White Paper

Improving GSM Cellular Network Performance and Reducing Cost with Broadcom's M-Stream Technology

This white paper introduces M-Stream high-performance modem technology from Broadcom. M-Stream improves cellular handset reception and voice quality while increasing network capacity. By combining half-rate Adaptive Multi-Rate (AMR) speech coding together with M-Stream and SAIC advanced signal processing technologies, network capacity can be increased by 1.5 to 2.0 times ordinary AMR technology without sacrificing call quality. Mobile operators can operate their networks at high capacity while users experience improved reception in weak signal areas.

April 2007

Introduction

Voice services based on GSM networks globally dominate cellular telephone operations today. The services provided by these networks have become critical enablers for economic growth, supporting mass penetration of telephony and providing the utility of widely available mobile access. GSM technology costs have matured, particularly for voice services. While 3G WCDMA technology is also evolving and offers a range of benefits, such as video-telephony and potentially higher capacity and faster data capabilities than existing technologies, GSM will continue to dominate for voice-centric and mass low-cost mobility for some time.

The availability of spectrum to deploy and grow cellular networks has always been a major issue for cellular operators. A great deal of effort has been directed at optimizing spectrum efficiency, and innovative, complex technologies continue to be developed to enhance performance. But with continued growth both in user penetration and in per-user usage, network congestion and performance remain as major challenges for low-cost operation. Combining half-rate AMR speech with Broadcom's M-Stream technology and SAIC advanced signal processing technologies can add high capacity and good performance to low-cost GSM networks. Broadcom's M-Stream technology also enhances voice services over 3G WCDMA networks.

Half-Rate AMR Voice Solutions

GSM half-rate was standardized and developed to support low-cost and high-capacity network operation with sixteen voice channels per base station radio in contrast to eight voice channels provided with GSM full-rate voice. Base station radios and associated RF combiners, and antennas are major costs in cellular networks. The capability to provide twice the number of voice channels per radio is a very important option to reduce network costs. Half-rate GSM voice coding uses lower bit-rate voice coding (5.9 Kbps) versus full-rate GSM voice coding (13 Kbps). This supports higher than normal multiplexing of channels onto backhaul facilities from the base stations to cellular switching offices, where voice coders are located, hence lowering than normal backhaul costs. However, half-rate GSM has compromised service in two major ways:

1. The quality of the GSM half-rate voice coder is noticeably lower than full-rate due to the reduced coding rate.
2. The wireless modem quality of half-rate operation, with one-half the number of modem channel bits compared to full-rate, means that half-rate is significantly more vulnerable to RF interference and noise impairments. As a result, call quality with half-rate GSM has limited its deployment and usage.

GSM AMR full-rate (AFS) and AMR half-rate (AHS) voice services were recently standardized and developed to enhance quality and RF performance for both full-rate and half-rate operations. A family of eight high-quality voice coders, ranging in rates from 4.75 Kbps to 12.2 Kbps, was developed. AFS uses all eight rates, and AHS uses six rates, from 4.75 Kbps to 7.95 Kbps.

Cellular operators can specify a family of up to four coders that are used during any call, and the radio link dynamically adapts within that family of coders to optimize voice quality dependent upon impairment conditions. With higher quality speech coding than normal and adaptive operation, AHS effectively addresses the limitations of GSM half-rate voice quality and reduces the vulnerability to interference and noise. However, AHS operation continues to have some weaknesses in resistance to RF impairments that limit capacity and service quality and partially negate potential AHS cost savings.

Single Antenna Interference Canceling (SAIC) technology was recently standardized by 3GPP for GSM to improve resistance to interference. It significantly suppresses a dominant interfering signal in a GSM modem, providing substantial benefit when limited by a strong single interferer. It does not enhance performance for weak signals limited by noise, however, and improvement is limited for typical scenarios combining weak signals and weak interference. M-Stream enhances performance significantly for scenarios that are limited by noise, as well as noise mixed with interference. M-Stream is complementary to SAIC. Combining these two technologies results in a powerful capability to enhance the potency of half-rate AMR to RF impairments. This combination is so powerful that it provides performance for AMR half-rate close to that provided by AMR full-rate for conventional receivers. Network operators are able to achieve the capacity improvements of half-rate while maintaining voice quality close to that of full-rate operation.

SAIC Technology

GSM 3GPP Release 6 provides specifications for Downlink Advanced Receiver Performance (DARP) in 3GPP TS 45.005. DARP is the term used to refer to SAIC in 3GPP. However, SAIC/DARP is also supported in earlier versions of GSM. There are two basic forms of SAIC: 1) joint detection and 2) blind interference suppression. Joint detection is difficult to implement unless the network is configured so that the base stations operate with alignment of the GSM frame structure. Since this is challenging for operations, blind interference suppression is generally in use. SAIC operates as a modem enhancement technology that is specifically designed to operate with the binary GMSK modulation of GSM.

Blind interference suppression forms of SAIC can suppress a very strong dominant interference signal by up to about 10 dB. But no improvement is provided against noise or other types of impairments. For typical live-network scenarios with a mixture of multiple interferers and noise, SAIC provides improvements in the 2 dB to 3 dB range. To double the capacity in a GSM network, approximately 4 dB to 6 dB of improved resistance to interference is required.

The Release 6 specifications for DARP specify a dominant interferer at -80 dBm or about 35 dB above the typical background noise level. This is a very strong interferer. Requirements are not considered for weaker dominant interferers, although this is much more common in operating networks. As the interference level is reduced towards the noise level, SAIC will start providing reduced performance gain and will eventually provide no improvement. M-Stream provides enhanced performance against noise, while SAIC does not. By combining M-Stream with SAIC, large performance gains are achieved over a wide range of conditions typically found in live networks. This is particularly attractive for AHS, which is more susceptible to interference due to the decreased number of signal coding bits.

M-Stream High-Performance Modem Technology

M-Stream extracts as much information in the received signal as possible to enhance cellular receiver performance. It enhances equalizer and channel decoding functions using redundant information in the signals. It is readily implemented in a standard DSP processor, as is SAIC, so it can be added at a very low cost to cellular handsets using existing hardware with a moderate increase in DSP processing.

Like SAIC, M-Stream is compatible with existing standards and can be implemented without changes to standards or to base stations when used for improving the downlink. In this case, only additional DSP processing is required in the cell phone. M-Stream can also be used independently for cellular network uplinks by adding DSP processing at the base station. However, the downlink tends to be interference-limited and is generally the constraint on capacity, because base stations usually have diversity reception for the uplink and do not have handset antenna space constraints.

M-Stream typically provides 2 dB to 3 dB of improvement over a wide range of conditions for GSM voice, including ordinary noise limited conditions, static and fading channels. Figure 1 compares an M-Stream-enabled cell phone platform, Eagleray, to a conventional receiver and a reference phone from a major supplier. AMR half-rate is tested here with the lowest bit-rate voice mode, 4.75 Kps. As this mode represents the most difficult network conditions, the gain for this mode and condition is most critical. Similar or higher gains are achieved for all modes for AMR speech. In addition, M-Stream provides gain for the control channels associated with voice channels, including the FACCH and SACCH channels.

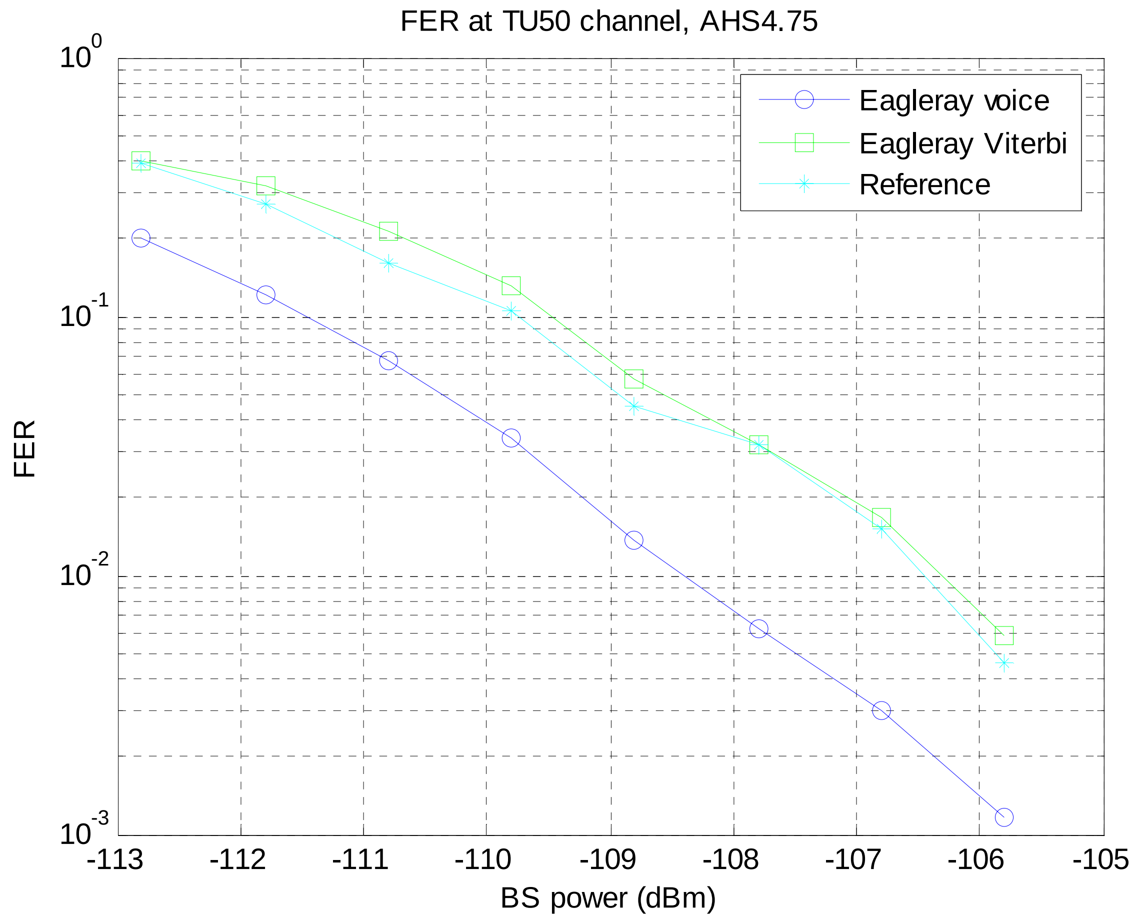


Figure 1: AMR Half-Rate Voice at 4.75 Kbps

Figure1 shows the Frame Error Rate (FER) versus Base Station signal level received at the cell phone with M-Stream (Eagleray voice mode) compared to conventional receivers for a Typical Urban mobile fading channel of 50 km/hr at 900 MHz. M-Stream has also been applied to both GPRS and WCDMA receivers for voice. In the case of WCDMA voice, 1-dB gain is typically achieved, providing about 25 percent capacity enhancement in a WCDMA network.

M-Stream and SAIC Combined with Half-Rate AMR Voice

M-Stream can be combined with SAIC in a complementary way. Automatic adaptation algorithms enable M-Stream and SAIC processing to optimize performance as needed and to minimize additional DSP processing requirements. Under fair-to-good channel conditions, M-Stream automatically disables enhanced processing, so the additional battery power associated with M-Stream is very small.

Figure 2 shows lab measurements for AHS with a weak interference signal at -110 dBm but still about 5 dB above the background noise, and compares the results to conventional receivers and several reference phones with SAIC. SAIC provides almost no gain in this case. However, M-Stream + SAIC (the line farthest to the left) provides about 3 dB of gain in this situation.

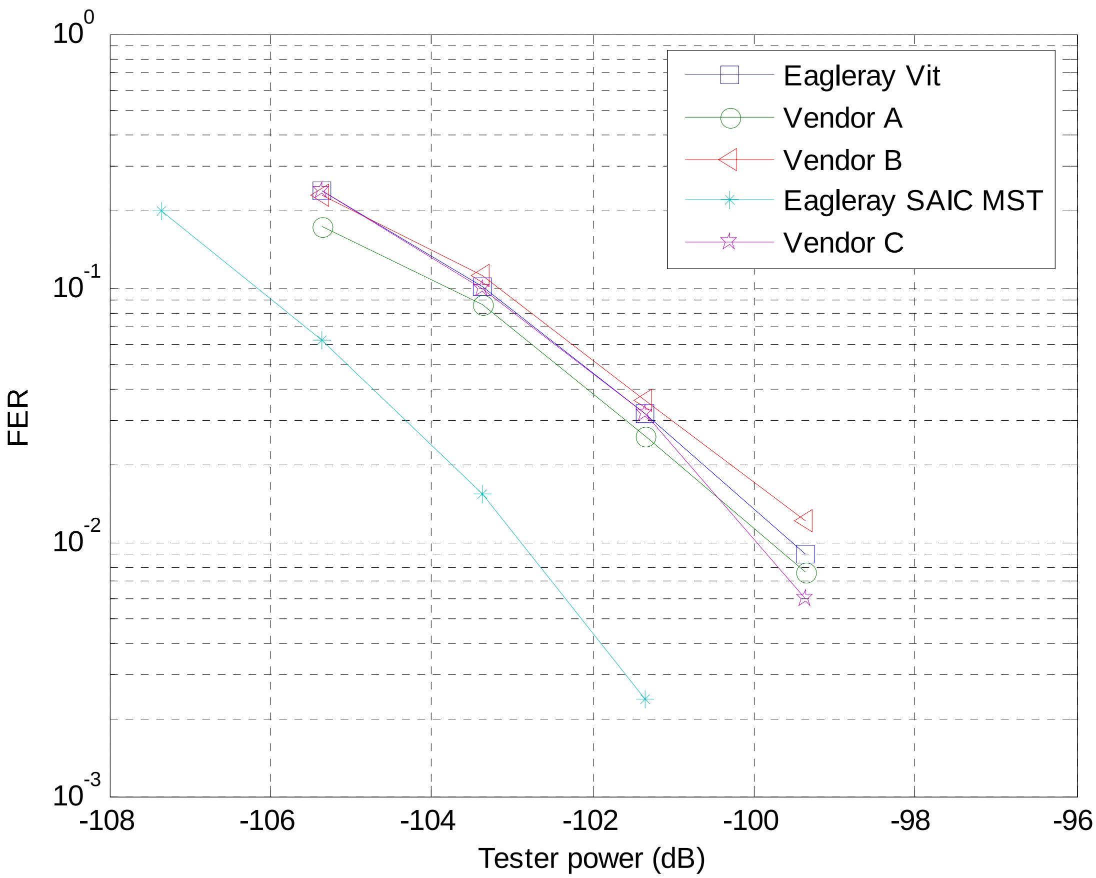


Figure 2: AMR 4.75-Kbps Half-Rate Performance for M-Stream + SAIC

Figure 2 shows AMR 4.75-Kbps half-rate performance for M-Stream + SAIC compared to one cell phone with a conventional receiver (Vendor A) and two cell phones with SAIC (Vendors B and C) with interference at -110 dBm and 75% burst overlap for TU50 fading channels at 1900 MHz

Figure 3 shows AMR full-rate results: AMR 4.75-Kbps full-rate performance for M-Stream + SAIC compared to one cell phone with a conventional receiver (Vendor A) and two cell phones with SAIC (Vendors B and C) with interference at -110 dBm and 75% burst overlap for TU50 fading channels at 1900 MHz. A comparison between Figures 2 and 3 shows that AMR half-rate with M-Stream + SAIC performs about the same as AMR full-rate with conventional receivers or even with SAIC, in this test, with a weak interferer. This indicates that AHS can provide quality similar to AFS if the AHS cell phone is equipped with M-Stream + SAIC. Since AHS can be equipped in the base stations with twice the number of voice channels per radio as AFS, this enables lower cost operation and improved quality of service.

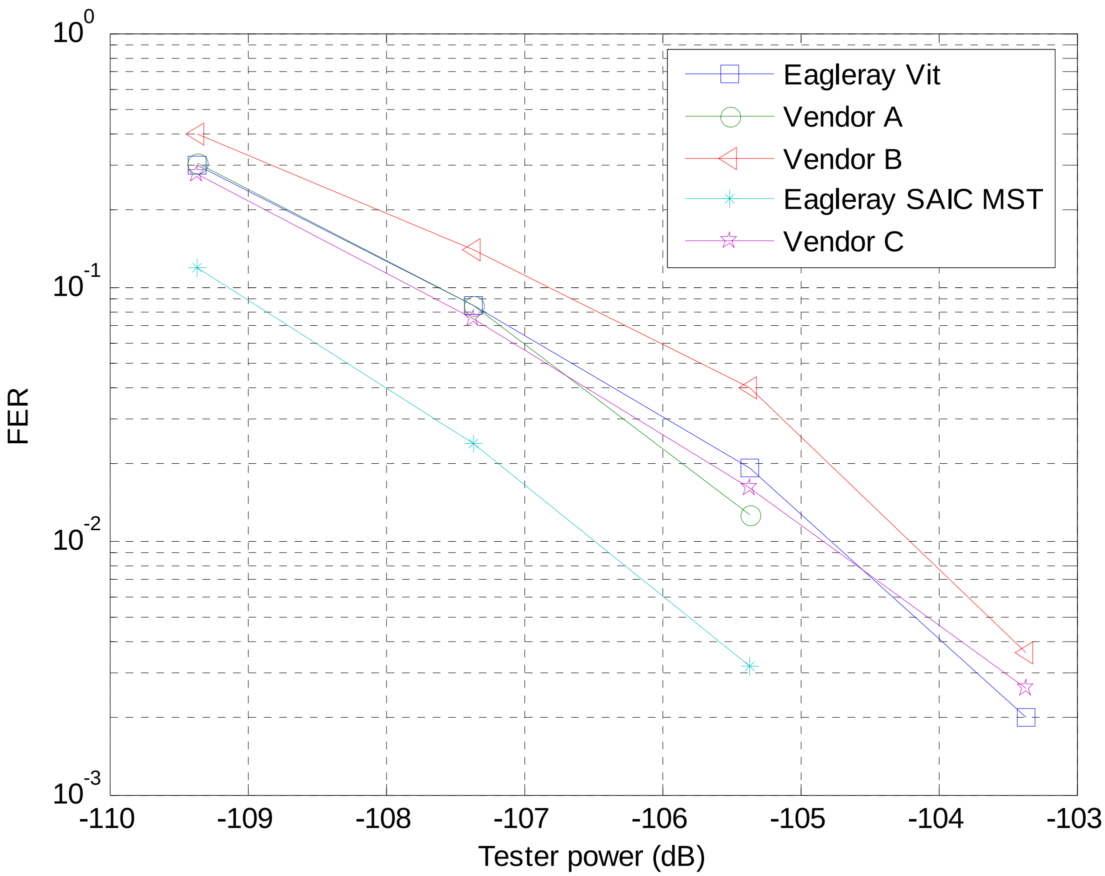


Figure 3: AMR 4.75-Kbps Full-Rate Performance for M-Stream + SAIC

AHS and AFS performance with a medium-strength interference signal at -100 dBm is shown in Figures 4 and 5. In this case, the SAIC receivers provide some gain, but M-Stream + SAIC provides much larger gain of 5 dB to 6 dB over a conventional receiver.

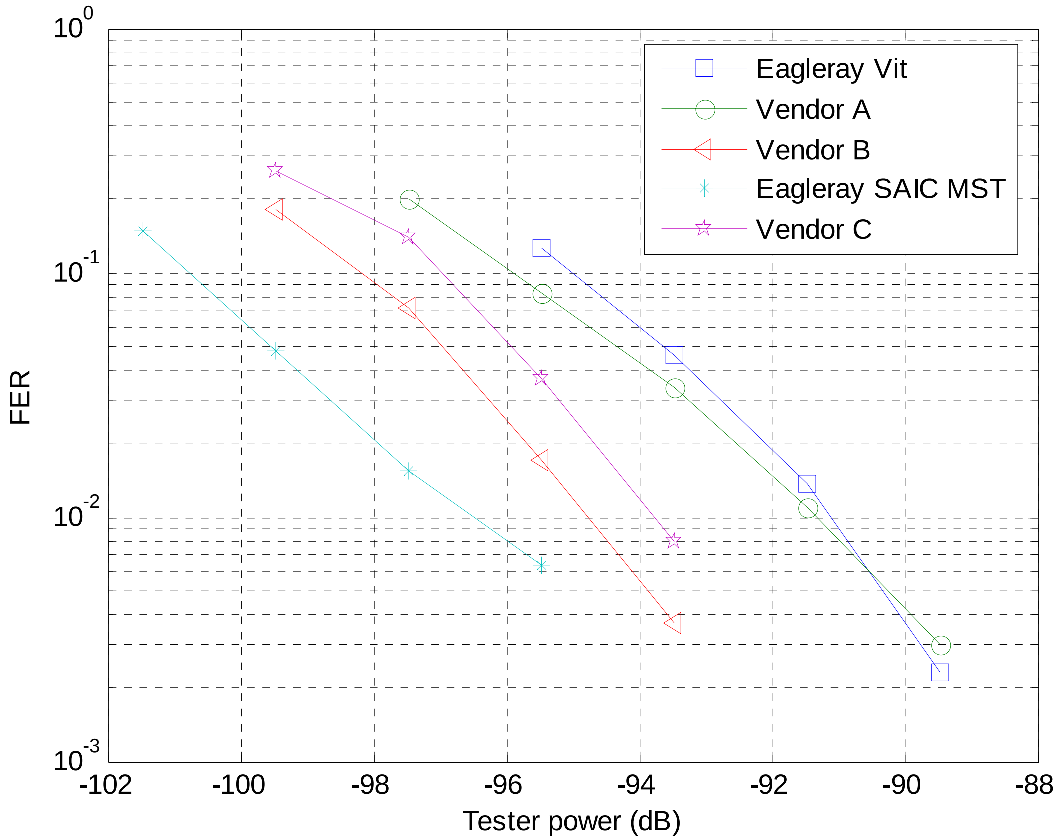


Figure 4: AMR 4.75-Kbps Half-Rate Performance for M-Stream + SAIC (Medium-Strength Interference Signal)

This performance is evident when comparing to one cell phone with a conventional receiver (Vendor A) and two cell phones with SAIC (Vendors B and C) with interference at -100 dBm and 75% burst overlap for TU50 fading channels at 1900 MHz.

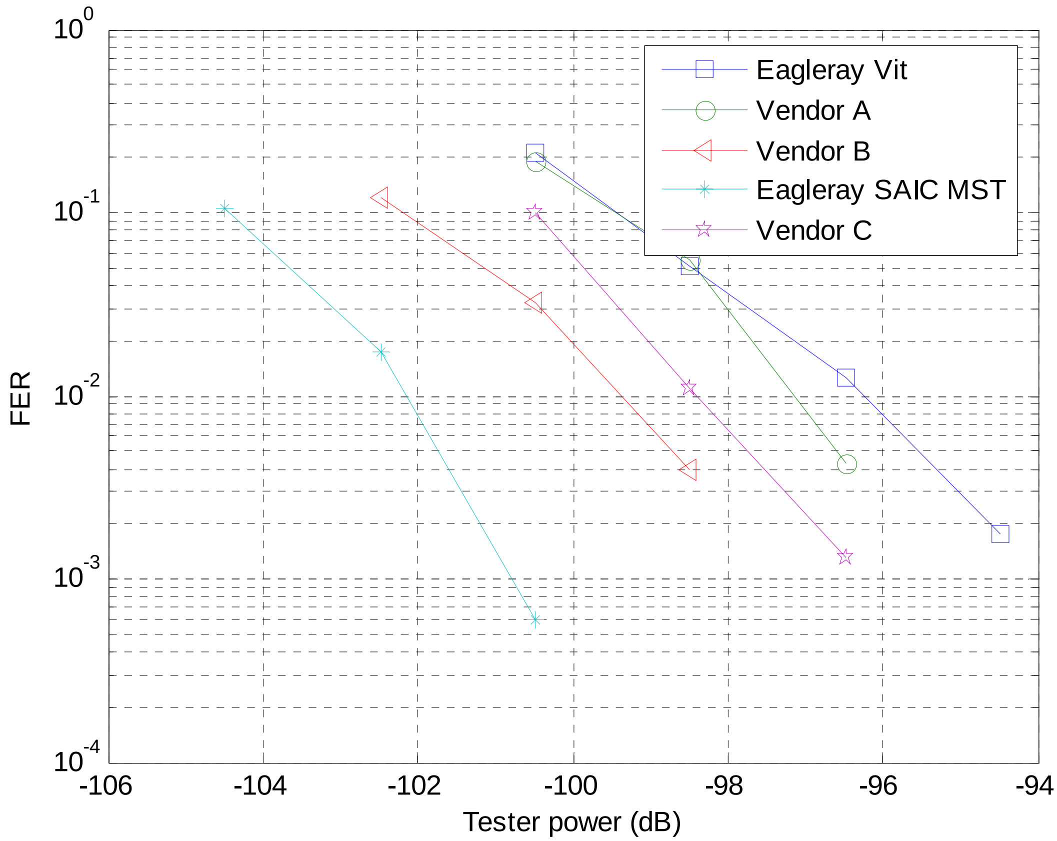


Figure 5: AMR 4.75-Kbps Full-Rate Performance for M-Stream + SAIC (Medium-Strength Interference Signal)

This performance is evident when comparing to one cell phone with a conventional receiver (Vendor A) and two cell phones with SAIC (Vendors B and C) with interference at -100 dBm and 75% burst overlap for TU50 fading channels at 1900 MHz.

Performance Requirements for Network Capacity Gains

M-Stream + SAIC combined with AMR Half-Rate voice can improve network capacity by 1.5 to 2.0 times ordinary AMR full-rate or ordinary AMR half-rate voice services. Here capacity gain is defined as the increase in the number of active users, supported for a given allocated band of spectrum, with the number of base stations or cells held constant. While M-Stream + SAIC can provide the required performance gains for this improvement, one approach to deployment to maximize flexibility is to specify the required performance for Advanced AMR cell phones and allow the usage of any techniques to meet the required performance. Advanced AMR specifications focus on AMR half-rate, but AMR full-rate is included.

Table 1 proposes performance requirements for Advanced AMR cell phones for half-rate and full-rate voice services that enable these large-capacity gains. At the specified average desired signal levels in the table, the cell phone is required to achieve an average Frame Error Rate of less than 1% on the downlink with a test signal of ordinary voice content. Class Ib and Class II Bit Error Rate (BER) performances are also specified. The testing is performed for so-called no-frequency-hopping TU50 fading channels for the GSM and PCS/DCS bands, as specified by 3GPP for GSM. The interference condition tested is a single interference signal at -110 dBm with frame burst timing offset from the desired signal to achieve 75% overlap with the desired signal. These performance requirements extend the DARP receiver performance requirements in 3GPP TS 45.005, release 6.

Voice Mode	Performance Category	GSM 900 and GSM 850	DCS 1800 & PCS 1900
TCH/AFS12.2	Required BS power (dBm) at 1% FER	-99.5	-100.5
	Class Ib	1.5	2.5
TCH/AFS7.95	Required BS power (dBm) at 1% FER	-102	-103
	Class Ib	1.0	2.5
TCH/AFS5.9	Required BS power (dBm) at 1% FER	-103	-104.5
	Class Ib	0.7	1.0
TCH/AHS7.95	Required BS power (dBm) at 1% FER	-97	-97
	Class Ib	0.8	0.8
	Class II	2.5	2.5
TCH/AHS5.9	Required BS power (dBm) at 1% FER	-99.5	-99.5
	Class Ib	0.5	0.5
	Class II	5.0	5.0
TCH/AHS4.75	Required BS power (dBm) at 1% FER	-102	-102
	Class Ib	0.7	0.6
	Class II	7.0	7.0

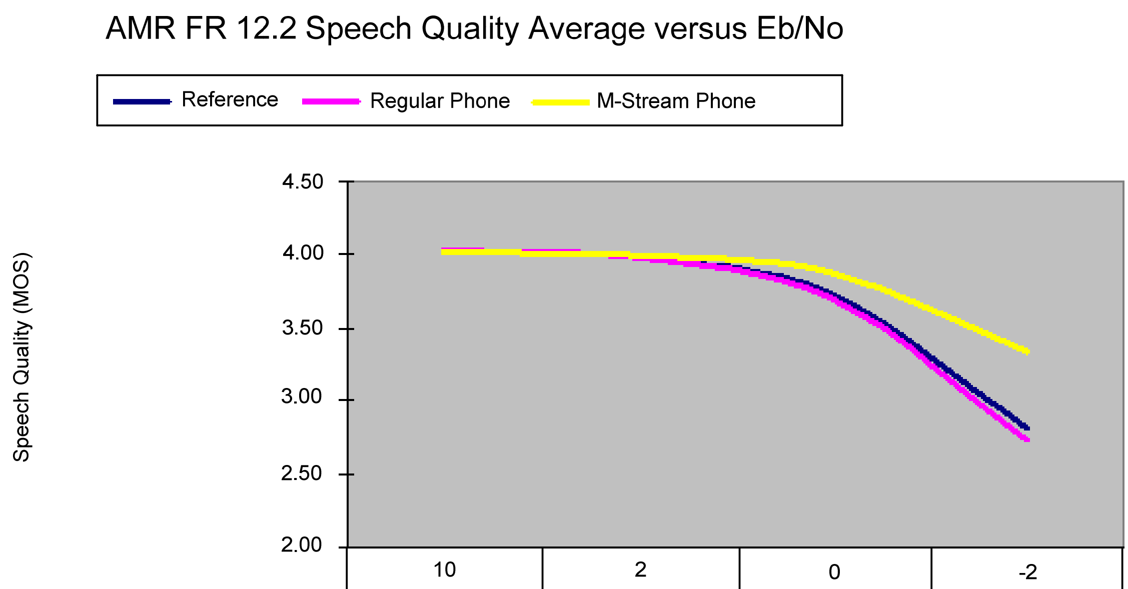
Table 1: Proposed Advanced AMR Specifications

The AMR half-rate frame error rate will be less than 1% at the specified levels. At the specified signal levels, the Class Ib and Class II Bit Error Rate performances will be less than the specified values. See the following text for detailed test information.

Laboratory PESQ Results with and without M-Stream

This section presents the results of measurements of PESQ taken in a laboratory for phones with and without M-Stream + SAIC. PESQ is similar to Mean Opinion Score (MOS) which rates speech subjectively on a range from 1 to 5 (1 = unusable, 2 = poor, 3 = fair, 4 = good, 5 = excellent). PESQ analysis is performed with objective measurements, and it is based on computerized algorithms comparing the original and the recovered speech. These measurements were performed by Metrico. AMR full-rate speech at 12.2 Kbps and AMR half-rate speech at 5.95 Kbps were tested for noise-limited conditions for a Typical Urban at 50 km/hr vehicular speed (TU50) fading channel representing urban driving scenarios under weak signal conditions. Three configurations were tested: 1) a reference phone from a leading vendor; 2) a Broadcom-equipped phone without M-Stream and SAIC enabled; and 3) a Broadcom-equipped phone with M-Stream and SAIC enabled.

Figures 6 and 7 show the PESQ results versus received average Eb/No, a measure of signal to noise ratio. For both full-rate and half-rate voice services, M-Stream provides about 2 dB performance improvement in the critical region of PESQ = 3, and M-Stream pushes the PESQ performance curves smoothly down into noise-limited conditions, where conventional receivers are providing degraded results.

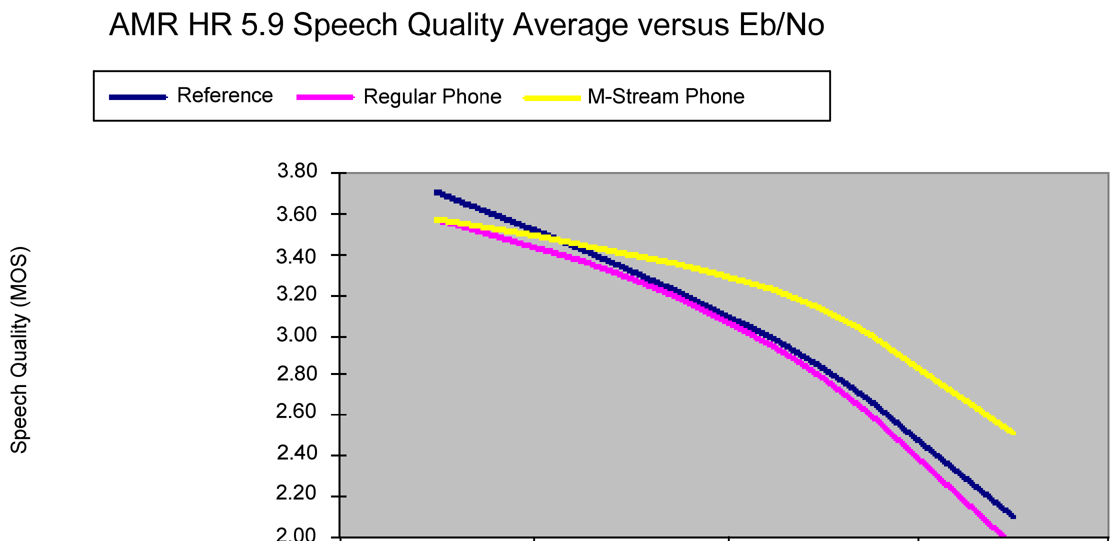


	10	2	0	-2
Reference	4.03	3.98	3.72	2.82
Regular Phone	4.03	3.98	3.70	2.73
M-Stream Phone	4.05	4.00	3.87	3.34

Figure 6: AMR 12.2-Kbps Full-Rate Voice PESQ Performance

The AMR 12.2-Kbps full-rate voice PESQ performance is for: 1) a reference phone; 2) a Broadcom-equipped phone with M-Stream + SAIC disabled; and 3) the same

Broadcom-equipped phone with M-Stream + SAIC enabled. M-Stream shows about 2 dB of performance advantage in the critical region of PESQ = 3, plus and minus.



	10	2	0	-2
Reference	3.70	3.32	2.85	2.11
Regular Phone	3.57	3.28	2.79	1.96
M-Stream Phone	3.57	3.39	3.13	2.51

Figure 7: AMR 5.95-Kbps Half-Rate Voice PESQ Performance

The AMR 5.95-Kbps half-rate voice PESQ performance is for: 1) a reference phone; 2) a Broadcom-equipped phone with M-Stream + SAIC disabled; and 3) the same Broadcom-equipped phone with M-Stream + SAIC enabled. M-Stream shows about 2 dB of performance advantage in the critical region of PESQ = 3, plus and minus.

Field Test Results with and without M-Stream + SAIC

This section presents results for a field test with Broadcom-equipped GSM phones with and without M-Stream + SAIC enabled. This test was performed in a suburban area with weak signal strength conditions, so the error rates are higher than typical network conditions to stress performance. Two identical units were used simultaneously in the test in a vehicular scenario. A number of precautions were undertaken to ensure fairness in the testing, such as including lab tests to ensure identical performance and rotation of positioning, and collection of a number of hours of data to achieve statistical significance.

In these tests, the AMR downlink signal thresholds to request the AMR voice rates were offset by 2 dB for the phone without M-Stream + SAIC and by 4 dB for the phone with M-Stream + SAIC from default conditions. This request tends to keep the M-Stream + SAIC phone at higher voice coding rates than compared to the phone without M-Stream + SAIC, and it stresses the frame error rate performance compared to the phone without M-Stream + SAIC. This takes advantage of the stronger performance of M-Stream + SAIC also to provide higher than normal voice coding rates.

Figure 8 shows that even with the higher voice coder rates with the M-Stream + SAIC phone, the frame error rates are significantly better for that phone than with the phone without M-Stream + SAIC. In this test, the percentage of 2-second periods with > 10% frame error rate is reduced by about a factor of 2 from 23% to 12% with M-Stream + SAIC enabled.

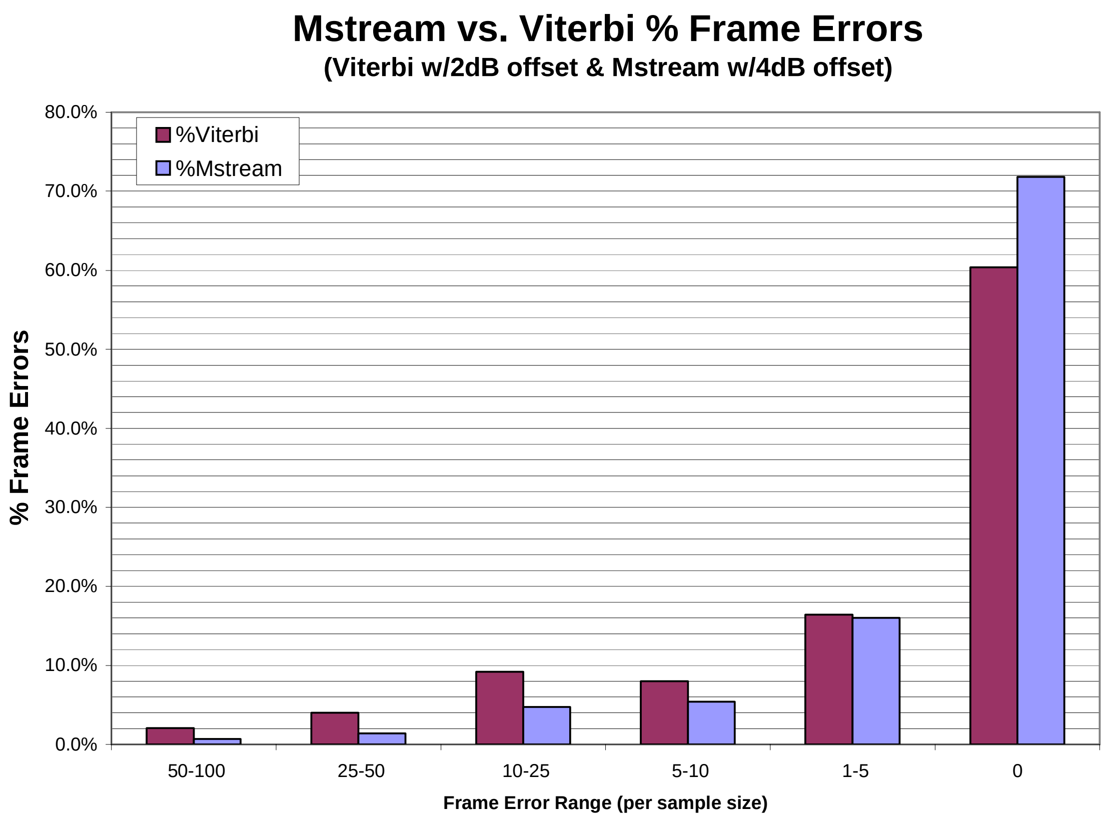


Figure 8: Distribution of Frame Errors

Figure 8 shows the distribution of frame errors in 2 seconds or in 100 frames for phones with and without M-Stream + SAIC (Viterbi decoding is without M-Stream + SAIC). M-Stream + SAIC shows a higher than normal percentage of error-free periods (72% versus 60 %) and a lower than normal percentage of periods with > 10% error periods (12% versus 23%).

In this test, the phone equipped with M-Stream + SAIC was set with a 4-dB offset (4 dB was added to the normal measurement) in the estimate of the downlink SNR, and the phone not equipped with M-Stream + SAIC was set with a 2 dB offset. This tends to take advantage of the improved performance of M-Stream + SAIC by maintaining higher rate than normal voice coders that can provide higher than normal PESQ over a large percentage of the cellular coverage. Figure 9 shows the comparison of the voice coder rate distributions in this test. The results show that the conventional phone was in the lowest half-rate mode of 4.75 Kbps with about 36% probability, but the M-Stream + SAIC phone was in the lowest half-rate mode with only about 26% probability.

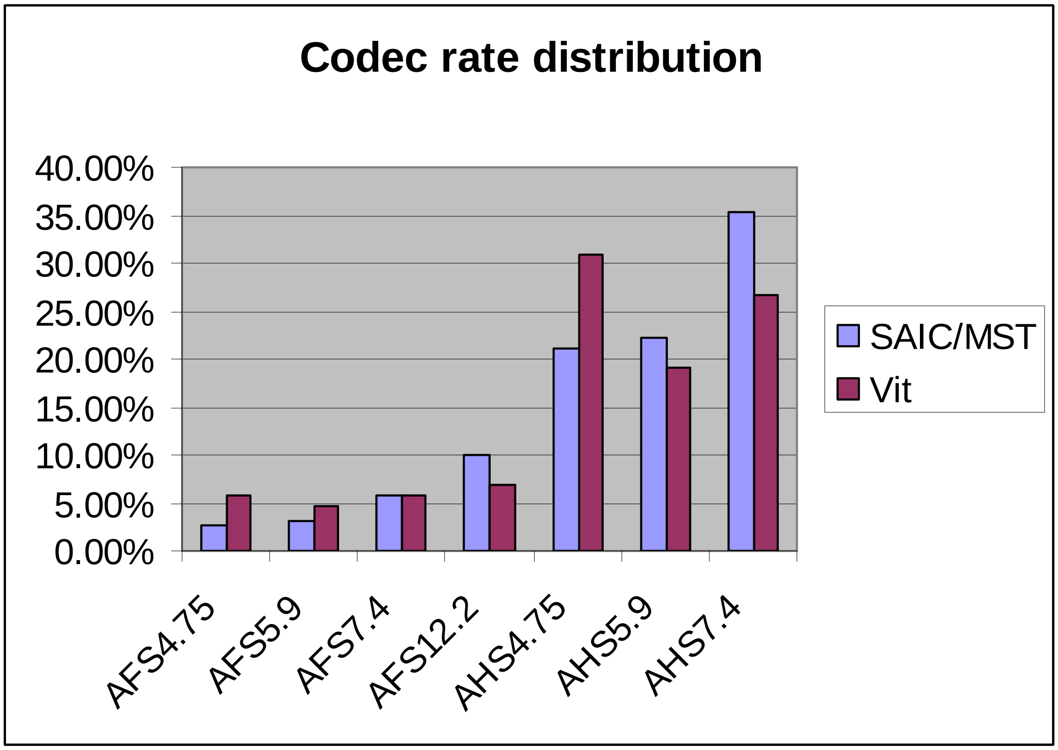


Figure 9: Distribution of Voice Coder Rates

Figure 9 shows the distribution of voice coder rates for phones with and without M-Stream + SAIC (Viterbi decoding is without M-Stream + SAIC). M-Stream + SAIC shows a higher than normal percentage of high-rate voice coders compared to without M-Stream + SAIC. This improves voice quality.

WCDMA and M-Stream Performance

M-Stream also provides improved voice service over 3G WCDMA cellular networks. Figures 10 and 11 show measured laboratory WCDMA receiver performance in terms of block error rates for 12.2 Kbps and 5.9 Kbps AMR voice modes. The gains are approximately 1 dB. For WCDMA, 3 dB in performance improvement represents a doubling of capacity, so 1 dB is significant.

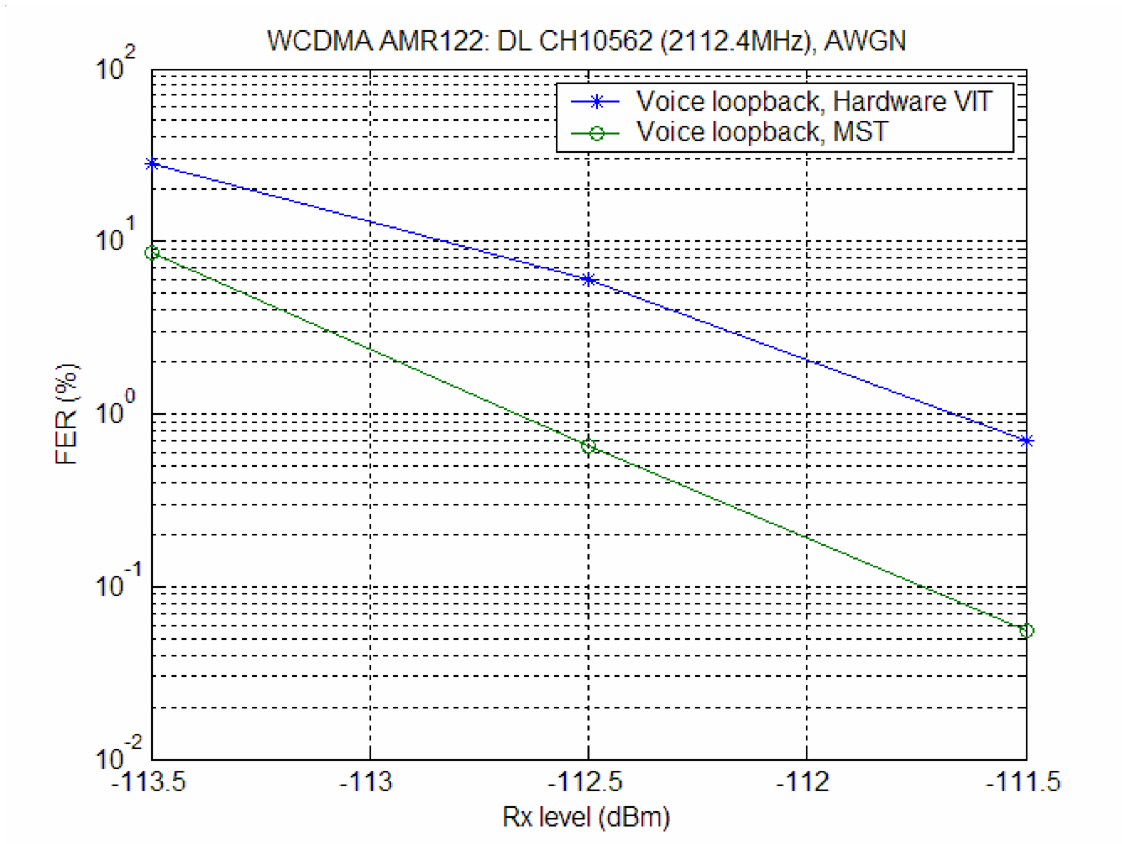


Figure 10: Frame Error Rate Performance (12.2-Kbps AMR)

Figure 10 shows the frame error rate performance of a WCDMA receiver with and without M-Stream decoding for 12.2-Kbps AMR voice service under noise limited conditions.

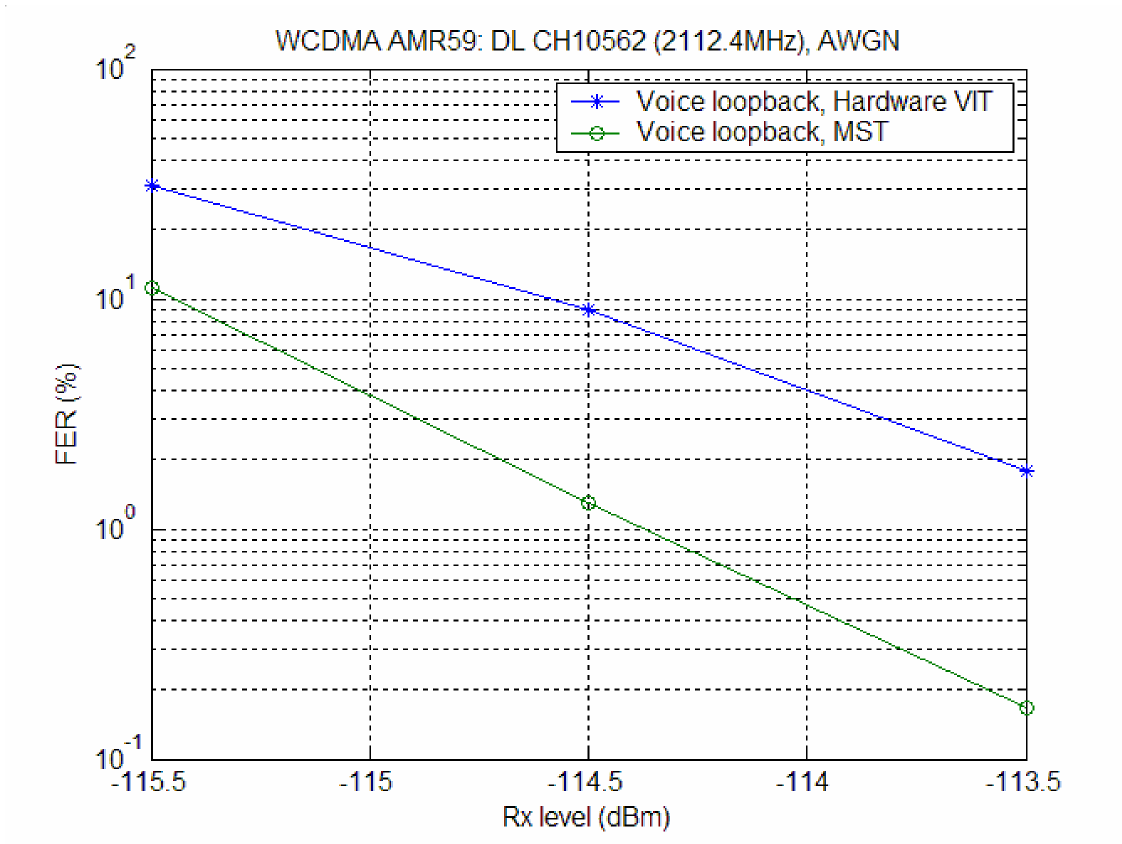


Figure 11: Frame Error Rate Performance (5.95-Kbps AMR)

Figure 11 shows the frame error rate performance of a WCDMA receiver with and without M-Stream decoding for 5.95-Kbps AMR voice service under noise limited conditions.

Conclusion

GSM AMR half-rate offers cellular operators the ability to maximize network capacity for low-cost operation. By implementing Broadcom's M-Stream + SAIC on cell phones in conjunction with half-rate, a robustness similar to AMR full-rate is achieved, and high capacity with good service quality is the result. M-Stream on its own provides 2 dB to 3 dB improvement in signal/noise over a wide range of noise and interference conditions that are typical in deployed GSM networks. The combination of M-Stream + SAIC enables improvements in the 3 dB to 5 dB range, illustrating the complementary nature of the technologies. Extensive laboratory and field tests have shown the significant performance advantages of M-Stream for improving voice quality under poor network conditions. These gains could be generalized to further improve overall network capacity via the proposed Advanced AMR specifications. M-Stream + SAIC performance improvement provides a powerful advantage for GSM networks to both extend mass penetration of voice services at low cost and maintain customer satisfaction with improved call quality. M-Stream also enhances 3G WCDMA voice service performance as demonstrated in laboratory tests.

Phone: 949-926-5000
Fax: 949-926-5203
E-mail: info@broadcom.com
Web: www.broadcom.com
Mstream-WP103-D1

BROADCOM CORPORATION
5300 California Avenue
Irvine, California 92617

04/17/07