INVESTIGATION OF THE CAPACITY IMPROVEMENTS IN THE GSM 900MHZ BAND THROUGH THE USE OF HETEROGENEOUS RADIO ACCESS TECHNOLOGIES (GSM900 & CDMA2000 1X)

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Abstract – In this paper we investigate whether or not a GSM and a CDMA system can co-exist within the same frequency bandwidth i.e. 900 MHz. Both the GSM and CDMA systems were designed and implemented using the Simulink plug-in in Matlab, and calibrated to conform to reality. The investigation shows that the two technologies can be placed in the same bandwidth, but this combination causes a decrease in the CDMA user capacity of at least 75%, while causing no major effects on the GSM network. This shows that the capacity of the entire cellular system can be increased by 25% overall, and allows for the introduction of advanced features on the cellular network.

Index of terms - GSM, CDMA, Bandwidth, Sharing, Capacity, Cellular, System, Simulation.

I. INTRODUCTION

The GSM system in South Africa occupies the frequency range from 890 MHz to 960 MHz [1], and more recently the 1800MHz range has also been occupied, utilizing both time division multiplexing (TDM), and frequency division multiplexing (FDM) in order to accommodate the maximum number of users on the network. In order to try and increase the maximum user capacity, and introduce new advanced features into the market this investigation will look into using both GSM 900 and CDMA 2000 1x within the same frequency spectrum. The object of this research is to ascertain whether the GSM system can accommodate the Code Division Multiple Access system within the same bandwidth that it currently uses, while not just maintaining the same user capacity but in fact increasing the overall user capacity. This should be possible owing to the fact that the CDMA system is more highly spectral efficient than the GSM system, and can accommodate more users than the GSM system while still utilizing the same bandwidth.

II. BACKGROUND & EXPECTATIONS

To date there are somewhere between 15 and 20 million cellular phone accounts in South Africa, which is a far cry from the estimated 2 to 3 million users that the economy was expected to yield in the mid 1990's [2]. For this reason we are researching whether or not the GSM system will be able to operate correctly if another interfering technology is added within the same bandwidth. It is expected that as soon as the second interferer is added, the maximum user capacity of the GSM system will drop, and as more interference is introduced - as the second system takes on a greater number of users, the maximum GSM capacity will drop further. It is however also expected a greater number of CDMA users will be accommodated with a lesser amount of interference. There should be a point where the GSM user capacity will be degraded with the addition of the CDMA users, but the addition of the CDMA users will more than make up for the loss of GSM capacity.

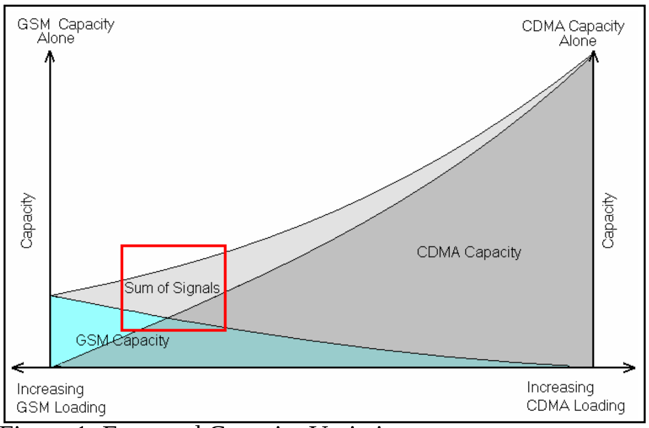

Figure 1: Expected Capacity Variations

Figure 1 above depicts the expected behavior of the system; the block shows the area of best response. The main driving force behind this project is that the body in South Africa that governs the frequency spectrum – the Independent Communications Authority of South Africa (ICASA) [3], has already allocated the entire spectrum that the CDMA system uses i.e. the 800 MHz band, to the television carrier Sentech, since the authority conforms to the ITU region 1 specifications.

III. THE GSM SYSTEM

GSM stands for the Global System for Mobile Communications. It is an accepted standard in cellular communications around the world, although not all countries world-wide use this specific technology.

The bandwidth of a GSM system is usually 25 MHz, which provides 125 carriers, each with a bandwidth of 200 kHz. This is achieved by means of frequency division multiplexing (FDM). Unfortunately due to the interference limited nature

[1] The Centre is support by Telkom SA Limited, Siemens Telecommunications, Sun Microsystems SA and the THRIP Programme of the Department of Trade and Industry.

of the GSM system and the fact that the system requires signalling, the first carrier cannot be used, which limits the system to 124 carriers. Each of these carriers are then divided into 8 equal time slots by means of time division multiplexing (TDM). The different multiple access schemes available influence the performance of the systems on which they are used – both the FDM and TDM schemes introduce filtering problems, non-linearities, and non-linear frequency drifts. These issues need to be taken into account when implementing the system, and for simulation purposes [4]. Generally, the frequency band used for the uplink of the signal i.e. from the mobile station to the base station, is from 890 MHz to 915 MHz, and the band used for the downlink – base station to the mobile unit, is from 935 MHz to 960 MHz [1]. This means that in general GSM systems around the world have 25 MHz of available frequency spectrum in which to transmit. Since each channel is 200 kHz wide, we have 124 RF carriers, each with 8 time slots, giving 992 physical channels for information transfer [5]. In South Africa, we had two separate service providers, with each originally having 2 sets of 11 MHz of the frequency band (22 MHz overall), i.e. Vodacom from 891 MHz to 912 MHz [6] and MTN from 913 MHz to 924 MHz [7] in the uplink direction and similarly for the downlink direction. This means that the maximum allowable number of users on the system is decreased. This allocation was re-evaluated when Cell C was allocated a frequency spectrum in both the 900 MHz range and the 1800 MHz range [8][10]. Vodacom and MTN were asked to relinquish 2 sets of 2 MHz spectrum in the 900 MHz range, in exchange for 2 sets of 10 MHz in the 1800 MHz [9].

The modulation scheme used for the GSM technology is the Gaussian Minimum Shift Keying (GMSK) method, which allows for the use of narrow bandwidth and coherent detection capabilities. What this means is that the modulation scheme almost satisfies the requirement that adjacent channel power spectrum density is -60 dBc as specified by the CCIR. For GSM the pre-Gaussian normalized bandwidth is kept to 0.3 – which compromises between an adequate bit error rate, and low-level side lobes, which are required to satisfy the adjacent channel interference requirements. This BT product gives a filter bandwidth of 81.25 kHz, and allows for an aggregate data rate of 270.8 Kbps. As mentioned earlier, the system also utilizes TDM, which means that the signal is not just filtered and passed through a modulation scheme, but is also pulsed so that eight users can be accommodated within one 200 kHz channel. The total data rate of the GSM network per channel is 270.8 Kbps, which when divided by eight users means that the peak data rate per slot is in actual fact 33.85 Kbps. This is however not all used for voice transmission. The speech coder used for the GSM technology uses a regular pulse excitation with a long-term predictor, the actual coder used is called the Regular Pulse Excitation – Long-Term Prediction LPC (RPE-LTP), which produces 260 bits in 20 ms, and results in a total voice rate of 13 Kbps. The lower voice bit rate is required in order to accommodate the control bits, channel coding, interleaving and other link control specifications in each channel. Once the user voice has been encoded into digital format, forward error correction coding is applied, and the bits are interleaved over eight frames to mitigate channel burst errors.

IV. GSM SIMULATION DESIGN

This investigation deals with the comparison of bit error rates in the two separate cellular technologies; when they are both employed within the same bandwidth, which is done as a measure of the interference levels. The part of the system that is most important to the investigations of this research is the air interface, and the modulation that occurs before the bits are placed into the atmosphere. What is required is to monitor exactly how many bits are modulated, and keep track of the value of these bits. Once the signal is received on the other side, the demodulated bits must be compared and a tally of the errored bits kept. This basic system can be seen in figure 2.

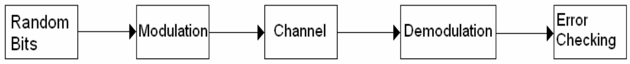

Figure 2: Simplified GSM System Set Up

Figure 3 is a screen capture of the final GSM system that was used for calibration and testing of the setup – all the systems were designed and setup in Matlab, using the Simulink plug-in.

This simulation consists of a random bit generator, which feeds into a unipolar to bipolar converter, which turns the bits into a format that can be used by the modulator. These modified bits are then fed into the modulator. The modulated bits are then passed through an air interface where Additive White Gaussian Noise (AWGN) and multi-path degradation is added, thereafter the bits are demodulated. The demodulated bits are then compared to the input bits and checked for correctness [11] by means of an error rate calculation block. Figure 4 includes the additional pass-band model that is not used when simulating the base-band system. This pass-band addition is depicted in the lower left corner of the figure, and is identical to the base-band system, except for the inclusion of a sine wave operating at the pass-band frequency, and a multiplication block to shift the signal spectrally.

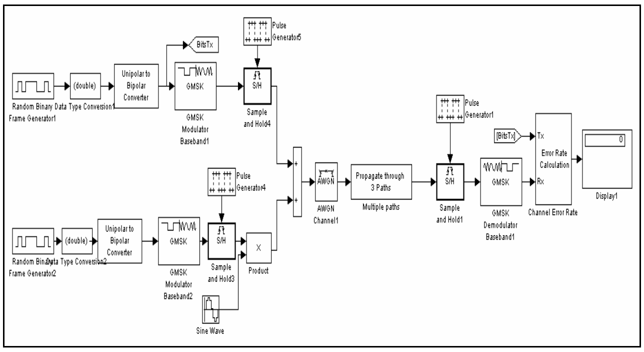

Figure 3: The Final GSM System Simulation

V. THE CDMA SYSTEM

The term CDMA stands for Code Division Multiple Access. In a CDMA system the signal energy is continuously distributed across the entire time-frequency plane. It is for this reason that the CDMA system has a much higher user capacity than other available systems. When utilizing this scheme, the frequency-time plane is not divided up among users; instead each user employs a wideband coding signalling waveform all within the same bandwidth. Although users share the same frequency band at the same time, the spreading of the base band signal spectrum allows interference from other users to be suppressed, so increasing the user capacity of the CDMA system in its entirety. This spread-spectrum modulation is accomplished by means of pseudo-random (PN) codes. These pseudo-random codes are generally accomplished using a linear feedback shift register of the form: $f(x) = x^n + c_{n-1}x^{n-1} + ... + c_2 x^2 + c_1 x + 1$. The digital voice data in the CDMA system has a rate of 9600 bits per second, these bits are then coded for channel error protection and the pseudo-random codes are used to code the bits into a spread-spectrum format, which finally results in a wideband signal at a rate of 1 228 800 chips per second..

The CDMA system has both forward and reverse link operations, and they both generally complete the same functions, one is just in the mobile to base-station direction, and the other is in the base-station to mobile direction. Here the forward link operations will be discussed. The forward link channel structure consists of the transmission of up to 64 simultaneous, distinct channels, each with varying functions, and all are multiplexed onto the same carrier. One of the 64 channels is used as a pilot signal that is continuously transmitted to provide a continuous phase reference for reception of carriers modulated by information. Another of the channels is used as a synchronization channel, and then seven paging channels are kept available to signal to mobile handsets within the cell concerning incoming calls, and to convey channel assignments and other signalling messages to individual mobile users in the cell. All remaining channels are used for transmitting user information.

In the CDMA system, the modulation technique adopted was the Quadrature Phase Shift Keying (QPSK) method, but for the purposes of this investigation, a Binary Phase Shift Keying (BPSK) modulation method was employed. The BPSK modulation method is not quite as efficient as the QPSK method, but is a good approximation for our purposes.

VI. CDMA Simulation Design

Again, we are just interested in the modulation process and the air interface. Random bits must be produced, modulated, passed through an air interface, demodulated and compared to the bits input. This basic setup can be seen in figure 4 below.

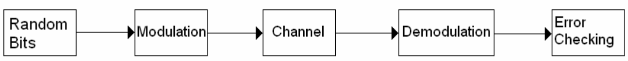

Figure 4: Simplified CDMA System Set Up

Figure 5 below is a screen capture of the CDMA system that was used for the simulations. It consists firstly of a random bit generator, which feeds random bits of type real into the modulator after having been converted to type double. This output is then multiplied bit by bit with the output created by the Gold Code Generator, and added to multiple CDMA users as required. The total signal is then sent through the air interface where signal degradation like AWGN and multi-path fading is added. The signal is then multiplied by the Gold Codes again, and demodulated with the BPSK standard, at which point the input and output bits can be compared using an error rate calculation block.

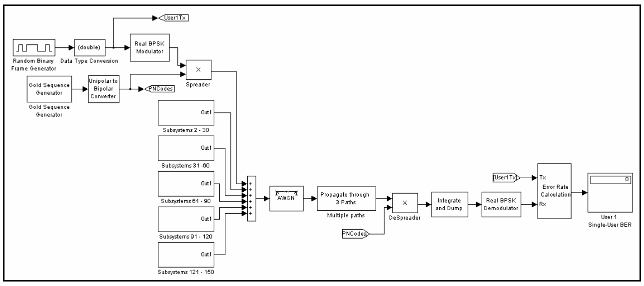

Figure 5: The Final CDMA System Simulation

VII. Setup for the Simulations

In order to test any setup, a basic system must be produced, and by using well known inputs so that certain outputs can be expected, the system must be checked for validity. This test was carried out on the GSM simulation. The system shown in figure 5 worked as planned, and followed all curves gleaned from literature very closely. Using the setup shown allowed for the simulation to be changed from a base-band model to a pass-band model with just one connection. This made the simulations very easy.

A basic setup of the CDMA system also had to be created to ensure that all simulations that were run were in fact correct. The basic setup was also tested using pre-specified inputs, so that all the results would be within an expected region. The system in figure 6 proved to work beautifully and followed all expected curves, so AWGN and multi-path degradation was added. This still proved to follow the required error rate, and was therefore taken as correct. Using this setup allowed for users to be added and removed very easily, allowing for testing on a single user to be carried out, and also on as many as 150 separate independent users. This circuit was the final circuit that was used for the simulations. After testing and evaluation it was decided that Gold Codes (instead of PN codes) would be used owing to the increased reliability and the fact that the Gold Codes followed the expected curves found in the literature. A second comparison was made to ensure that the design was correct; users were added to the system one by one, and the results again compared to literature [12]. The Results gained from the PN Codes were slightly offset from the expected results, while the Gold Codes produced results that represented reality nicely.

Once the two separate systems had been designed, implemented, and it had been verified that they reacted as was expected; the new task was to combine the two systems into one homogenous whole. The first problem that had to be overcome was that the two systems ran at different bit rates in reality, and these rates needed to be retained when the simulation was set up. The GSM system runs at a rate of 270 833 bits per second, while the CDMA system runs at a rate of 1 228 800 bits per second. Matlab would not allow different bit rates to be summed together and used within the same simulation, so the bit rates of the two systems needed to be adjusted slightly to make provision for the summing of the separate symbols. It was noted that if the bit rate of the CDMA system were rounded off the 1 200 000 bits per second, and the rate of the GSM system were taken as 200 000 bits per second, the faster system would be an integer multiple of the slower. This can be accommodated by the Matlab program. This approximation is unavoidable, but does not jeopardize the simulations in any way, and is widely used in the communications field when referring to the systems in question. Therefore all bit rates in the CDMA system were reduced to 1 200 000 bits per second, and all bit rates in the GSM system were reduced to 200 000 bits per second. This has no effect on the outcome of the GSM circuit, but serves to increase the overall bit rate of the system and bring it in line with the bit rate of the CDMA system, allowing for easy comparison. This rate cannot be maintained all the way to the end of the system though, as we will be producing extra interference in the system, and this is not practical for the simulations, as higher sampling rates means more calculations for the computer, and therefore more time spent on each of the simulations. For this reason the sampling rate was then decreased back to the original 200 000 bits per second after the air interface, where errored bits were checked.

VIII. Calibrations

Both the GSM and CDMA systems react in an expected fashion when confronted with certain inputs. These reactions can allow us to calibrate the system to conform to industry standards. Since specific inputs will be introduced into the system, the system characteristics can then be varied to ensure that the outputs that are created by the system conform as expected.

Since the GSM system consists of many 200 kHz channels all within the allowable 900 MHz bandwidth, we need to reassure ourselves that the system that is being simulated does in fact work within these boundaries. Therefore the 3 dB point must occur at 200 kHz. The figure 6 below is the spectral density of the GSM and CDMA signals as produced by the simulated system. This figure shows that the GSM system has a 3 dB point within the required 0.2 MHz. The CDMA system requires the same attention as the GSM system to ensure that the spectral density plot follows the expected. The CDMA system runs within a bandwidth of 1.25 MHz per channel, which again means that the plot of the spectral density of the system must have a 3 dB point at the 1.25 MHz region – again figure 6 shows that the 3 dB point of the CDMA system falls within 1.25 MHz. Both systems are correctly simulated.

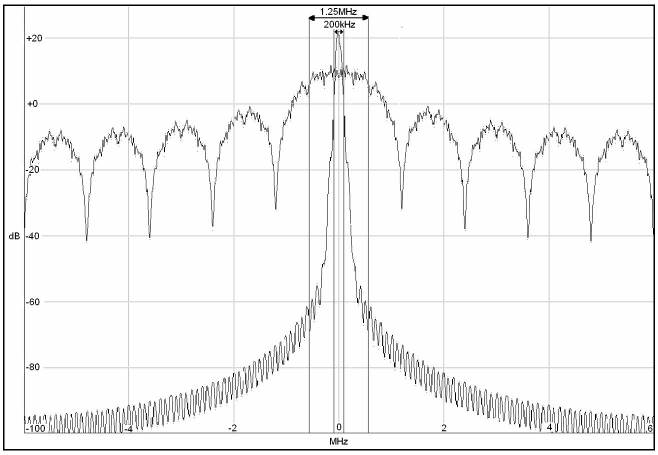

Figure 6: The Spectral Densities of the Separate Systems on one axis

IX. Results

A. The GSM Simulations

In order to ensure that the design was correct, the GSM system was run while varying the amount of AWGN added in the air interface - there was graphic material in the literature [13] showing the performance of a GSM system in reality – this was the reason for doing similar in the simulations. The bit error rate that was produced was recorded, and the readings were then displayed in a graphic form and compared to the expected results in the literature.

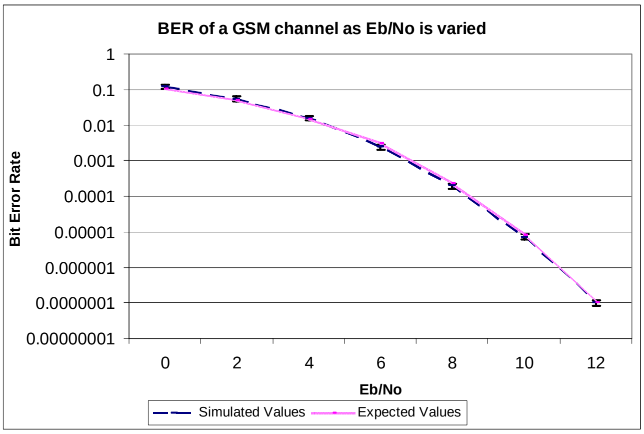

Figure 7: The GSM Calibration Curve (BER of the System as AWGN was Varied)

These results can be viewed in figure 7, and serve to show that the system is correct, and is in fact ready for simulations in combination with the second technology to occur. A pass-band model was also produced to test the final combined system in a more real environment, where interference is introduced by adjacent frequency channels.

B. The CDMA Simulations

The CDMA system was run by itself while varying the amount of AWGN present in the air interface. This test was done to compare the created BER to that expected in the literature [12]. Once again the BER that was created by the system was recorded after a specific time, and this BER was compared graphically with the expected BER. Gold Codes were used for the system, since the results gained conformed closely with the expected results laid out in the literature (figure 8) [12]. A second test was carried out, to ensure that the first findings were in fact correct, and this involved increasing the number of interfering users present in the air interface, and checking that the resulting BER followed the literature [14]. The results of the experimentation as users are added can be viewed in figure 9 below.

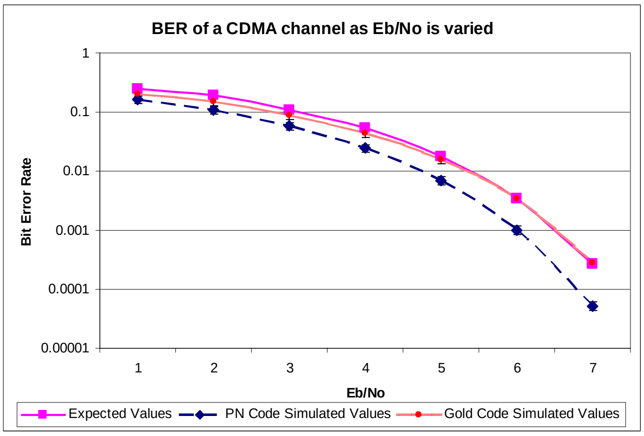

Figure 8: The Comparison Between Gold & PN Codes For CDMA (BER of the System as AWGN was Varied)

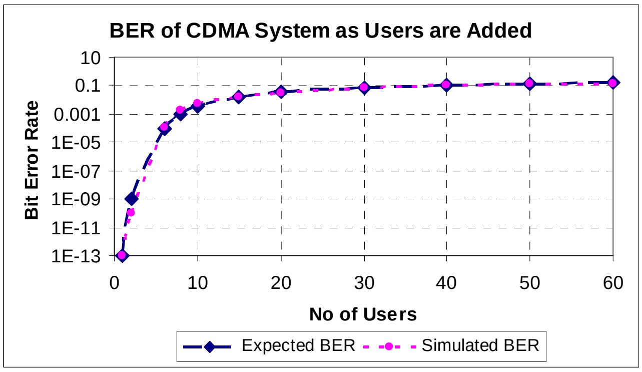

Figure 9: The CDMA Calibration Curve (BER of the System as CDMA Users are Added, Keeping AWGN = 12 dB)

C. The Combined System Simulations

Since the two systems react correctly when used separately, it can be assumed that the systems will react correctly when used in tandem. Since the minimum Signal to Noise Ratio (SNR) that can be tolerated on the GSM network is 9 dB, with a range of up to and including 20 dB [13], the entire network was set to 12 dB. On the CDMA system, the pilot channel requires -15 dB, both the Sync and Paging channels require a minimum of 6 dB, and the traffic channels require 7 dB, so if the overall SNR is set to 12, the CDMA system should work perfectly [12]. In order to introduce multi-path fading in the simulations and replicate reality, three signal paths were introduced. The systems were tested by varying the number of users introduced on the CDMA system with a constant fully loaded GSM channel.

As can be seen by the graphical (figure 10) results above, the GSM system is greatly affected by the addition of the first CDMA user, and is further degraded as each additional user is added. With the addition of just one GSM channel into the bandwidth occupied by a single CDMA user, while the Signal to Noise ratio is set to 12 dB, the error rate of the GSM system was degraded from 1×10^{-7} to 1×10^{-3}, and the error rate of the CDMA system was degraded from 1.8×10^{-4} to 3×10^{-2}. Both degradations are very large and indicate that the interference introduced by the different systems is not compatible. Figure 10 shows that as more CDMA users were added to the simulation, the BER of both systems continued to degrade at an almost linear rate, until the GSM error rate reached 6×10^{-2}, and the CDMA rate reached 1.7×10^{-1} when 20 CDMA users were inserted in the simulation. The maximum number of users that were simulated was set at 20 CDMA users because the BER was very large at this point and the system was already beyond any viable point.

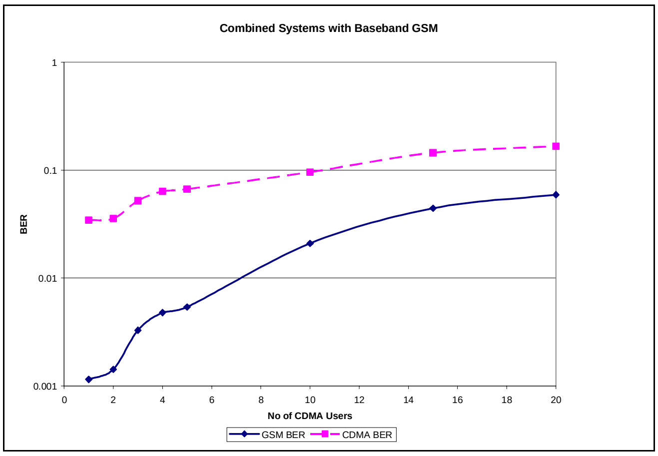

Figure 10: The BER of the Base-band Model

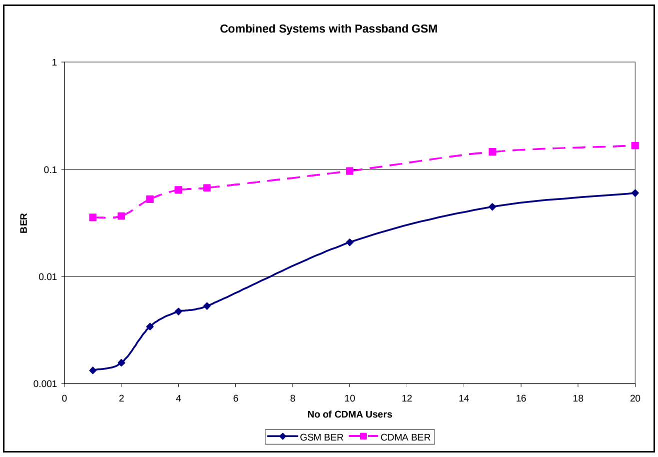

Figure 11: The BER of the Pass-band Model

The pass-band system was then simulated. This system was again simulated using increasing numbers of CDMA users, but this time with 3 adjacent GSM channels, which served to increase the interference, and better model the conditions found in reality. The BER created by the pass-band model can be viewed in the graphical representation seen in figure 11. These results are very similar to the results found in figure 10, with a minimal added degradation – the percentage increase in BER on the GSM system is on average less than 16% and on the CDMA system is less than 3%. This shows that the addition of the extra GSM channels has very little impact on the overall workings of the system. And only the base-band model has a real impact on the error rate of the system. The simulations were carried out without any forward or reverse error correction, no voice activity detection, and no cell sectorization; if these techniques were employed the BER of the entire combined system could be lowered, and more CDMA users could be included.

X. CONCLUSION

The simulations were designed to follow reality as closely as possible. The systems were each individually tested by adjusting the AWGN present in the air interface, running the system, and recording the BER that was produced. The results were then compared to measured values found in reality, and the systems were calibrated to conform. Once the calibrations were correct, the simulations were begun, where a user from the CDMA system was added one at a time to the combined system, and the BER recorded.

From the results, it can be seen that the two systems interfere greatly with each other when they are used in the exact same frequency band, but each has very little effect on the other when used in adjacent bands, as can be seen by the results of the pass-band model. Since a full GSM channel is simulated, the decrease in GSM users is zero, as long as the BER of the system remains below 1×10^{-3}, and this is achieved by keeping the number of CDMA users low. The BER of the CDMA system also increases dramatically as users are added, so there is a maximum number of CDMA users that can be accommodated anyway. Generally under normal conditions; at 12 dB AWGN, and with multi-path fading; between 4 and 5 CDMA users can be accommodated on a system that has had no error correction techniques applied to it [14]. With just one CDMA user on the new system, the BER is already above these conditions, which means that the CDMA system will only have between 20 and 25% of its maximum user capacity. Any error techniques that will be applied must be very accurate to enable a viable user capacity. This therefore means that the two systems can be used in conjunction within the same frequency band, but there will be an overall user capacity increase of only 25% at best.

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