the buffer on the source cell should be emptied to the utmost extent possible, which is unpredictable as well. Thus, it typically indicates a conservative activation time, leading to potentially large interruption for voice traffic, particularly if the source cell signal strength degrades before the cell change occurs.

For the unsynchronized procedure, the network indicates an activation time of “now”. Thus, the UE is allowed to start listening to the target cell the moment it receives the RRC reconfiguration message and finishes its reconfiguration. This procedure does not need to assume the worst-case reception time of the RRC reconfiguration message at the UE, and is thus more suited for voice traffic. In this contribution, our focus is thus on the performance of the unsynchronized serving cell change procedure. It should be noted that for the synchronized serving cell change procedure, we expect the call drop results to be similar to those shown for the unsynchronized procedure in Section 3 since the mechanism for performing an SCC is the same (through the RRC message sent on the source cell which is rapidly deteriorating) .

2.2 Description of Enhanced SCC Procedure

In the enhanced SCC procedure (ESCC) standardized in Release 8, a High Speed Shared Control Channel (HS-SCCH) order from the target cell is used for indicating serving cell change to the UE. In this procedure, for a short period of time, the UE has to monitor a High Speed-Shared Control Channel (HS-SCCH) from the target cell while still monitoring HS-SCCH channels and decoding data from the source cell.

When the UE generates a Measurement Report triggered by an Event 1A for adding a cell to its Active Set, the network typically responds with an Active Set Update (ASU) message instructing the UE to add the cell to its Active Set. In the enhanced SCC procedure, the network pre-configures the UE with serving cell related information as part of the ASU message for each cell being added to the Active Set. It should be noted that in the legacy procedure, such information is received only as part of the RRC reconfiguration message that causes an SCC (i.e., a RBR/PCR/TCR message), whose reception in Urban Canyon scenarios is unreliable. The pre-configured information at the UE also includes a particular HS-SCCH channel (i.e., channelization code) that the UE needs to monitor after sending a Measurement Report triggered by an Event 1D.

When the UE sends a Measurement Report triggered by an Event 1D, it starts monitoring the pre-configured HS-SCCH on the target cell, in addition to receiving data on the source cell. At some later point, the target cell sends an indication of its readiness on the HS-SCCH being monitored by the UE. Upon receiving this indication, the UE changes its serving cell to the target cell, and applies the pre-configured information stored for the target cell.

It should be noted that as part of the enhanced procedure, the network is allowed to send either only HS-SCCH order on the target cell, or both RRC reconfiguration message on the source cell and HS-SCCH order on the target cell. In the latter case, the UE will change its serving cell on the earlier of the two SCC indications.

The call flow for the enhanced SCC procedure is shown in Figure 1 and described below:

- 1) The UE sends an Event 1A and receives all serving cell related information (such as Serving HS-DSCH Cell Information, E-DCH Reconfiguration Information) in the Active Set Update (ASU) message, for each cell being added to the active set. This information also includes the HS-SCCH channelization code that the UE has to monitor if a cell in the active set becomes the target cell.
The RNC also prepares the new cell being added to the Active Set for potentially becoming the serving cell, using the NBAP message Radio Link Reconfiguration Prepare. This message includes the HS-SCCH channelization code to be used for indicating serving cell change to the UE.
- 2) After sending Event 1D, the UE starts to monitor HS-SCCH (on the channelization code indicated in the ASU message) from the target cell, while still decoding data from the source cell (this helps to minimize interruptions in voice traffic).
- 3) On receiving Event 1D, RNC instructs the target cell to indicate change of serving cell to the UE. Note that we have also shown data being bicast in the call flow; this is not a mandatory part of the enhanced SCC procedure, and may be optionally done by the RNC to reduce voice interruption time.
- 4) The target cell starts sending HS-SCCH orders to the UE.
- 5) On receiving indication of serving cell change from the target cell through an HS-SCCH order, UE changes its serving cell to the target cell, applies the pre-configured information stored for the target cell and sends an RRC Complete message to the RNC.

The key advantage of the enhanced SCC procedure is that even under conditions where the source cell may be deteriorating rapidly, the UE can receive indication of SCC from the target cell using fast physical layer signaling. This significantly increases the robustness of the procedure and reduces call drops under such Urban Canyon conditions.

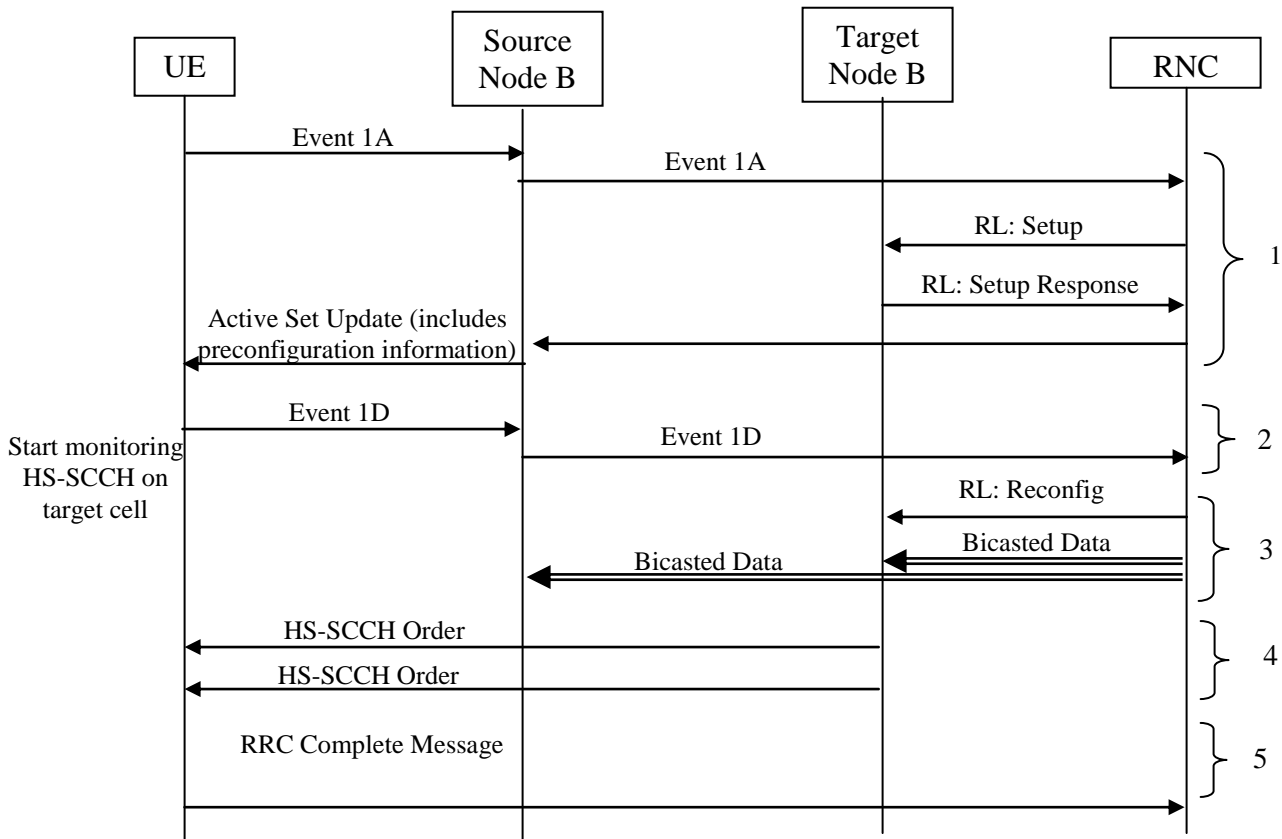


Figure 1: Call Flow of Enhanced SCC Procedure

It should be noted that similar to the legacy SCC procedure, even the enhanced SCC procedure can be either synchronized or unsynchronized. The unsynchronized case is shown in Figure 1. In this case, the UE switches to the target cell within 40 msec of receiving the HS-SCCH order [7].

In the synchronized case, the network indicates an “Activation Time Offset” (ATO) to the UE as part of the Active Set Update message. When the UE triggers a measurement report based on Event 1D, it adds the ATO to the current time and reports this in the measurement report. This time serves as the Activation Time in the synchronized version of the enhanced SCC procedure. In this case, even if the UE receives the HS-SCCH order before the Activation Time, it switches to the target cell at the Activation Time.

We believe that the synchronized version of the enhanced SCC procedure may add some extra delay in the SCC procedure, and we expect the unsynchronized ESCC procedure to give better performance. In our lab testing results shown in Section 5, we show results for the unsynchronized ESCC procedure.

3 Simulation Results

In this section, we provide simulation results comparing the legacy and enhanced SCC procedures under Urban Canyon-like conditions. These simulations take as input actual field traces taken from downtown areas of different cities.

3.1 Details of Simulation Environment

The network-level simulator used in the simulations is a slot-level simulator. The simulator models HS-SCCH, HS-PDSCH on the downlink as well as HS-DPCCH and EUL channels on the uplink. A VoIP-optimized scheduler, which gives strict priority to SRBs messages, is used to schedule over HS channels. Events 1A, 1B for active set updates and Event 1D for serving cell switching are modeled. Further details of simulation assumptions are captured in Table 1. Note that the TTT value of 320 msec and network delay values of 80 and 200 msec, as shown in Table 1, are aggressive when compared to typical values seen in today’s WCDMA networks.

We collected CPICH E_c/I_o and CQI traces while driving in downtown areas of two different cities with deployed WCDMA networks. A type 1 UE with Rake receiver and Receive diversity was used. It should be noted that the traces were collected from different areas in the downtowns of the cities, so the traces are not representative of only a few city blocks. Rather, the traces represent a sampling of different areas of the downtown, so the simulation results can be seen to represent average behavior over the entire downtown area. The field traces were applied to one UE in the simulation. Load from other cells was modeled as interference. Different loading factors from other cells were considered.

Table 1: Simulation Parameters

Parameter	Value
Maximum Cell Power	43 dBm
CPICH Ec/Ior	-10 dB
Total % Fixed Power for Overhead Channels	30%
Modeling of HS-SCCH Power	Power controlled using CQI reports
Other Cell Power	(40%, 80%) of maximum cell power
Event 1A, 1B: Weighing Factor W	0
Event 1A, 1B: Reporting Range	3 dB
Event 1A, 1B: Hysteresis	0 dB
Event 1A: Time to trigger TTT	0 msec
Event 1B: Time to trigger TTT	320 msec
Event 1A, 1B, 1D: Filter Coefficient K	3 (485 msec)
Event 1D: Hysteresis	3 dB
Event 1D: Time to trigger TTT	(320, 640) msec
RBR (Radio Bearer Reconfiguration)/ASU (Active Set Update) Message Size	300 bits
Maximum H-ARQ transmissions for RBR/ASU	4, 8
Network Delay (defined as the delay from the sending of Event 1D to the arrival of RBR message at the Source Node B)	(80, 200, 280) msec
Load	(High, Low) High: 100% power from neighboring cells Low: 50% power from neighboring cell

3.2 Analysis from City 1

The sample space for traces from City 1 was around 150 minutes. Figure 2 shows an actual CPICH Ec/Io field trace, with different events (such as Event 1D, RBR etc) marked on it for a legacy unsynchronized SCC. It can be seen that the slope of degradation of CPICH Ec/Io is approximately 25 dB/sec, i.e., CPICH Ec/Io goes from -8 dB to -20 dB in less than half a second. Also, the events shown on the figure for a particular setting of TTT = 320 msec and network delay = 200 msec indicate that reception of the RBR message would be unsuccessful after four H-ARQ transmissions since the serving cell Ec/Io has dropped below -23 dB.

The key performance metric we are focusing on is the reliability of the delivery of the RBR message. We record the percentage of times the RBR message could not be delivered to the UE in our simulations; these occurrences are referred to as “call drops” in the remainder of the document. Call drop percentage is calculated as:

$$Call_Drop_Percentage = 100 * \left(\frac{Number_of_Call_Drops_in_Log}{\left(\frac{Total_Log_Duration}{Call_Duration} \right)} \right) \quad (1)$$

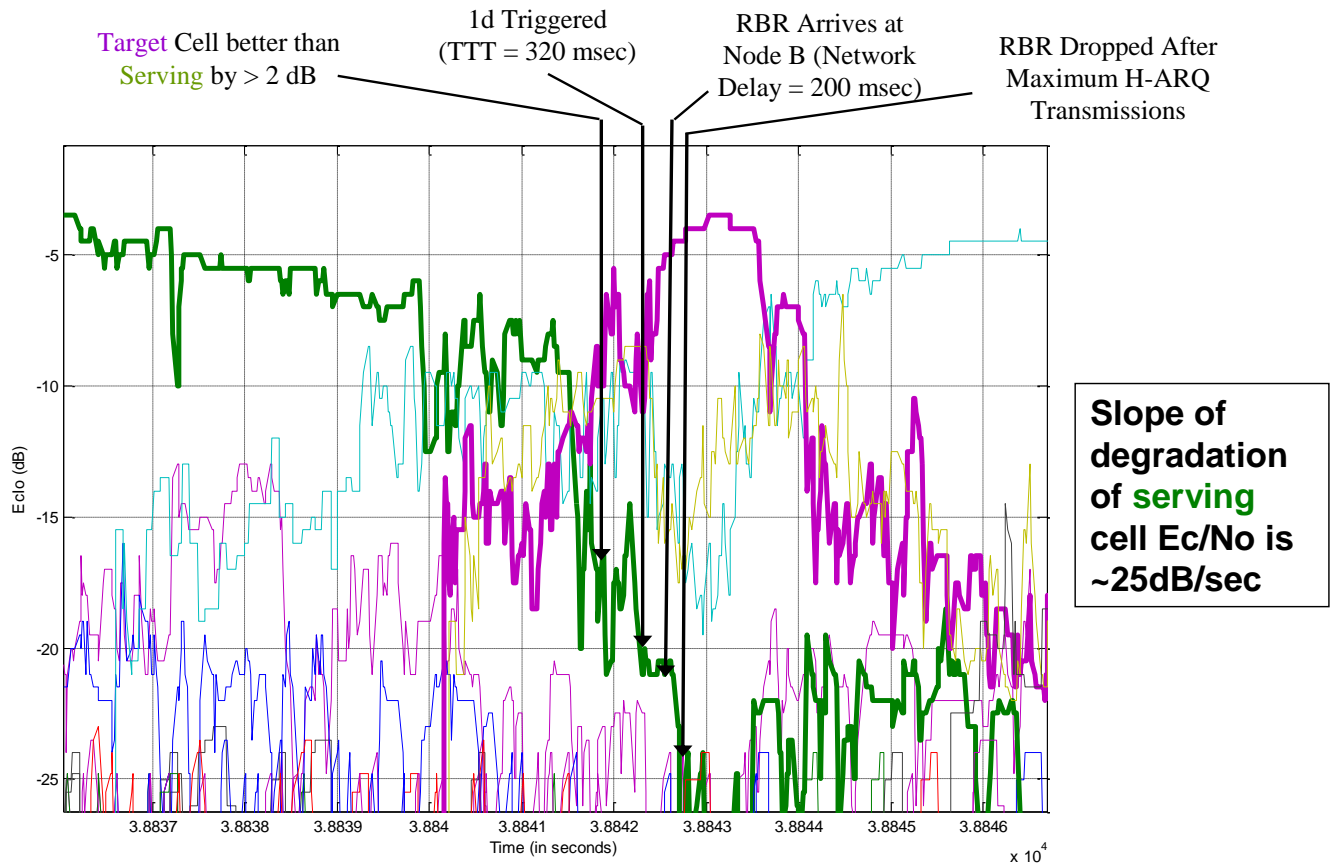


Figure 2: Example CPICH Ec/Io trace from City 1

Table 2 shows the call drop percentages for the legacy unsynchronized SCC procedure, assuming average voice call duration of 2 minutes. For different settings of Network Delay, Load and Maximum H-ARQ transmissions, the call drop percentage varies between 4% and 10%. Even with aggressive settings of Node B HS-PDSCH power (set to 70% of total cell power), maximum H-ARQ transmissions, Network Delay and TTT (which was set to 320 msec), call drop rates are seen to be quite high. For the enhanced SCC procedure, the call drop percentage was seen to be ~0 under all cases shown in Table 2.

Table 2: Call Drop Percentages from City 1 for legacy SCC procedure

Call Drop %	Maximum HARQ=4, Low Load	Maximum HARQ=8, Low Load	Maximum HARQ=4, High Load	Maximum HARQ=8, High Load
ND=280msec	10.2	8.9	10.7	10.7
ND=200msec	7.4	5.9	9.3	8.9
ND=80msec	4.2	3.5	6.7	5.3

3.3 Analysis from City 2

The sample space for traces from City 2 was around 84 minutes. Figure 3 shows an example CPICH Ec/Io trace from City 2, with different events (such as Event 1D, RBR etc) marked on it. It can be seen that the serving cell CPICH Ec/Io goes from -7 dB to -20 dB in around half a second. Also, the events shown on the figure for a particular setting of TTT = 320 msec and network delay = 200 msec indicate that reception of the RBR message is unsuccessful after four H-ARQ transmissions.

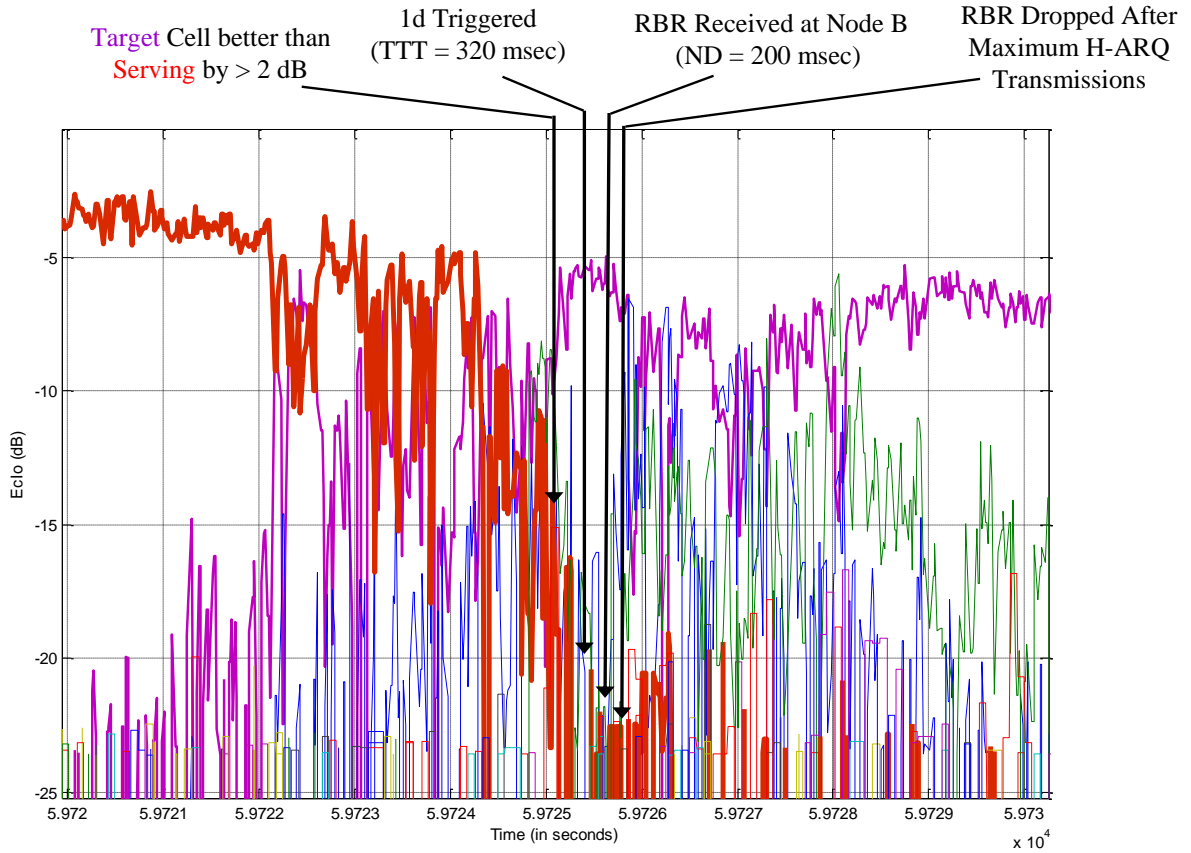


Figure 3: Example CPICH Ec/Io trace from City 2

The above Urban Canyon field traces were applied to one UE in the simulation. Simulation settings were similar to those chosen for City 1, except that the TTT was allowed to take two different values: 320 msec and 640 msec. Note that 640 msec is the value of TTT typically configured in today's networks.

Table 3 shows the call drop percentages (calculated as in Equation 1), assuming average voice call duration of 2 minutes. The maximum number of H-ARQ transmissions for RBR messages was set to 8. For different settings of Network Delay and Load, the call drop percentage varies between ~3% and ~10%. Again, for the enhanced SCC procedure, the call drop percentage was seen to be ~0 under all cases shown in Table 1.

Table 3: Call Drop Percentages from City 2 for legacy SCC procedure

		TTT=320msec	TTT=640msec
ND = 80 msec	Low Load	2.4	9.6
	High Load	4.8	9.6
ND = 200 msec	Low Load	4.8	9.6
	High Load	7.2	9.6
ND = 280 msec	Low Load	7.2	9.6
	High Load	9.6	9.6

4 Implementation of SCC in the Prototype

In this section, we describe details of our prototype that implements legacy and enhanced SCC as well as several features recommended for support of VoIP.

4.1 Description of Prototype

The VoIP mobility testing was performed on an HSPA research prototype system developed by Qualcomm. This system supports all the layers of the WCDMA protocol stack and supports end to end voice and VoIP calls with mobility. It supports dedicated channels as described in R99 and HSDPA and HSUPA as specified in R5 and R6 respectively. The UEs used for this prototype are based on commercially available MSM chips and system software.

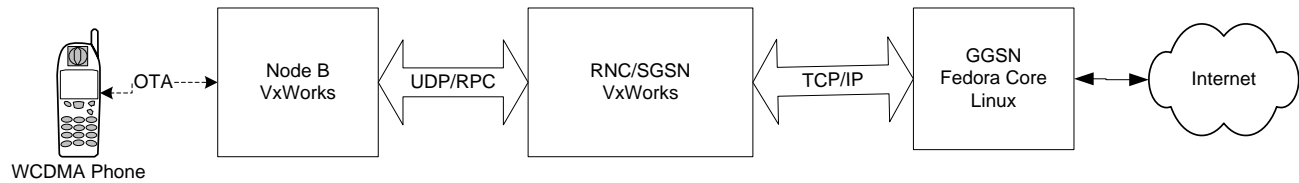


Figure 4: Prototype system

The prototype system maps Signaling Radio Bearers (SRBs) on HSDPA on the downlink and on HSUPA on the uplink. The HSUPA uplink for the prototype system uses 10ms TTI. The prototype supports a priority based scheduler with signaling radio bearers having the highest priority followed by RLC retransmissions followed by first time data. Between multiple users, the scheduler does round robin scheduling.

The prototype system supports a limited number of users. To mimic the delay introduced by scheduling behavior of commercial systems at high loads, a scheduler delay algorithm is implemented. This algorithm can be tuned at run time to emulate different loads. If the algorithm is configured to support say a 60% load, it acts as if the number of users is 60% of the peak load and schedules the available users as such. In this respect, the delays incurred by the VoIP packets are similar to a loaded commercial system.

The prototype system's backhaul delay is smaller than that in a commercial system. Also, processing of RRC messages at the RNC is less time-consuming than in typical commercial UTRAN systems. To mimic the behavior of a commercial UTRAN under various loads and configurations, a processing delay for Event 1D is introduced at the UTRAN. This processing delay can be configured from 0ms to as high as 200 ms. Once the RNC receives Event 1D, it delays processing it until the configurable value specified in the processing delay.

With the combination of the scheduler delay and the processing delay, the prototype system behaves similar to a commercial system in terms of delays on the User and Control planes for the user under observation. Since the prototype system uses commercial UE software, it follows the same call flows and data paths as in commercial systems.

4.2 VoIP-related Features supported in the Prototype

In addition to legacy and enhanced SCC procedures, the prototype system supports a number of features that allow optimization of VoIP such as Robust Header Compression (RoHC), De-Jitter Buffer at the UE, Downlink HS-PDSCH Scheduler and Bicasting. These features are described below:

Robust Header Compression (RoHC): The prototype system supports RoHC as defined in RFC 3095 [4]. Since RTP/UDP/IP headers add a significant overhead to VoIP payloads (AMR 12.2 full rate frame size is ~244 bits, while RTP/UDP/IPv6 headers are 320 bits), it is essential to use a header compression scheme such as RoHC. RoHC provides a high degree of compression while still being very robust to packet drops. For instance, even the smallest Type 0 header can typically absorb up to 13 consecutive packet drops. With VoIP headers, RoHC is able to compress the RTP/UDP/IP headers down to 3 or 4 bytes a high percentage of the time. The 3 bytes corresponds to 1 byte for Type 0 header (UO-0) and 2 bytes for UDP checksum, while the 4 bytes corresponds to 2 bytes for Type 1 header (UO-1) and 2 bytes for UDP checksum.

De-Jitter Buffer: Another important feature required to support VoIP is a de-jitter buffer at the UE. VoIP packets see jitter as they traverse through the network primarily due to scheduling and Hybrid ARQ (H-ARQ) delay on the downlink as well as buffering and H-ARQ delay on the uplink. The AMR decoder, on the other hand, expects a synchronous stream of packets. A de-jitter buffer is thus required to remove jitter in arrival of VoIP packets. The de-jitter buffer implemented on the UE in our prototype system tries to find a desirable trade-off between adding too much delay and maintaining a small percentage of packets that are discarded due to being late for their playout time. This de-jitter buffer has been tested against the VoIP minimum performance specifications defined in 3GPP [5], and easily meets the minimum requirements.

Scheduler Power Allocation for HS-PDSCH: The downlink scheduler assigns power to HS-PDSCH payloads carrying VoIP packets based on the CQI reported by the UE. The scheduler also runs an outer loop that adds a variable margin on top of the CQI based power to achieve 10% BLER after a single H-ARQ transmission.

Bicasting: Bicasting of PDUs can be very useful in reducing serving cell change related packet drops for VoIP, particularly under severe urban canyon conditions. The prototype system's bicasting implementation does not send packets simultaneously to source and target cells; rather, it stores the last 100 msec (or equivalently up to 5 PDUs depending upon silence intervals) of speech forwarded to the source cell, and forwards these to the target cell on completion of serving cell change.

5. Serving Cell Change Lab Results

In this section, we show lab results comparing performance of legacy and enhanced SCC under different fading channels and urban canyon conditions. Note that over-the-air testing of SCC performance is currently in progress.

5.1 Key metrics for Serving Cell Change performance analysis

The lab tests focus on the following key metrics related to VoIP performance:

Metrics for Duration of Serving Cell Change:

- a. Delay between UE sending Event 1D and receiving serving cell change command (i.e., Physical Channel Reconfiguration (PCR) for Unsynchronized Serving Cell Change (USCC) and HS-SCCH order for ESCC).
- b. Delay between UE sending Event 1D and sending Physical Channel Reconfiguration Complete (PCRC).

Packet Errors: The number of packet errors during serving cell change duration. Packet errors are calculated from missing VoIP frames post the de-jitter buffer.

Effectiveness of Bicasting: The reduction in number of packet errors during serving cell change as a result of bicasting.

The above metrics are studied for USCC, USCC with bicasting and ESCC with bicasting. For ESCC, we study the performance of the unsynchronized procedure only.

5.2 Test environment for Serving Cell Change lab tests

The following scenarios were used for the Serving Cell Change lab study. Fading and geometry were controlled using a fader box.

Urban Canyon: In Urban Canyon scenarios, the received power from the serving cell can drop with a very high slope of attenuation when the user turns a corner. Such scenarios have been typically seen to occur in dense urban areas such as downtown areas of cities with high rises, when line of sight paths suddenly disappear after turning a corner [2] [6]. In the lab tests, urban canyon scenarios are modeled by attenuation of the serving cell signal strength with slopes of 20dB/sec and 40 dB/sec and the serving cell E_c/I_o of the pilot channel going as low as -24dB. An actual trace from the lab for the 20dB/sec urban canyon scenario is shown in Figure 5. After the SCC is complete, the attenuation is removed to add the cell back into the active set so that the test can be repeated multiple times. Urban Canyon conditions are modeled for AWGN and VA30 channels. For AWGN, slopes of 20dB/sec and 40dB/sec are modeled, while for VA30, the slope is uniformly randomly picked between 10 and 30dB/sec.

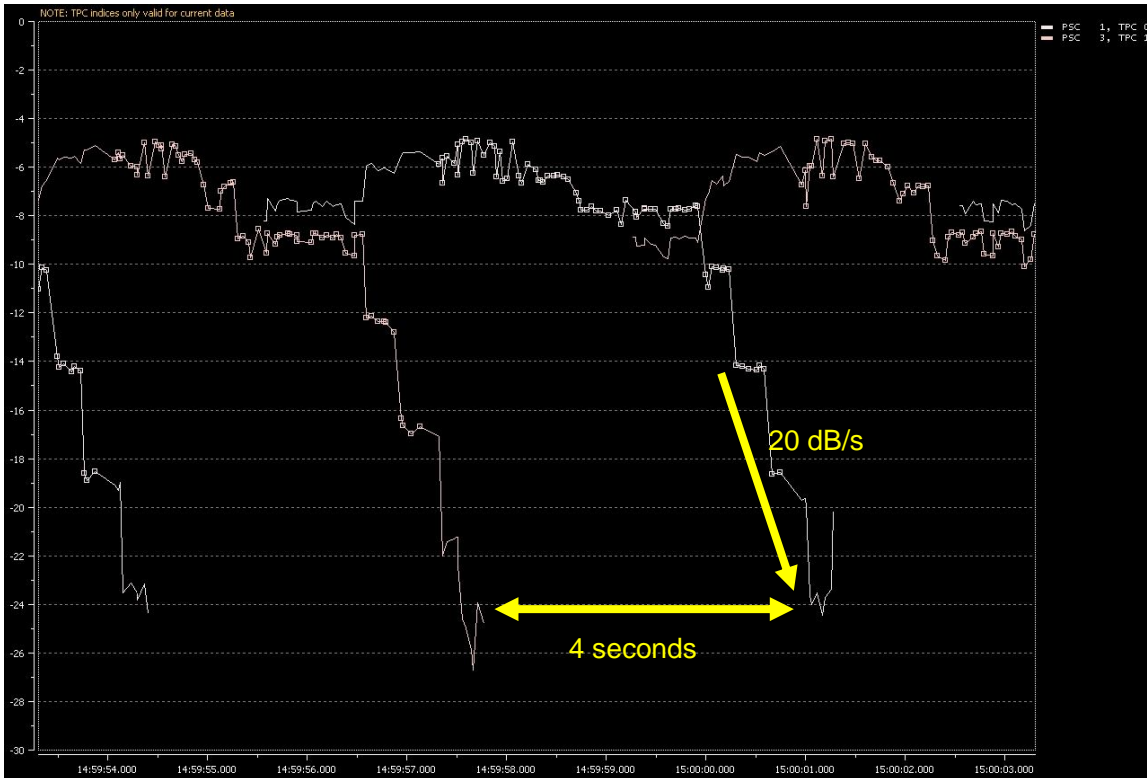


Figure 5: AWGN 20dB/sec slope showing time trace of serving and non serving cell Ec/Io

PA3 channel with 0dB geometry: A cell edge pedestrian user at 0dB geometry may perform serving cell changes based on the slow fading alone. In such a scenario, the serving cell Ec/Io may be below the non-serving cell Ec/Io for more than the time-to-trigger (TTT) based only on the fading of the channel.

5.3 Serving Cell Performance from Lab tests

In this section, performance results and analysis are presented for Serving Cell Change performance for a single UE in the system. The UE uses a Type 0 receiver (Rake with no receive diversity). The Ec/Ior for HS-PDSCH is -3dB and the Ec/Ior for HS-SCCH is -10dB. There are two cells in the system and the UE performs serving cell changes between the cells.

5.3.1 Results on Duration of Serving Cell Change:

Figure 6 (a) and (b) show the Serving Cell Change durations for the Enhanced SCC and the USCC procedures with AWGN channel and urban canyon slopes of 20dB/sec and 40dB/sec respectively. Note that for USCC, an RRC message for reconfiguration is sent on the source cell while for ESCC, HS-SCCH orders are sent on the target cell. For both the Urban Canyon slopes tested with an AWGN channel, the ESCC procedure performs faster serving cell changes. As the Urban Canyon slope increases, a distinct multimodal behavior of the distribution is noticed for USCC due to multiple Radio Link Control (RLC) retransmissions of the Physical Channel Reconfiguration message which is sent through the weak source cell. The PCR to PCRC delay is also larger for USCC due to larger UE reconfiguration delays; in the case of ESCC, HS-SCCH order to PCRC delay is smaller since the specification mandates the UE to reconfigure within 40 msec from reception of the HS-SCCH order [7].

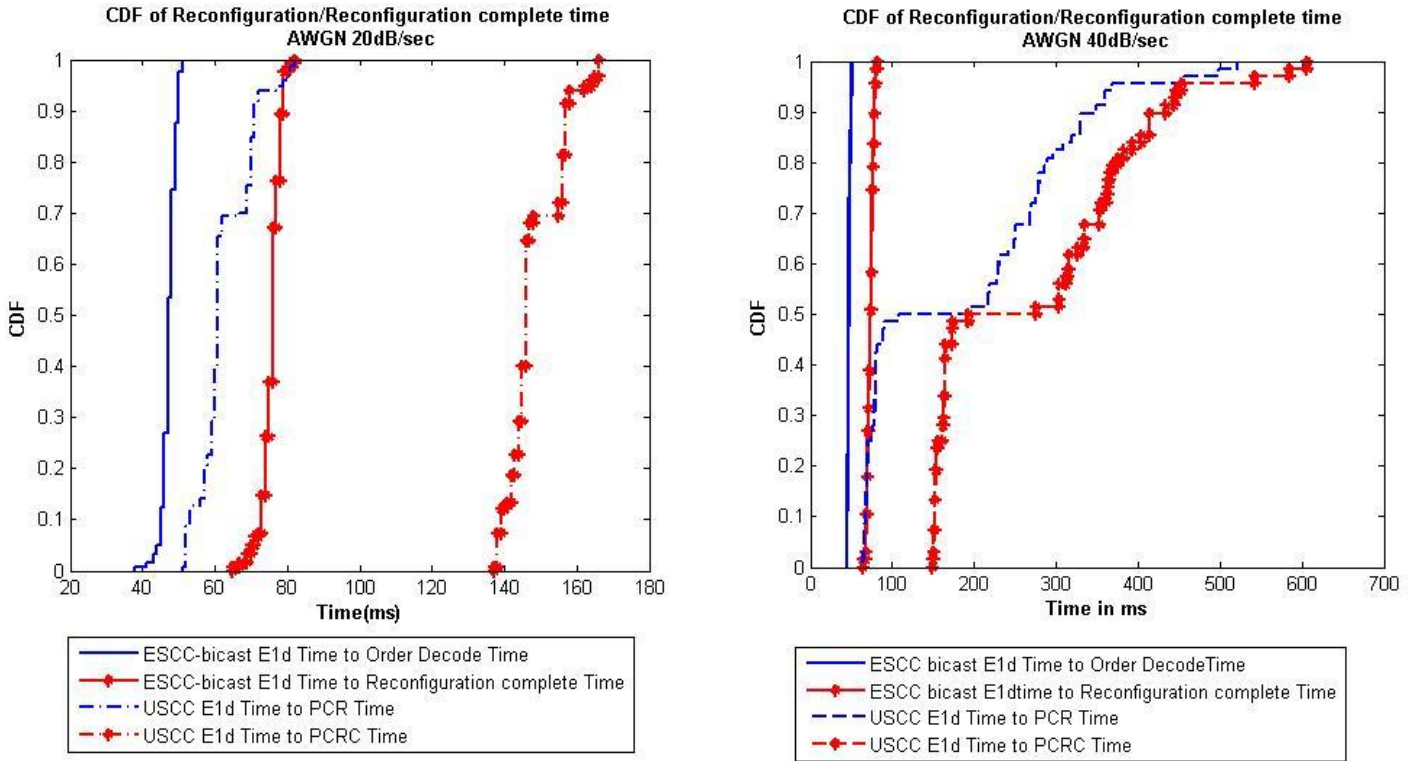
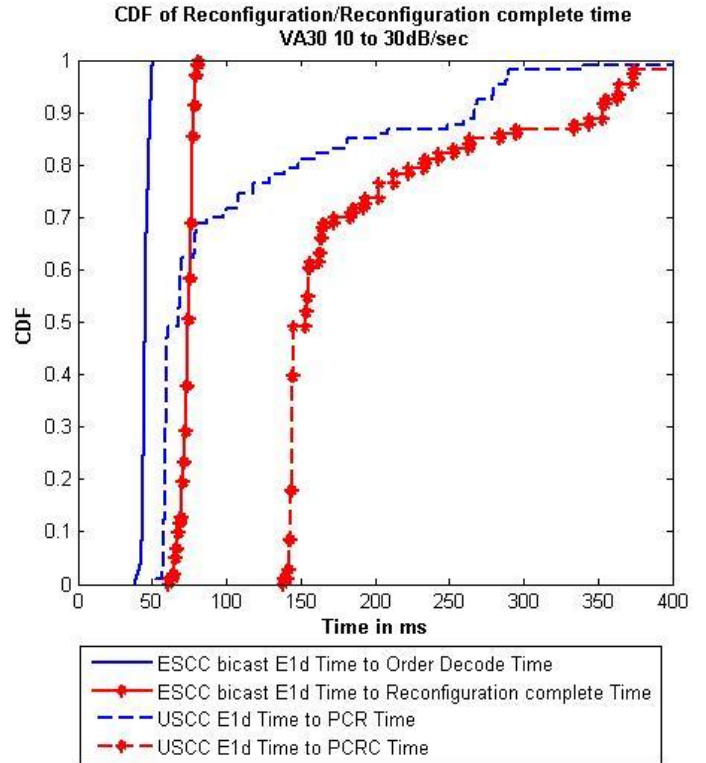
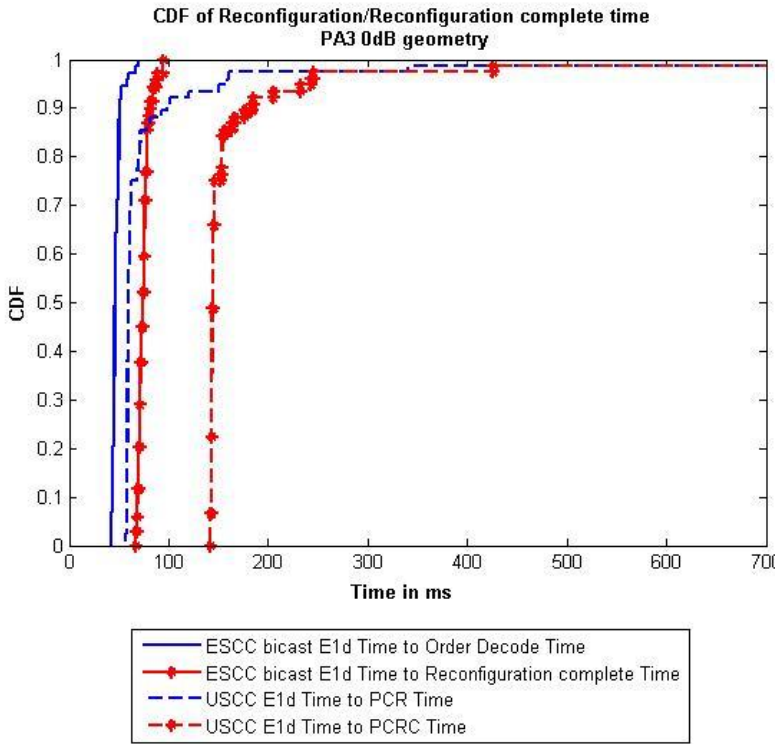


Figure 6: CDF of SCC duration for AWGN channel and Urban Canyon slopes of (a) 20dB/sec and (b) 40dB/sec

Figure 7 (a) shows the SCC duration in a PA3 channel with a 0dB geometry. Here SCCs are caused due to slow fading in a stationary environment (no slope to model urban canyon behavior is applied to the source cell). From the figure, the ESCC procedure performs faster serving cell changes compared to USCC. Moreover, RLC retransmissions of the Physical channel reconfiguration message are observed for USCC. Figure 7(b) shows the SCC duration for VA30 with 10 to 30dB/sec slope. The distinct multimodal behavior of the SCC duration is also seen in the VA30 fading channel for the USCC algorithm due to RLC retransmissions of the Physical Channel Reconfiguration message. From the graphs, it can be seen that the SCC duration for ESCC is almost independent of channel type/fading, whereas fading and the slope of source cell has a big impact on the USCC algorithm. Note that in all the fading scenarios, the target cell has a similar fading profile as the source cell.



(a)

(b)

Figure 7: CDF of SCC duration for (a) PA3 with 0dB geometry and (b) VA30 with 10 to 30dB/sec slope

5.3.2 Results on Packet Errors

Figures 8 and 9 show the distribution of erased VoIP frames observed post the dejitter buffer, i.e., the voice decoder plays out erasures for these voice frames, during a time window around SCC. Since the pilot signals are filtered, the serving cell's signal strength may start degrading before Event 1D is triggered. Thus, we evaluate the performance of SCC procedures starting 100 msec before UE sends Event 1D. Once the SCC procedure is complete and UE sends a PCRC message, some bicasted packets may still be received. Since our prototype system bicasts up to 100 msec of voice data, we evaluate the performance of SCC procedure till 100 msec after the UE sends the PCRC message. Thus, our time window for evaluation of SCC performance starts from 100ms before UE sends Event 1D and ends at 100ms after the PCRC message is sent.

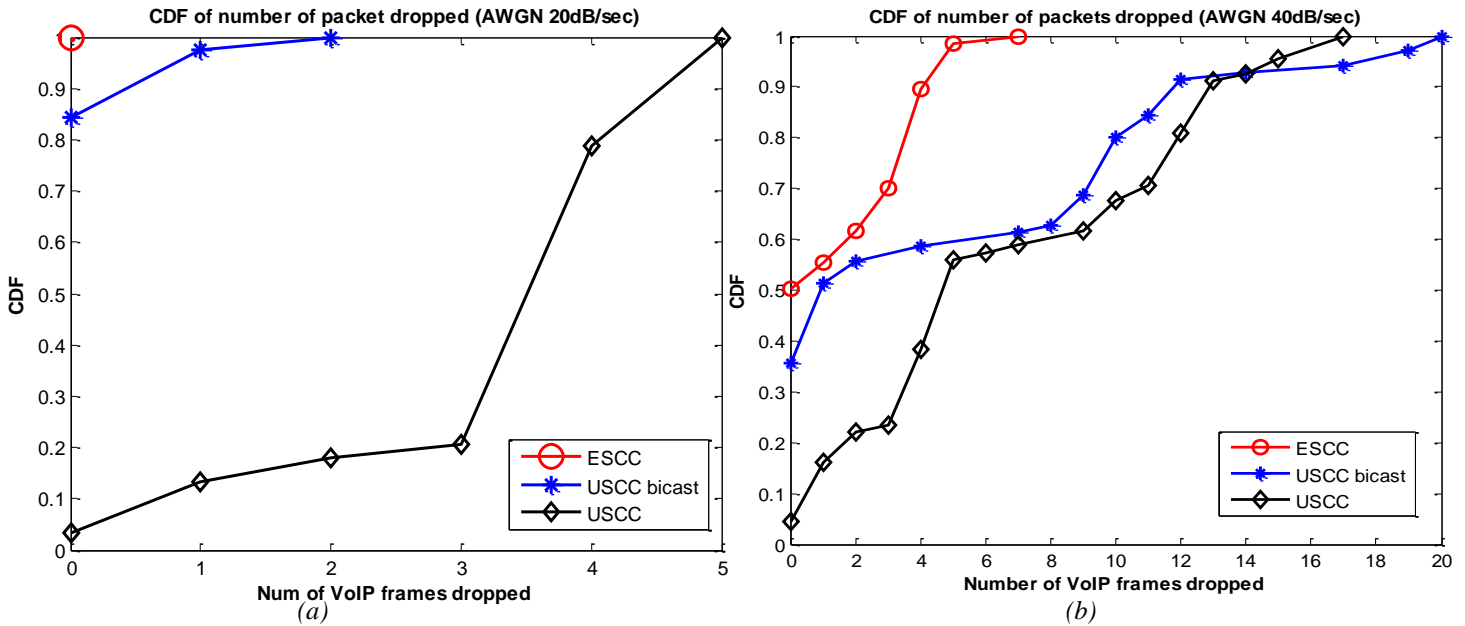


Figure 8: cdf of erased VoIP frames during SCC for AWGN channel and Urban Canyon slopes of (a) 20dB/sec and (b) 40 dB/sec

Figure 8 (a) shows the cdf of erased VoIP frames in an urban canyon scenario with a 20dB/sec slope for USCC, USCC with bicasting and ESCC (with bicasting). It can be seen that performance gets progressively better going from USCC to USCC with bicasting to ESCC with bicasting. ESCC performance is very impressive with nearly zero dropped packets for most of the SCCs. Figure 8 (b) shows the performance under a severe urban canyon scenario (40dB/sec slope). Under this scenario, we see that USCC performance is very poor with as high as 14 to 20 dropped packets for more than 10% of SCCs; this is likely to cause severe audible artifacts. Although there is some gain for USCC with bicasting, bicasting by itself is not able to recover all dropped packets in this severe scenario. There is substantial gain for ESCC with bicasting (90% of the time number of packets dropped is 4 or less) and ESCC does not show a long tail like USCC.

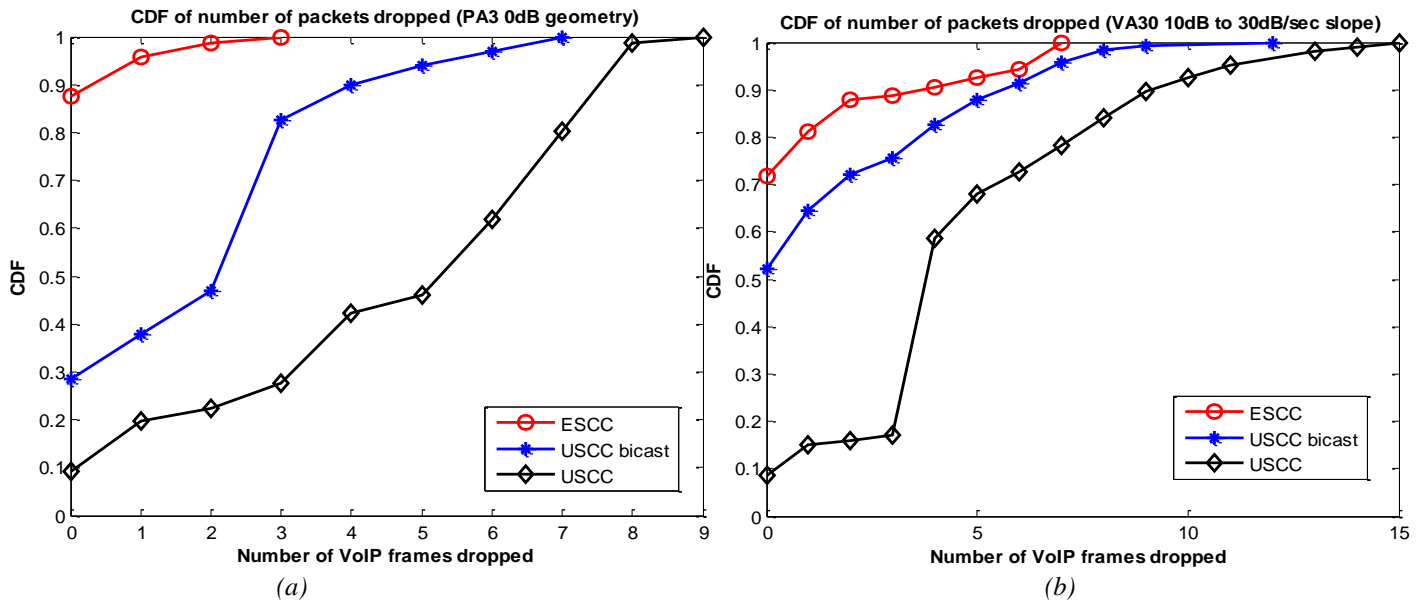


Figure 9: cdf of dropped VoIP frames during SCC for (a) PA3 0dB geometry and (b) VA30 (10 to 30dB/sec slope)

Figure 9(a) shows the distribution of dropped VoIP frames in a PA3 channel with 0dB geometry. It can be observed from the distribution that with ESCC, more than 85% of SCCs have zero packet drops compared to only about 10% SCCs for

USCC. Bicastng for USCC gives some gain over no bicastng, but bicastng alone is not able to recover all the dropped packets from the source cell. Figure 9(b) shows the results for VA30, with urban canyon slope varying from 10 to 30dB/sec. Again, ESCC performance is seen to be very good, with no packet drops for more than 70% of SCCs.

5.3.3 Results on Bicastng Effectiveness

We characterize gains due to bicastng in different fading channels for both USCC and ESCC. As described in Section 4.2, our bicastng implementation involves bicastng of the last 100ms of data (up to 5 RTP PDUs depending on silence intervals) through a store and forward mechanism. We characterize the bicastng PDU as:

- Bicastng: PDUs that were bicastng.
- Successful: Bicastng PDU that were successfully received from the target cell after SCC.
- Effective: Bicastng PDUs that were successfully received from the target cell and were not received from the source cell. This represents the actual number of recovered packets through bicastng.

Figure 10 (a) shows the bicastng gain for both USCC and ESCC in an AWGN urban canyon scenario with a slope of 20dB/sec. Under this scenario, we see that bicastng helps USCC more than ESCC (all successful bicastng PDUs are not effective), since more PDUs are dropped on the source cell with USCC. Figure 10 (b) shows the bicastng gain for an urban canyon scenario with 40dB/sec slope. Under this scenario, ESCC bicastng gains are similar to those of USCC. This is expected since for a 40dB/sec slope, even with ESCC a few packets are dropped on the source cell. As can be inferred from Figure 8(b), USCC still drops more packets during SCC, but since our prototype's bicastng implementation only bicastng the latest 5 PDUs, USCC bicastng gains are limited to 5 VoIP frames.

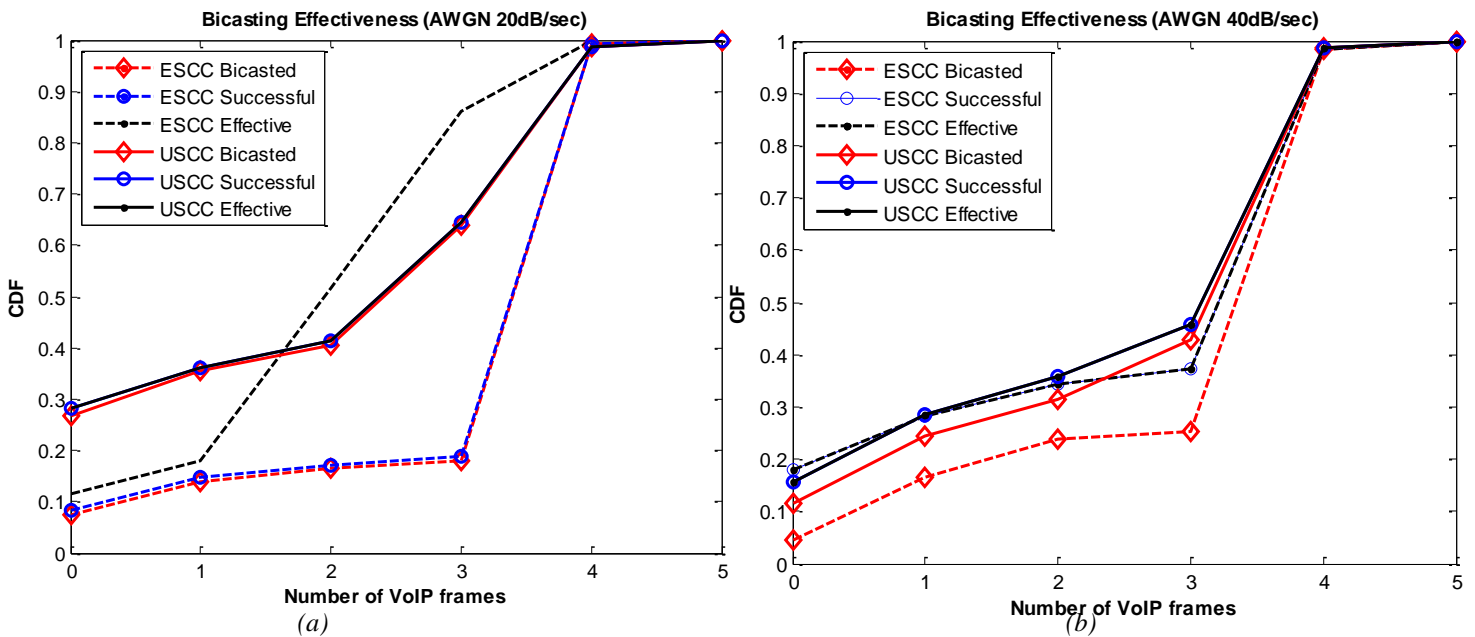
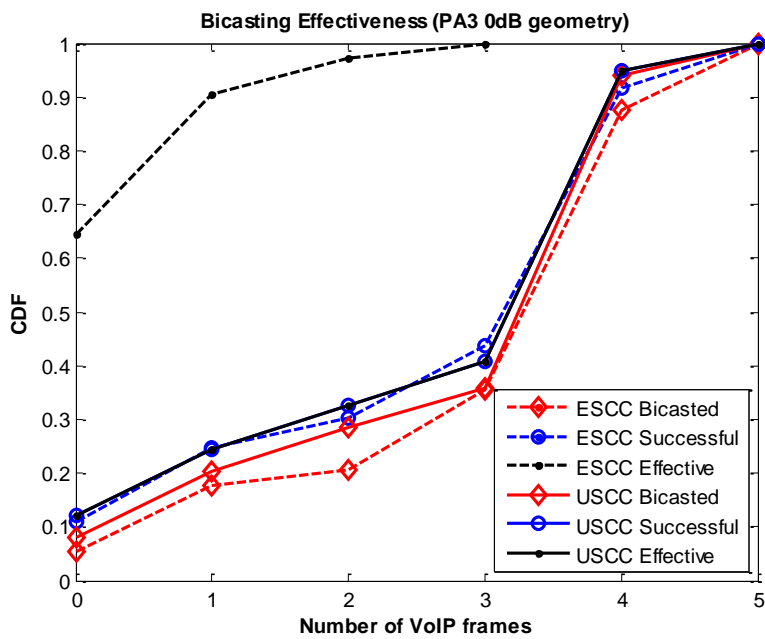


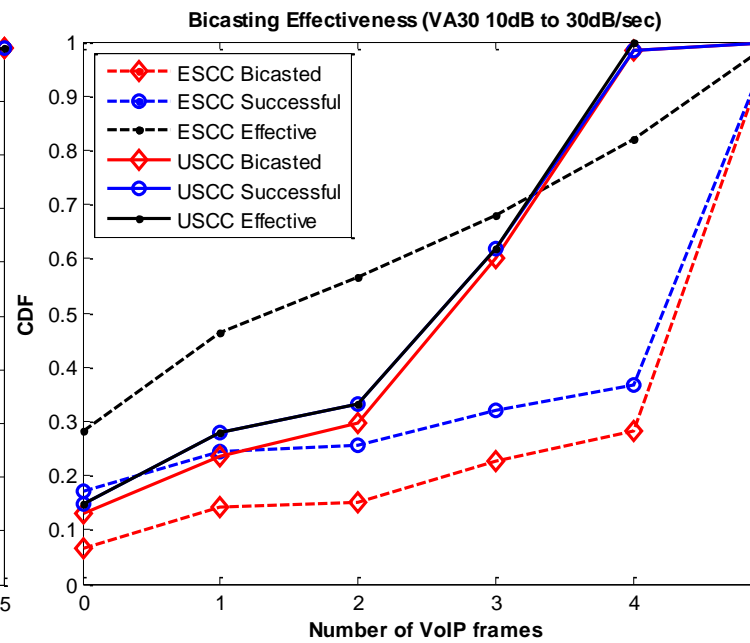
Figure 10: Bicastng Effectiveness for AWGN channel and Urban Canyon slopes of (a) 20dB/sec and (b) 40dB/sec

Figure 11 (a) and (b) show bicastng gains under PA3 with 0dB geometry and VA30 with urban canyon slope varying from 10 to 30 dB/sec. In particular in the PA3 channel, bicastng has very little gain for ESCC compared to USCC. This can be explained through Figure 9(a), which shows that ESCC drops very few frames during SCC.

It should be noted that these bicastng results do not comment about the overall packet loss during serving cell change. Although Figures 10 and 11 show that bicastng seems to help USCC more than ESCC, Figures 8 and 9 show that ESCC with bicastng has much better packet error performance compared to USCC with bicastng.



(a)



(b)

Figure 11: Bicasting Effectiveness for (a) PA3 0dB geometry and (b) VA30 (10 to 30dB/sec slope)

6. Conclusions

To enable high-capacity voice over HSDPA, it is necessary to map SRBs on HS-DSCH (mapping SRBs on DCH leads to ~40% voice capacity loss due to code consumed by DCH). To enable such a configuration, SRBs on HS-DSCH should provide similar level of reliability as SRBs over DCH. In this paper, we first studied the performance of legacy pre-Release 8 SCC procedures under tough Urban Canyon conditions, which are characterized by rapidly deteriorating source cell signal strength. We showed that the call drop rates for the legacy SCC procedures are unacceptably high (as high as 10% under some scenarios) under realistic Urban Canyon conditions obtained from field logs of dense downtown areas. We also simulated the performance of the enhanced SCC procedure standardized by 3GPP in HSPA Release 8 and found the performance to be very reliable under Urban Canyon-like conditions. Note that for SRBs mapped on Release 99 channels (i.e., DCH), performance would be reliable as well due to macro diversity.

We then implemented the enhanced SCC procedure in our prototype HSPA system. In addition to enhanced SCC, the prototype system also supports other features recommended for VoIP such as RoHC, de-jitter buffer at the UE, HS-PDSCH scheduler and bicasting. We compared the performance of legacy and enhanced SCC procedures under lab conditions using our prototype. Our lab testing further confirmed our simulation results, i.e., that under tough urban canyon conditions, the enhanced SCC procedure provides significant gains, in terms of packet drops and duration of serving cell change, compared to the legacy SCC procedure. At the moment of writing this paper, we are evaluating the performance of legacy and enhanced SCC under actual over-the-air conditions. When we have these results, we will update this document.

To conclude, our simulation and lab results show that the enhanced SCC procedure standardized in HSPA Release 8 provides a very robust solution for handling of mobility over HSDPA, and provides good performance even under severe urban canyon-like scenarios. Although the enhanced SCC procedure may not strictly be needed in all scenarios, for robustness reasons it is recommended that it should be deployed network-wide. We believe that the adoption of this procedure will enable high voice capacity with telco-quality voice (i.e., voice quality and reliability at least comparable to circuit-switched voice) even under downtown-like dense urban areas.

7. References

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