Agenda item:	**AdHoc #24 HSDPA**
Source:	**Motorola**
Title:	**Text proposal on H-ARQ Performance**
Document for:	**Discussion/Include in TR**

7.2.1 Link and System Performance of H-ARQ

7.2.1.1 Link Performance Comparison of Type-II and Type III HARQ Schemes

Chase Combining

The simplest form of Hybrid ARQ scheme was proposed by Chase [1]. The basic idea in Chase's combining scheme (also called H-ARQ-type-III with one redundancy version) is to send a number of repeats of each coded data packet and allowing the decoder to combine multiple received copies of the coded packet weighted by the SNR prior to decoding. This method provides diversity gain and is very simple to implement.

H-ARQ with Partial IR (H-ARQ-Type-III)

Incremental redundancy is another H-ARQ technique wherein instead of sending simple repeats of the entire coded packet, additional redundant information is incrementally transmitted if the decoding fails on the first attempt. Incremental redundancy is called H-ARQ-type-II, or H-ARQ-type-III if each retransmission is restricted to be self-decodable. In this report both H-ARQ-type-II and H-ARQ-type-III was implemented for the MCS levels shown in Table 1.

Table 1. MCS Level for Method-2

MCS	Modulation	Turbo Code Rate
7	64 QAM	3/4
6	16 QAM	3/4
3	QPSK	3/4

The turbo codes used in the hybrid ARQ system consists of a parallel concatenation of two R=1/3 systematic and recursive convolutional encoders as shown in Figure 1. The overall code rate of the turbo code entering the puncturing circuit is 1/6. For each input stream, six output streams are formed: the input stream x itself, two parity streams produced by the first convolutional code y_1 and y_2 interleaved input stream x' and the second parity streams z_2 and z_3 produced by the second convolutional code. The puncturing block after the encoder is used to form (for example) R=3/4, R=2/3 and R=1/2 codes by puncturing the parity bits. As an example, for R=1/2 codes alternate parity bits are sent over the channel (x, y_1, x, z_2, x, y_1,…). In case of partial IR using R=3/4 code the following algorithm was simulated:

?? In case of even order transmission, the following set of coded bits are transmitted for every six information bits, : $P_1=\{x_A, x_B, x_C, y_{1C}, x_D, x_E, x_F, z_{1F}\}$.

- In case of odd order transmission, the following set of systematic and parity bits are transmitted: $P_2=\{x_A, x_B, x_C, y_{2C}, x_D, x_E, x_F, z_{2F}\}$.
- The very first transmission is decoded as an R=3/4 code, and subsequent re-transmissions are decoded as an R=3/5 code, where the bits in each subsequent retransmission are added symbol-wise to the corresponding stored bits.

The puncturing patterns P_1 and P_2 can be represented as the following two matrices. The multiplexing rule is to multiplex first by column, left to right. Within a column, read out top to bottom.

$$P_1 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \qquad P_2 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

H-ARQ with Full IR (H-ARQ-Type-II)
In case of full IR using R=3/4 code the following algorithm was implemented:

- In case of first transmission, the following set of coded bits are transmitted for every six information bits, : $P_1=\{x_A, x_B, x_C, y_{1C}, x_D, x_E, x_F, z_{1F}\}$.
- In case of second transmission (first re-transmission), the following set of parity bits are transmitted: $P_2=\{y_{1A}, y_{2A}, z_{1C}, z_{2C}, y_{2D}, y_{1E}, z_{1F}, z_{2F}\}$.
- For the third transmission, a different set of parity bits are transmitted: $P_3=\{z_{1A}, z_{2B}, y_{1C}, y_{2C}, z_{2D}, z_{1E}, y_{1F}, y_{2F}\}$.
- The sequence is then repeated.
- The very first transmission is decoded as an R=3/4 code, the next transmission is decoded as an R=3/8 code, and the third transmission is decoded as a R=1/4 code. Subsequent retransmissions are decoded as a R=1/4 code, where the bits in each subsequent retransmission are added symbol-wise to the corresponding stored bits.

The puncturing patterns P_1, P_2, and P_3 can be represented as the following three matrices. The multiplexing rule is to multiplex first by column, left to right. Within a column, read out top to bottom.

$$P_1 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \qquad P_2 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \end{pmatrix} \qquad P_3 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{pmatrix}$$

Results and Conclusions:

Figure 2 to Figure 6 to compares the performance of Chase combining, Partial IR and Full IR with three MCS levels using R=3/4 code and at various values of vehicle speeds. The following conclusions are drawn from the figures:

1. For QPSK, full IR benefits over Chase are not significant in the region of interest.
2. For higher order modulation (mainly MCS-7), the full IR provides more than 1dB gain in Ior/Ioc in a fading channel. However, the gain occurs in a region where a lower MCS may have been selected.
3. The decoder and signaling complexity of the full IR scheme over Chase combining needs to be evaluated, and weighed against the likelihood of the MCS selection process degrading to the point where a significant overall throughput gain is seen for the full IR.
4. Similar conclusions is also derived in [4] (Tdoc# TSGR1#18(00)1428) with respect to performance gains of Full IR over Chase combining for higher order modulation schemes.

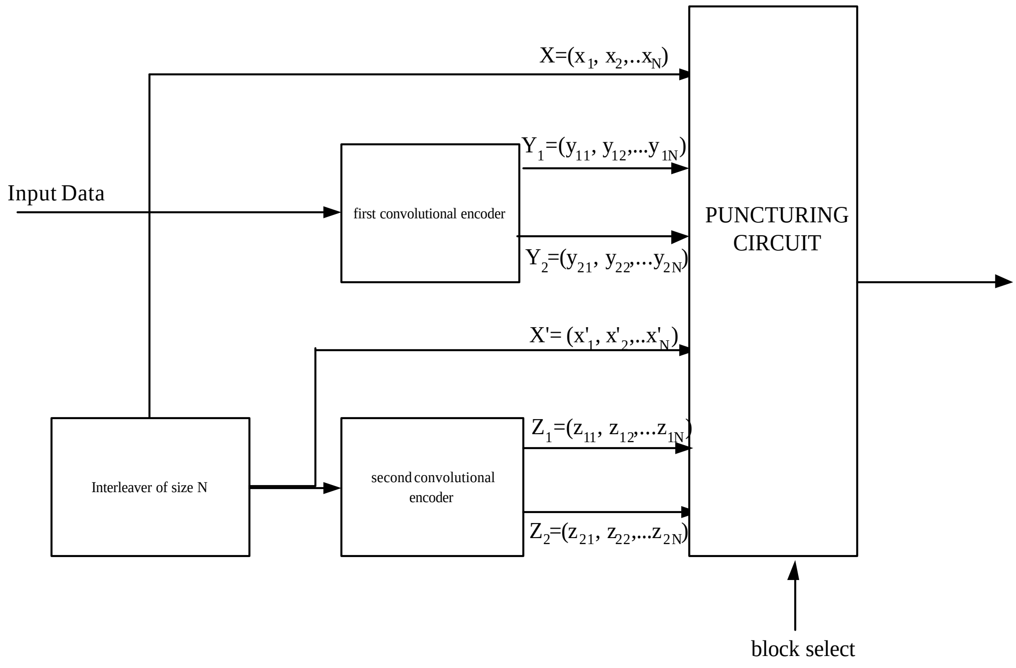

Figure 1. Block Diagram of a Turbo Encoder

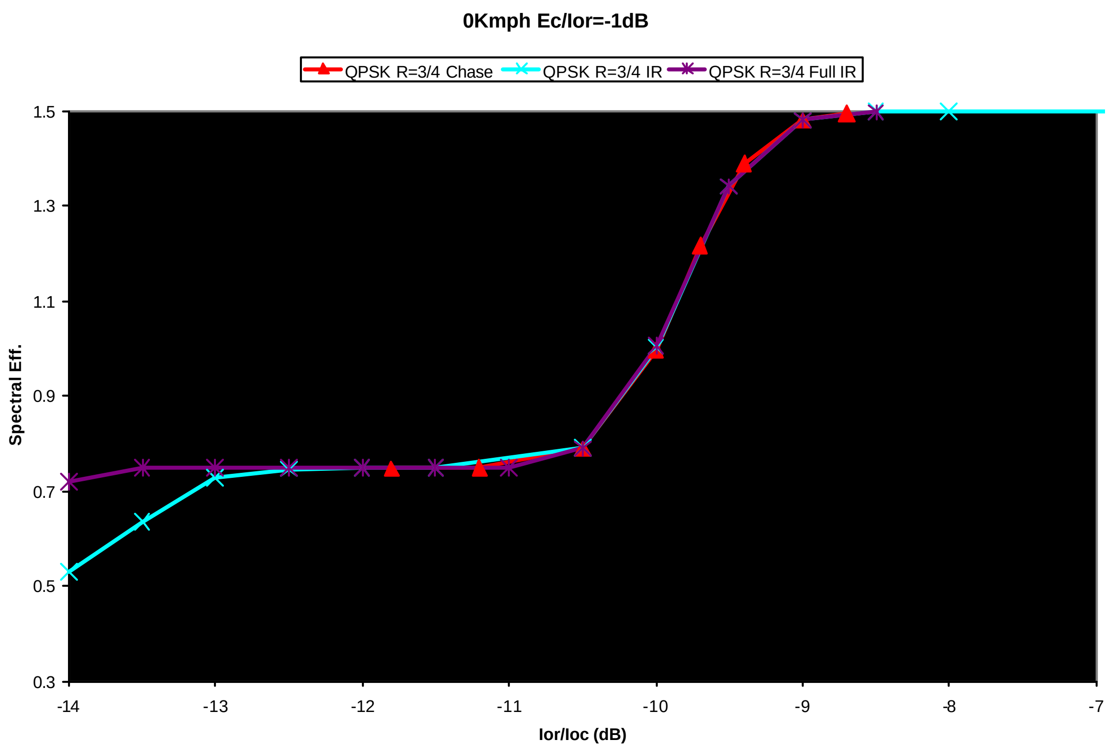

Figure 2. 0 Kmph QPSK

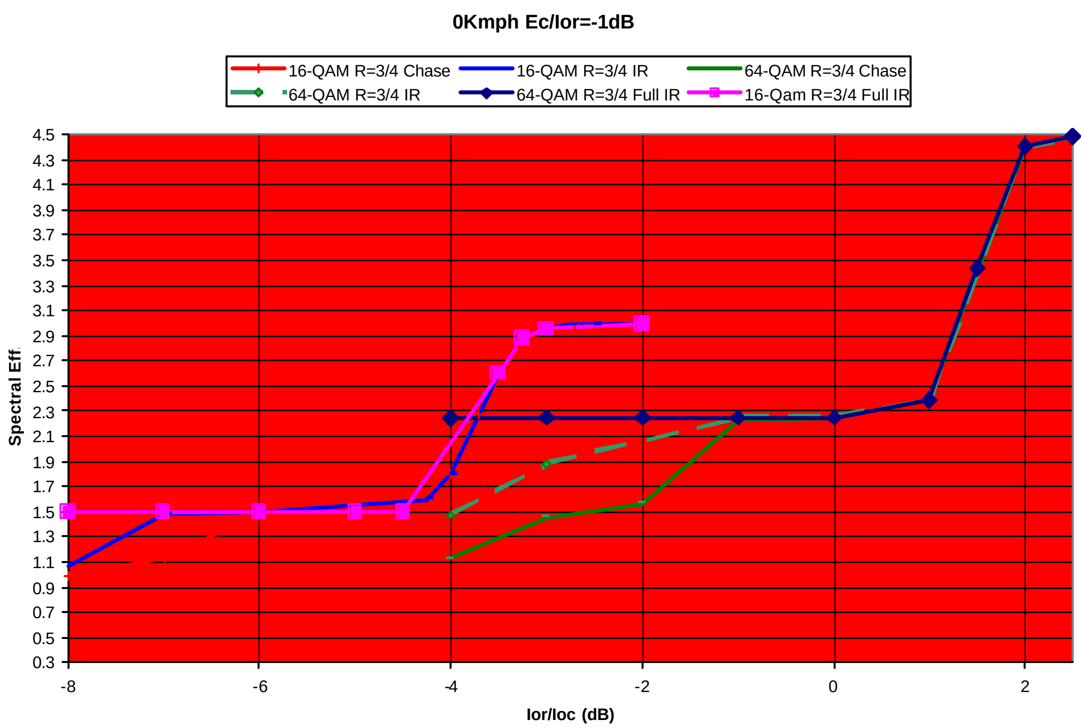

Figure 3. 0 Kmph 16/64-QAM

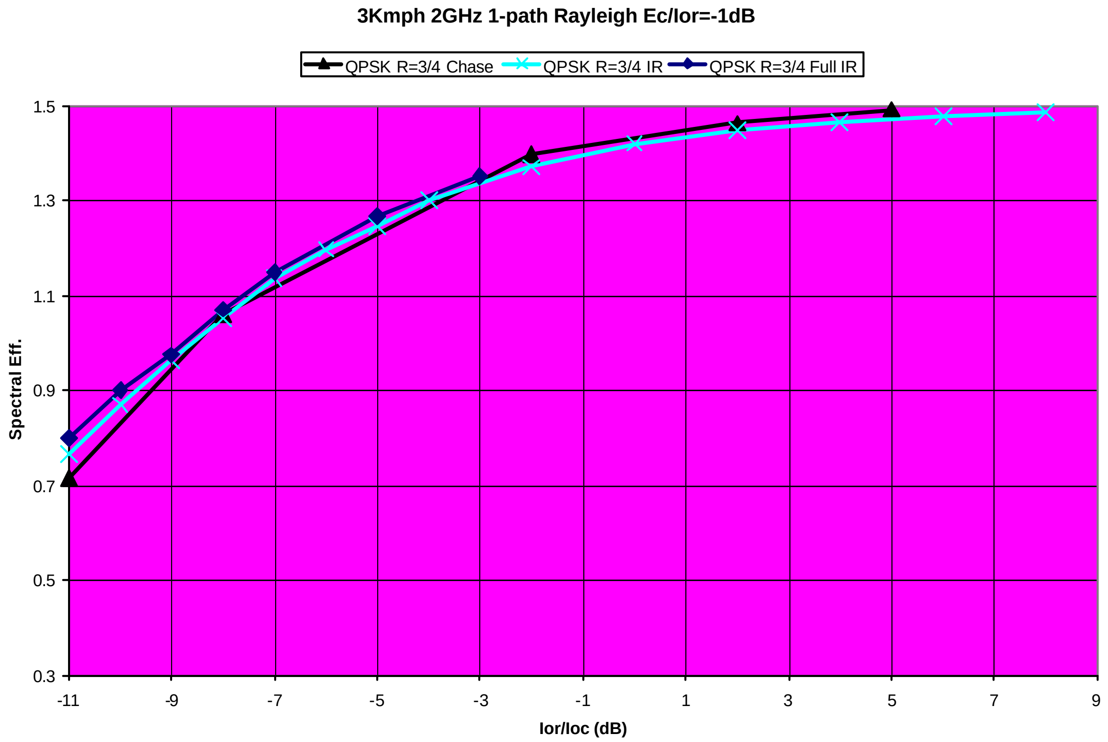

Figure 4. 3 Kmph QPSK

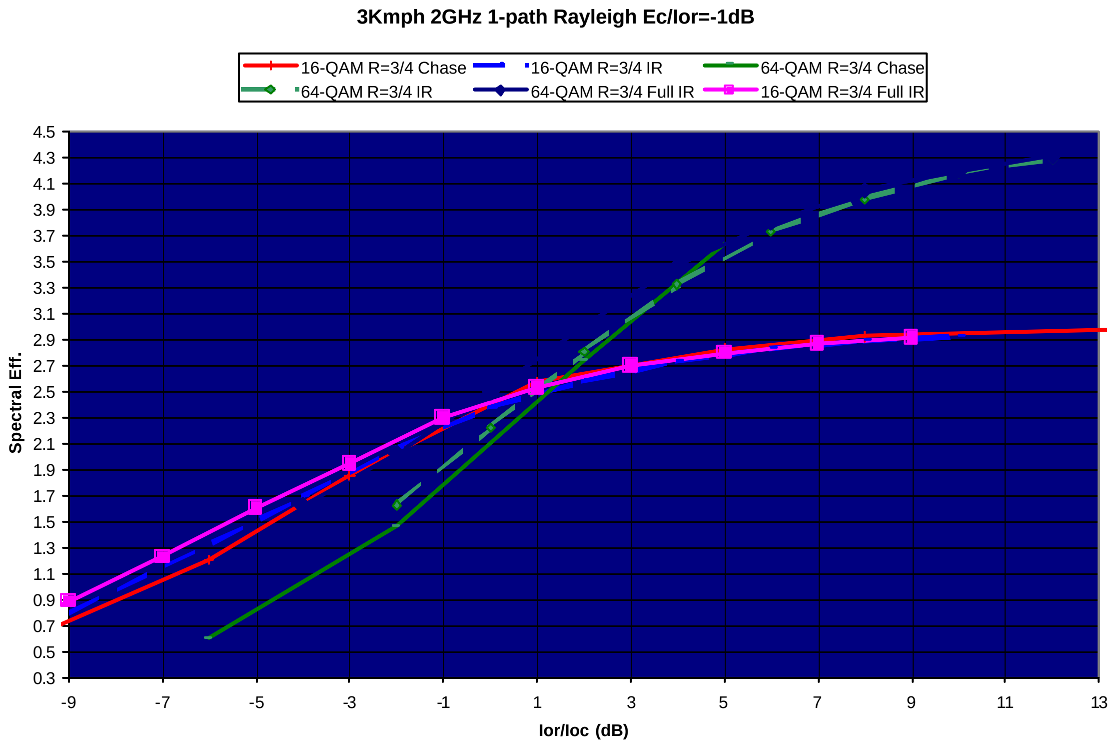

Figure 5. 3 Kmph 16/64-QAM

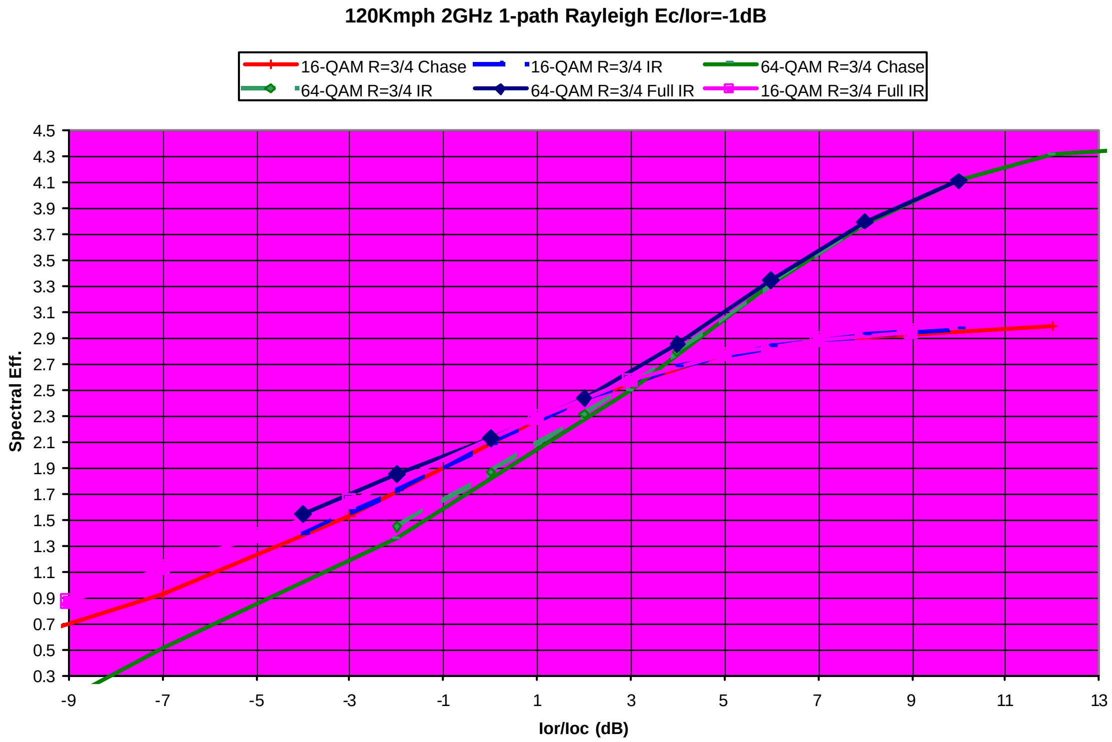

Figure 6. 120 Kmph 16/64-QAM

REFERENCES

[1] Motorola, “Performance Comparison of Hybrid-*ARQ* schemes,” TSGR1#17(00)1396.

[2] Ericsson, “Performance Comparison of Chase Combining and Incremental Redundancy for HSDPA,” TSGR1#18(00)1428.

[3] Motorola, “Performance Comparison of Hybrid-ARQ schemes,” TSGR1#18(01)0044.

[4] D. Chase, "Code Combining: A maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," IEEE Trans. on Commun., Vol. 33, pp. 593-607, May, 1985.

7.2.1.2 Summary for CPICH SIR errors w/wo H-ARQ based on System Simulations:

The effect of CPICH SIR measurement errors (0,1 and 3dB) on throughput with and without Hybrid ARQ (chase combining) is studied using a dynamic system simulation tool. The system simulator tool models Rayleigh and Rician fading, time evolution with discrete steps (0.667ms e.g.), adaptive modulation and coding (AMC), fast Hybrid ARQ, fast cell selection FCS, and open loop transmit diversity (STTD). The simulator also models Lognormal shadowing, delay spread, and fractional recovered power (per ray). Most of the system simulation assumptions used are described in Annex().). The system simulation assumptions used are described in sections 12.3.2 to 12.3.7 and in Tdoc# R1-01-0046. Each UE experienced 3kph rayleigh fading with fractional recovered power of 0.98.

7.2.1.3 CPICH SIR Measurement Error model

In the adaptive modulation and coding (AMC) schemes proposed for HSDPA, the UE uses the CPICH to estimate the downlink SIR (also known as C/I or Ec/Nt) in the current slot. This information is then fed back on an uplink control channel. Node B then uses this estimate to determine the modulation and coding level for that users subsequent frame and possibly also for setting scheduling priorities. Past contributions by Motorola have assumed perfect estimation of the downlink SIR. The simulation results presented below give throughput statistics when the measured CPICH SIR is modeled as:

$$\hat{SIR}_{CPICH} = SIR_{CPICH} + \varepsilon_{CPICH}$$

where SIR_{CPICH} and $\hat{SIR}_{CPICH}$ are the actual and estimated CPICH SIR respectively in dB and ε_{CPICH} is a Gaussian random variable with standard deviation σ_{ε} dB.

7.2.1.4 Hybrid ARQ (Chase combining) modeling

The system simulation tool models Chase combining process by accumulating the received signal energy of frame retransmissions. Based on this accumulated energy, a random number is drawn to determine if the frame is in error. In equation form, the energy used to determine a frame error, $Error\_Energy_{HARQ}(k)$, is accumulated across k transmissions:

$$Error\_Energy_{HARQ}(k) = \sum_{i=1}^{k} E_{DSCH}(i)$$

where $E_{DSCH}(k)$ is the received energy of the kth frame.
Hybrid ARQ is disabled by simply neglecting the accumulated energy and basing frame error determination on the current frame energy:

$$Error\_Energy_{NO\_HARQ}(k) = E_{DSCH}(k)$$

7.2.1.5 Simulation Results/Conclusions for CPICH SIR errors w/wo H-ARQ

Tables 1 - 6 summarize best effort packet data throughput performance for a data only HSDPA system with a Maximum C/I scheduler and a modified ETSI source model [3]. The different throughput metrics presented are defined in **Annex C**. The MCS used for the H-ARQ enabled case were QPSK R=1/2, 16QAM R=1/2, 16QAM R=3/4, and 64QAM R=3/4. The seven MCS used for the H-ARQ disabled case were QPSK R=1/4, QPSK R=1/2, QPSK R=3/4, 16QAM R=1/2, 8PSK R=1/2, 16QAM R=3/4, and 64QAM R=3/4. The minimum block size for the non-Hybrid ARQ case is set smaller (44 bytes versus 336 bytes) to allow more flexibility in allocating as small an MCS as needed for poor channels conditions which is important when H-ARQ is not available to help. This is needed to keep residual FER low.

From **Tables 1- 3** we see that with H-ARQ on, there is a drop in packet call throughput of between 5% and 10% with 1 dB CPICH measurement error. Sector throughput decreases by only about 5%. For 3dB CPICH measurement error, however, the packet call throughput drop approaches 50% and the sector throughput drop reaches 20%. The columns marked "Residual FER" give the percentage of users whose frame error rate, after all retransmissions, is above 1% and .1%. Estimation errors of 1 dB are seen to cause only very small increases in residual error rate.

Comparing **Tables 1 - 3** with H-ARQ to **Tables 4 - 6** without H-ARQ we see a significant drop in packet call throughput and residual FER without H-ARQ as also illustrated in **Figures 1-3**. (Note the throughputs are quite close for the no H-ARQ case when comparing 0dB and 1dB SIR measurement error cases. In some cases the throughputs are even slightly better for 1dB than 0dB. This is because the 10^-4 residual FER for the 1dB error case was not reduced enough to match the lower coresponding residual FER values achieved with 0dB error. If this was done then the throughputs for the 0dB error would have been consitantly better than the 1dB case)

In general every effort should be made to find algorithms which keep the CPICH SIR measurement error smaller than 3dB and preferably no larger than 1 dB.

TABLE 1 H-ARQ Enabled with CPICH Error ? =0dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=336 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, HARQ, ? =0dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA (bps)	Center Cell Service (bps)	Packet call (bps)	Percent Utilization (%)	Offered Load (bps)	User Packet Call Throughput CDF <32k/64k/128k/384k/1M (%)	%UEs with Residual FER >10-2 / >10-4 (%)
012ue/sect, 20size32	2,189,367	476,764	1,494,552	21.7	492,820	00 / 00 / 00 / 02 / 29	0.0 / 0.0
037ue/sect, 20size32	1,934,215	1,422,217	1,164,068	72.0	1,475,268	00 / 00 / 02 / 16 / 49	0.0 / 1.0
056ue/sect, 20size32	1,985,243	1,872,642	1,008,999	91.6	1,934,544	01 / 03 / 10 / 32 / 61	0.0 / 1.2
075ue/sect, 20size32	2,251,443	2,312,162	943,371	99.2	2,371,219	05 / 09 / 21 / 43 / 65	0.3 / 2.0
100ue/sect, 20size32	2,787,112	2,890,511	924,114	99.7	2,935,203	12 / 19 / 29 / 49 / 67	0.0 / 0.9

TABLE 2 H-ARQ Enabled with CPICH Error ? =1dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=336 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, HARQ, ? =1dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA (bps)	Center Cell Service (bps)	Packet call (bps)	Percent Utilization (%)	Offered Load (bps)	User Packet Call Throughput CDF <32k/64k/128k/384k/1M (%)	%UEs with Residual FER >10-2 / >10-4 (%)
012ue/sect, 20size32	2,041,386	468,907	1,439,111	23.0	489,320	00 / 00 / 00 / 02 / 29	0.0 / 0.7
037ue/sect, 20size32	1,769,061	1,359,925	1,091,056	74.8	1,396,482	00 / 00 / 02 / 18 / 53	0.0 / 2.0
056ue/sect, 20size32	1,918,134	1,885,656	915,797	94.4	1,853,439	03 / 06 / 14 / 38 / 64	0.0 / 3.1
075ue/sect, 20size32	2,106,633	2,186,367	841,139	99.0	2,188,733	05 / 11 / 23 / 46 / 69	0.3 / 2.4
100ue/sect, 20size32	2,546,921	2,697,633	821,589	99.7	2,748,435	16 / 24 / 34 / 53 / 71	0.1 / 1.1

TABLE 3 H-ARQ Enabled with CPICH Error ? =3dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=336 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, HARQ, ? =3dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA (bps)	Center Cell Service (bps)	Packet call (bps)	Percent Utilization (%)	Offered Load (bps)	User Packet Call Throughput CDF <32k/64k/128k/384k/1M (%)	%UEs with Residual FER >10-2 / >10-4 (%)
012ue/sect, 20size32	1,800,245	468,615	1,268,680	25.9	485,515	00 / 00 / 00 / 03 / 38	0.0 / 6.6
037ue/sect, 20size32	1,539,392	1,327,651	857,181	81.6	1,367,491	00 / 01 / 05 / 28 / 65	0.1 / 21.6
056ue/sect, 20size32	1,596,800	1,733,146	650,307	97.9	1,755,674	03 / 10 / 25 / 51 / 79	3.8 / 37.5
075ue/sect, 20size32	1,739,118	2,010,782	548,694	99.7	2,028,803	17 / 28 / 41 / 62 / 84	10.8 / 45.1
100ue/sect, 20size32	1,984,111	2,344,356	488,986	100.0	1,685,867	29 / 40 / 51 / 70 / 88	19.2 / 43.1

TABLE 4 H-ARQ Disabled with CPICH Error ? =0dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=44 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, no HARQ, ? =0dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA (bps)	Center Cell Service (bps)	Packet call (bps)	Percent Utilization (%)	Offered Load (bps)	User Packet Call Throughput CDF <32k/64k/128k/384k/1M (%)	%UEs with Residual FER >10-2 / >10-4 (%)
012ue/sect, 20size32	1,520,408	485,743	1,308,356	32.0	504,649	00 / 00 / 00 / 08 / 39	0.0 / 12.9
037ue/sect, 20size32	1,416,810	1,288,633	967,353	89.7	1,326,531	01 / 03 / 09 / 29 / 60	0.4 / 8.5
056ue/sect, 20size32	1,749,294	1,769,641	874,218	98.7	1,800,613	05 / 11 / 22 / 43 / 66	0.8 / 5.5
075ue/sect, 20size32	2,002,801	2,069,836	862,819	99.9	2,131,931	10 / 16 / 25 / 46 / 70	1.1 / 3.1
100ue/sect, 20size32	2,486,878	2,594,540	842,428	100.0	2,624,878	21 / 29 / 39 / 56 / 73	1.7 / 2.6

TABLE 5 H-ARQ Disabled with CPICH Error ? =1dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=44 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, no HARQ, ?=1dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA	Center Cell Service	Packet call	Percent Utilization	Offered Load	User Packet Call Throughput CDF <32k/64k/128k/384k/1M	%UEs with Residual FER >10-2 / >10-4
	(bps)	(bps)	(bps)	(%)	(bps)	(%)	(%)
012ue/sect, 20size32	1,530,806	481,501	1,286,691	31.7	499,832	00 / 00 / 00 / 08 / 40	0.4 / 29.2
037ue/sect, 20size32	1,454,641	1,282,069	970,561	87.4	1,319,830	01 / 02 / 08 / 28 / 60	0.1 / 28.1
056ue/sect, 20size32	1,765,049	1,779,992	863,970	98.7	1,808,100	05 / 11 / 22 / 44 / 67	1.2 / 21.8
075ue/sect, 20size32	2,113,291	2,171,857	829,287	99.7	2,191,233	12 / 20 / 31 / 49 / 70	1.9 / 19.1
100ue/sect, 20size32	2,545,747	2,647,440	811,905	99.9	2,684,573	20 / 28 / 39 / 56 / 74	2.7 / 17.5

TABLE 6 H-ARQ Disabled with CPICH Error ? =3dB

Single Rayleigh Ray, 3kph, FRP=0.98 Blk Size=44 bytes Max C/I, Mod. ETSI 30% Overhead AMC, no FCS, no HARQ, ?=3dB

#Users per sector, Max ovsf codes	Average Throughput Statistics OTA	Center Cell Service	Packet call	Percent Utilization	Offered Load	User Packet Call Throughput CDF <32k/64k/128k/384k/1M	%UEs with Residual FER >10-2 / >10-4
	(bps)	(bps)	(bps)	(%)	(bps)	(%)	(%)
012ue/sect, 20size32	651,769	421,017	562,266	64.7	428,874	02 / 12 / 22 / 50 / 85	0.0 / 27.3
037ue/sect, 20size32	1,001,833	994,474	441,438	98.8	996,024	20 / 32 / 44 / 66 / 92	0.4 / 34.5
056ue/sect, 20size32	1,289,235	1,299,310	404,842	99.9	1,318,800	32 / 42 / 53 / 73 / 93	1.8 / 33.2
075ue/sect, 20size32	1,534,659	1,549,681	388,628	99.9	1,583,774	39 / 49 / 59 / 77 / 94	3.6 / 41.9
100ue/sect, 20size32	1,856,090	1,887,593	379,859	100.0	1,932,895	46 / 56 / 64 / 80 / 95	6.2 / 33.7

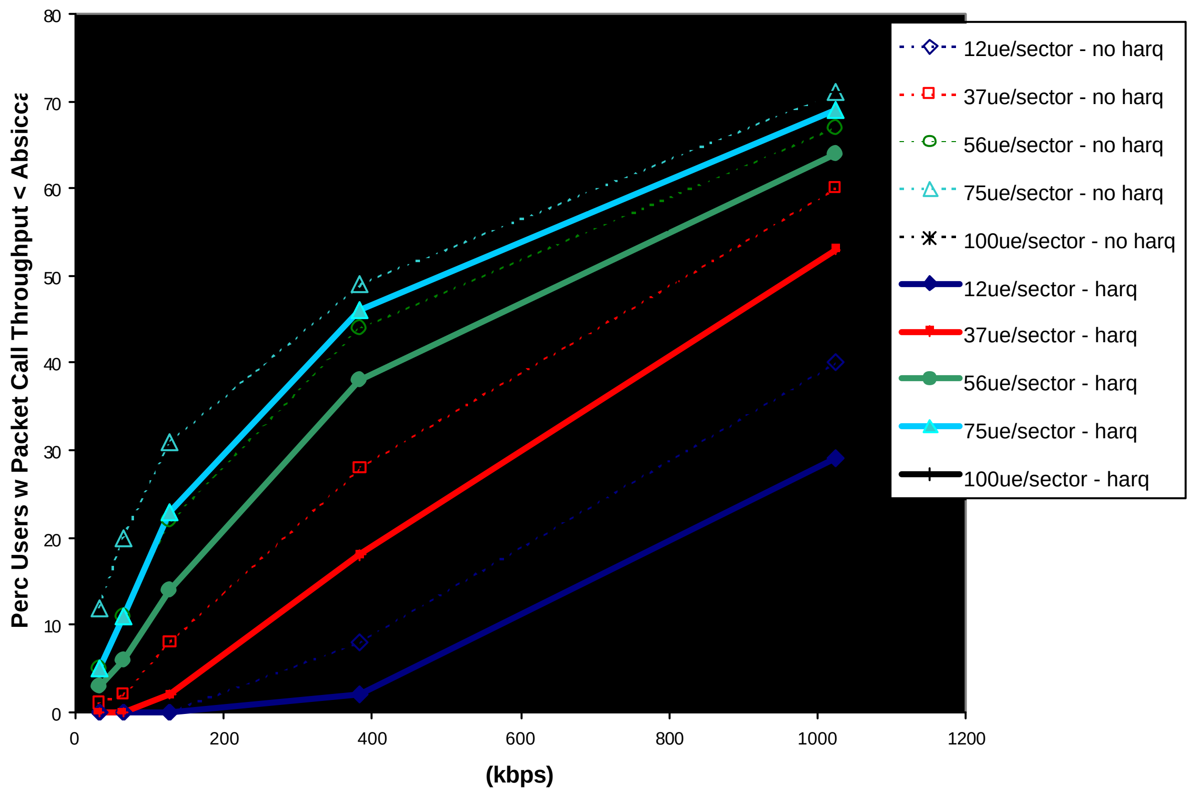

Figure 1 %User Packet Call Throughput CDF w/wo H-ARQ for the 1dB CPICH SIR measurement error case using a Max C/I Scheduler

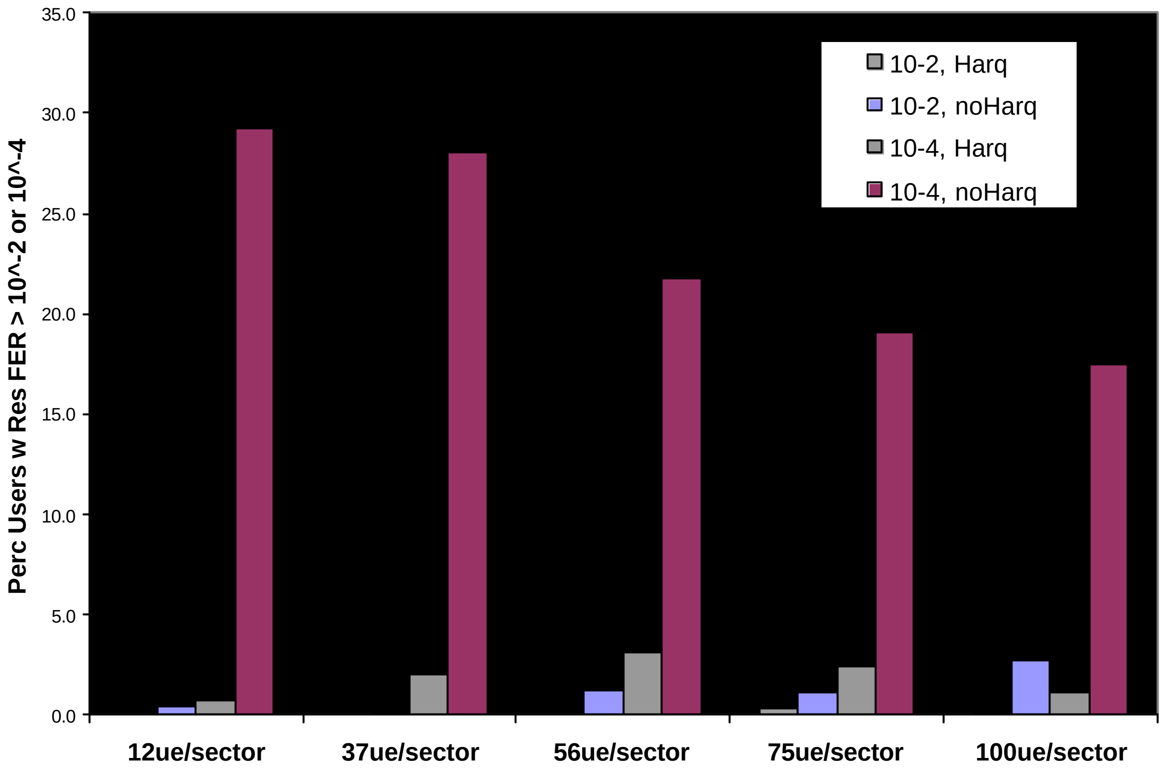

Figure 2. Residual FER with and without H-ARQ for the 1dB CPICH SIR measurement error case using a Max C/I Scheduler

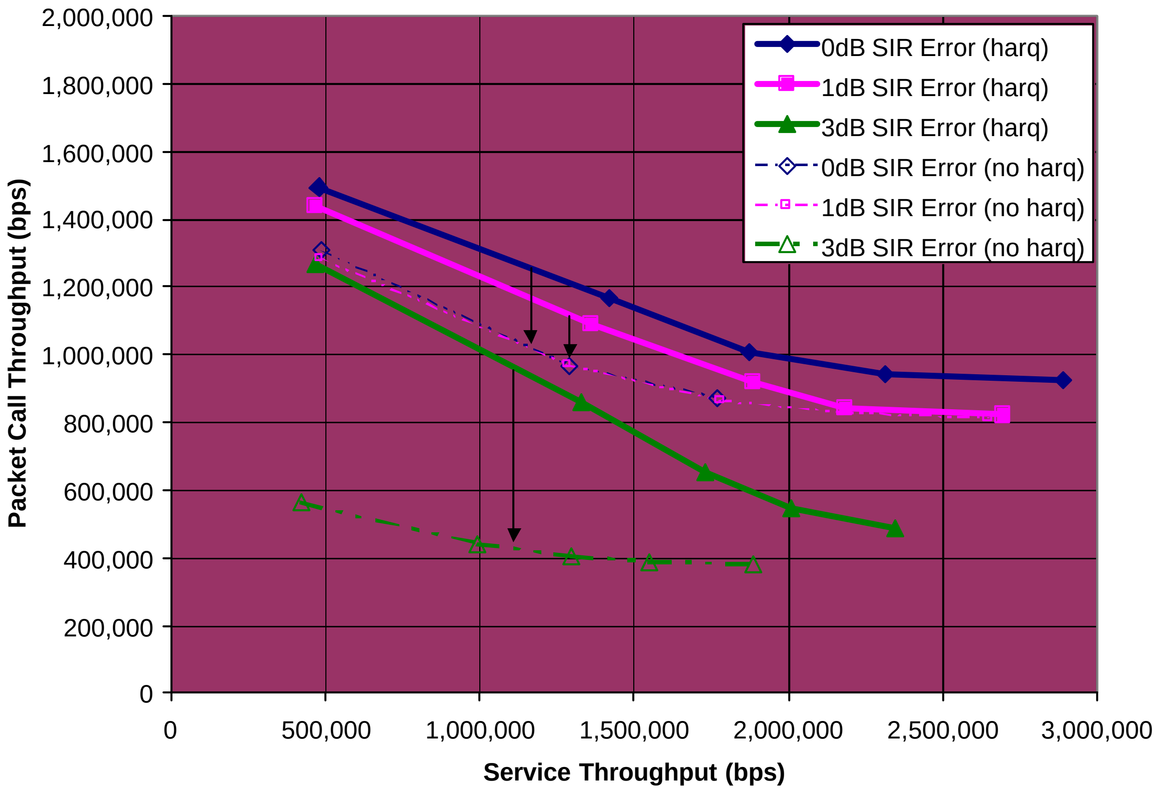

Figure 3 Packet Throughput vs Service Throughput w/wo H-ARQ for different CPICH SIR Measurement Errors using a Max C/I Scheduler.