

Radio Link Performance of Third Generation (3G) Technologies For Wireless Networks

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(Abstract)

Third generation wireless mobile communication networks are characterized by the increasing utilization of data services – e-mail, web browsing, video streaming, etc. Such services allow the transition of the network from circuit switched to packet switched operation (circuit switched operation will still be supported), resulting in increased overall network performance.

These new data services require increased bandwidth and data throughput, due to their intrinsic nature. Examples are graphics-intensive web browsing and video streaming, the latter being delay sensitive and requiring priority over less sensitive services such as e-mail. This increasing demand for bandwidth and throughput has driven the work of third generation standardization committees, resulting in the specification of improved modulation and coding schemes, besides the introduction of more advanced link quality control mechanisms.

Among the several proposals for the evolution from 2G to 3G, GPRS (General Packet Radio Services) and EDGE (Enhanced Data Rates for GSM Evolution) stand out as transitional solutions for existing TDMA IS-136 and GSM networks (they are also referred to as **2.5G** systems). In the CDMA arena, WCDMA (Wideband CDMA) has emerged as the most widely adopted solution, with CDMA 2000, an evolution from IS-95, also being considered.

This thesis compiles and analyzes the results of the work by the standardization committees involved in the specification of 3G standards, focusing on the receiver

performance in the presence of additive noise, fading and interference. Such performance results will ultimately determine design and optimization conditions for 3G networks.

This document concerns the description of the TDMA-based 2.5G solutions that allow the introduction of multimedia and enhanced data services to existing 2G networks. It focuses on GPRS and EDGE. It also addresses WCDMA – a 3G spread spectrum solution. Such proposals permit the utilization of existing spectrum with increased efficiency, yielding extended network capacity and laying the ground for full support of wireless multimedia applications. The study is focused on the link implementation aspect of these solutions, showing the impact of the modulation schemes and link quality control mechanisms on the performance of the radio link.

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Chapter 1 - Introduction

1.1 The Need for Third-Generation Wireless Technologies

The first generation of wireless networks was primarily concerned with the provision of voice services, allowing users to transition from conventional fixed telephony to mobile telephony. First generation systems are commonly referred to as analog systems. The wide acceptance of mobile telephony rapidly exhausted the capacity that could be provided with analog technologies, requiring the introduction of second-generation systems. These systems have transitioned the voice services supported by analog networks into a digital environment, thus increasing the supported capacity and allowing for additional services such as text messaging and limited access to data services.

Second generation networks (2G) are currently in use and also very near their maximum capacity, due to the remarkable penetration of mobile telephony. Third generation systems (3G) propose the evolution of existing systems, further increasing their capacity and introducing multimedia communications. They offer enhanced features, adding video and images to the voice services and allowing improved access to data networks and to the Internet.

Unlike the transition from first to second generation, the migration from 2G to 3G will occur smoothly. Existing 2G networks will **evolve** to 3G, with transitional solutions known as 2.5G bridging the gap between them. The development work on 3G is still underway; the technological challenges it presents are extraordinary. The increasing demand for capacity in the already saturated 2G networks, as well as for enhanced data and Internet services, have made 2.5G solutions very appealing and important. These solutions rely on technology improvements to existing networks and allow for an extension of their “lifespan”, until the 3G proposals are finalized and validated.

The primary factor limiting the capacity of wireless networks is the amount of spectrum available for these services, making the choice of modulation schemes and, ultimately, spectral efficiency, of paramount importance in the resulting capacity. In addition, power limitations imposed by the intrinsic nature of the handsets further accentuate the importance of the modulation and its characteristics.

The introduction of multimedia services in third generation networks implies an increase in the bandwidth requirements. In order to accommodate the growth in capacity and bandwidth needs, the World Administrative Radio Conference (WARC) of the ITU (International Telecommunications Union) has identified extended spectrum for 3G, around the 2GHz band. Additionally, the third generation technology proposals, known within the ITU as IMT-2000, use improved, more sophisticated modulation schemes, so as to maximize the new spectrum allocation.

Chapter 2 - Evolution of Wireless Technologies from 2G to 3G

2.1 The Path to Third Generation (3G)

The evolution of wireless technologies and standards applied to commercial mobile services began with the introduction of the first generation of commercial mobile telephony networks, circa 1946[Rap96]. Figure 2-1 shows the technology evolution from the current second generation to the proposed 3G solutions. Among the second-generation technologies GSM (Global System for Mobile communications) is the most widespread, with over 400 million users worldwide [And01]. It is also the best-positioned technology to provide a 2.5G transitional solution to 3G.

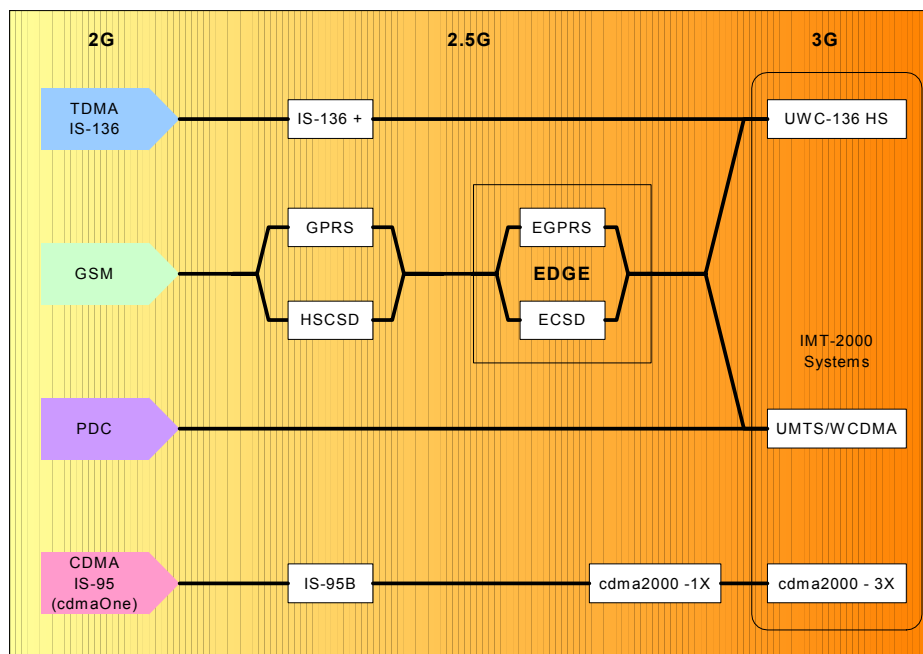


Figure 2-1 - Evolution of Wireless Technologies from 2G to 3G. TDMA – Time Division Multiple Access; UWC – Universal Wireless Consortium; GSM – Global System For Mobile Communications; GPRS – General Packet Radio Services; HSCSD – High Speed Circuit Switched Data, EGPRS – Enhanced GPRS; ECSD – Enhanced Circuit Switched Data; PDC – Pacific Digital Cellular; UMTS – Universal Mobile Telecommunications System;; CDMA – Code Division Multiple Access; WCDMA – Wideband Code Division Multiple Access; IMT-2000 – International Mobile Telecommunications

The IMT-2000 framework defined several candidate air-interfaces for 3G, based either on TDMA or CDMA technologies, with the objective of obtaining one single common global air-interface. Among the various proposals discussed in the standardization forums, a single-carrier wideband CDMA (WCDMA) and a multi-carrier CDMA (CDMA 2000) have emerged as the most widely accepted air interfaces for third generation [Hol00]. The Enhanced Data-Rate for the GSM Evolution (EDGE) solution, originally intended as a 2.5G technology, has also received substantial support as an initial 3G option for its high data rate capabilities.

Besides the conventional voice services supported by 2G networks, 3G systems will provide enhanced data services and multimedia capabilities. The system requirements for third generation networks are listed below [Hol00]:

- High spectral efficiency
- Bit rates of up to 384 kbps for full coverage area and 2 Mbps for local coverage area
- Bandwidth on demand
- Quality requirements from 10% frame error rate to 10^{-6} bit error rate
- Multiplexing of services with different quality requirements on a single connection
- Delay requirements from delay-sensitive real-time traffic to flexible best-effort packet data
- Coexistence of second and third generation systems
- Inter-system handovers for coverage enhancements and load balancing
- Support of asymmetric uplink and downlink traffic
- Coexistence of FDD (Frequency Division Duplex) and TDD (Time Division Duplex) modes

The following sections describe the evolution paths depicted in Figure 1.

2.2 GSM Evolution

GSM has become the most accepted second generation standard, providing pan-European coverage and presences in Asia, Australia, North and South Americas. The system was primarily designed to handle voice, offering limited data and Internet capabilities. Data sessions are established as circuit-switched connections (named CSD) through a regular dial-in procedure, with billing occurring per connection time. Bit rates of up to 14.4 kbps can be achieved [And01].

The evolution of the original circuit-switched technology is named **High Speed, Circuit-Switched Data** (HSCSD). It uses multi-slot operation to achieve bit rates of up to 57.6 kbps with the original GMSK modulation adopted for voice. With HSCSD up to four time slots per frame can be assigned to a connection, allowing a fourfold increase in the data rate of circuit-switched sessions [And01].

GSM support of packet-switched connections is achieved by using **General Packet Radio Services** (GPRS). It can be viewed as an overlay technology upgrade to existing GSM networks, allowing single (voice only) and dual mode handsets (voice + data) to coexist. GPRS also relies on the original GMSK modulation, making use of variable coding rates to achieve bit rates of up to 22.8 kbps per time slot [And01]. Link adaptation is used to accommodate the data rate to link quality and user's demand.

The smooth evolution of GSM towards 3G can be accomplished with **Enhanced Data Rates for GSM Evolution** (EDGE). It keeps the fundamentals of GPRS, concentrating on the improvement of capacity and spectral efficiency over the air interface. EDGE introduces a more elaborate modulation scheme – 8PSK, for higher data rates, while maintaining GMSK for lower rates. The new modulation scheme allows data rates of up to 59.2 kbps per time slot, using a combination of link adaptation and incremental redundancy to improve link robustness [Fur98]. The packet-switched mode of EGDE is commonly referred to as **Enhanced GPRS** (EGPRS).

EDGE maintains the support to circuit-switched connections through Enhanced Circuit Switched Data (ECSD). Also using 8PSK in addition to GMSK, ECSD allows data rates of up to 38.8 kbps per time slot [Fur98]. A key positive aspect of EDGE is that no additional spectrum is necessary, since the original 200 KHz channel bandwidth is used.

2.3 TDMA (IS-136) Evolution

No support to packet-switched connections was originally introduced to TDMA; it was essentially a voice technology. Cellular Digital Packet Data (CDPD) was proposed as a cost-efficient add-on, supporting Internet Protocol (IP) applications with limited data rates [And01]. The major limitation of CDPD, besides its low data rate restrictions, is the lack of an evolution path to 3G. Since EDGE is also a timeslot-based solution, TDMA is being evolved to adopt it as a third generation technology. The IS-136+ recommendation addresses the adaptation of the 8PSK modulation scheme to the 30KHz carrier bandwidth and the multi-slot operation.

2.4 CDMA (IS-95) Evolution

CDMA, in its IS-95 version (cdmaOne), will migrate to 3G in two phases. The original IS-95 interface (Revision A) supports voice services and data connections of up to 14.4 kbps, whereas Revision B (IS-95B) improves the overall functionality, allowing the combination of multiple 9.6 or 14.4 kbps to achieve up to 115.2 kbps [And01].

The first phase of the cdmaOne evolution was named cdma2000 1X. It uses 1.25 MHz of bandwidth per carrier, with improved modulation and power control mechanisms, providing average bit rates of up to 144 kbps. Due to the carrier bandwidth compatibility, cdma2000 1X can be deployed as an overlay solution to existing cdmaOne networks.

In the second phase cdma2000 1X evolves to cdma2000 1XEV, which is itself divided in two steps: 1XEV-DO and 1XEV-DV. 1XEV-DO stands for 1X **E**volution - **D**ata **O**nly and 1XEV-DV stands for 1X **E**volution - **D**ata and **V**oice. Both steps use 1.25 MHz carriers, assuring backward compatibility with existing IS-95 networks.

1XEV-DO requires a separate carrier for data services, but offers the possibility of handing over to a regular 1X carrier in the case of simultaneous voice and data connections. The separate carrier offers the advantage of delivering best-effort peak rates of up to 2Mbps. 1XEV-DV consolidates voice and data services in a single carrier [And01].

2.5 Wideband CDMA (WCDMA)

Wideband CDMA (WCDMA) is the technology proposal that emerged as the most widely adopted third generation air interface [Hol00]. There is no direct evolution from any of the 2G technologies to WCDMA, rather intermediate 2.5G solutions that facilitate the transition, such as GPRS and EDGE.

WCDMA is a single-carrier, wideband, direct sequence spread spectrum (DS-SS) technology. It relies on a 5 MHz carrier to provide both **F**requency **D**ivision **D**uplex (FDD) and **T**ime **D**ivision **D**uplex (TDD), utilizing **V**ariable **S**preading **F**actor (VSF) and multicode to support **B**andwidth **o**n **D**emand (BoD). It introduces improvements over the existing narrowband CDMA systems (IS-95), among them [Hol00]:

- Asynchronous base station operation: IS-95 requires a global time base (GPS) to synchronize the base stations, making the installation of indoor micro and pico cells more difficult`.
- Use of coherent detection on the downlink and uplink: IS-95 systems employ coherent detection on the downlink only. The use of coherent detection on the uplink should result in increased coverage and capacity.

- Support of **M**ultiuser **D**etection (MUD) and smart antennas
- Transmit diversity: IS-95 does not support this feature.
- Inter-frequency handovers: Inter-frequency measurements are not specified in IS-95, making inter-frequency handovers more difficult to implement.
- Fast Closed-Loop Downlink Power Control: provide for improved low-speed performance, when Rayleigh fading causes error-correcting codes and interleaving to work with reduced efficiency.

Additionally, WCDMA has been designed to coexist with GSM, allowing for handovers to/from GSM. WCDMA is also known as **U**niversal **M**obile **T**errestrial **S**ystem (UMTS).

2.6 PDC

The **P**acific **D**igital **C**ellular (PDC) air interface is the current second generation standard used in Japan, being also known as **J**apanese **D**igital **C**ellular (JDC) [Rap96].

Despite having TDMA architecture, similar to some extent to IS-136, PDC will not adopt the GPRS/ EDGE evolution path, but rather migrate to WCDMA.

Chapter 3 – General Radio Packet Services (GPRS) Link Performance

3.1 GPRS Data Rates

GPRS (General Radio Packet Services) is the packet-switched technology that allows data services on GSM networks. It can be viewed as an IP data overlay system upgrade to GSM systems [And01].

The physical layer of GPRS builds on the existing GSM structure, utilizing the same modulation technology – GMSK (Gaussian Minimum Shift Keying) with BT product=0.3, but allowing four distinct Coding Schemes (CS). These coding schemes are named CS1 to CS4 and differ on the maximum data rate they can carry, as shown in Table 3-1[3GP00a].

Coding Scheme	Modulation	Code Rate	Data Rate per Time Slot
CS-1	GMSK	0.49	9.05 kbps
CS-2	GMSK	0.64	13.4 kbps
CS-3	GMSK	0.73	15.6 kbps
CS-4	GMSK	1	21.4 kbps

Table 3-1 - Channel Coding Schemes for GPRS [Source: 3GPP00a].

3.2 Link Quality Control

GPRS introduces the concept of Link Quality Control (LQC) to the packet-switched overlay. Link quality control adapts the protection of the data to the quality of the channel in such a way that, for any channel quality, an optimal bit rate is obtained. The LQC technique used in GPRS is named Link Adaptation (LA). With link adaptation the system chooses the best code rate for the prevailing radio channel condition, i.e., the link is

adapted to the channel [Mol00]. The variation of the code rate is achieved via *puncturing* - the selective removal of protection bits from the coded blocks, reducing its error protection and allowing for an increase in the net data rate.

3.3 GPRS Channel Coding

The original GSM frame structure is maintained. Four coding schemes, CS-1 to CS-4, are defined for GPRS packet data traffic channels.

The GPRS Radio Blocks carrying **Radio Link Control (RLC)** data blocks are composed of a 3-bit **Uplink State Flag (USF)** field, a variable length coded data field and a 40 or 16-bit **Block Check Sequence (BCS)** field, used for error detection [3GP00a].

CS-1 to CS-3 rely on a Rate= $\frac{1}{2}$ convolutional code followed by variable bit-puncturing to produce their final data rates, whereas CS-4 uses no error correction coding, realizing the highest data rate achievable with GPRS. Figures 3-1 and 3-2 illustrate the Radio Block structure for both cases, respectively [3GP00a].

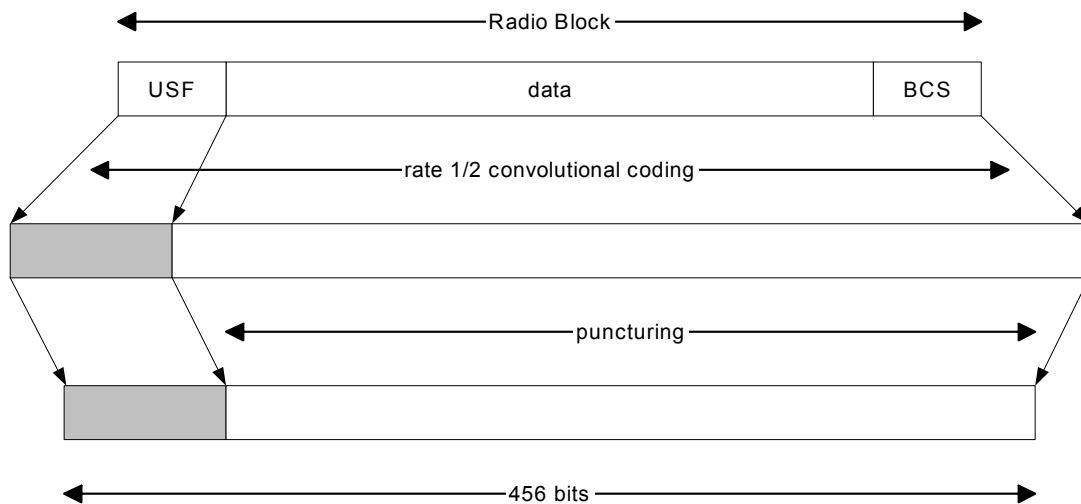


Figure 3-1 - Radio Block structure for CS-1 to CS-3 [Source: 3GP00a].

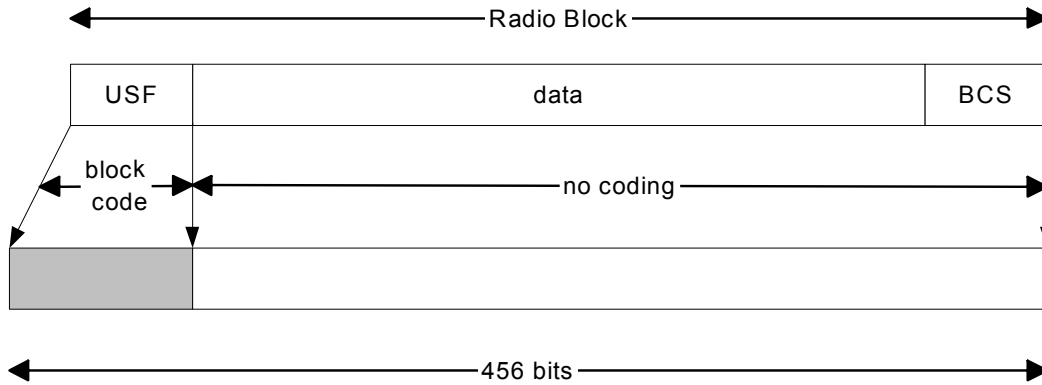


Figure 3-2 - Radio Block structure for CS-4 [Source: 3GP00a]

The first step of the coding process is the inclusion of the BCS for error detection. For CS-1 to CS-3 the second step consists of pre-coding the USF (except for CS-1), adding four tail bits. CS1 consists of a half rate convolutional code for forward error correction (FEC) and a 40-bit FIRE code for BCS (optionally Forward Error Correction). CS-2 and CS-3 are punctured versions of the same FEC code as CS-1. For CS-1 the whole Radio Block is convolutionally coded and the USF field must be decoded as part of the data.

CS-2 to CS-4 use the same 16-bit Cyclic Redundancy Check (CRC) word for BCS. It is calculated over the entire uncoded RLC Data Block, including the MAC (Media Access Control) header (USF in Figures 2 and 3). Table 3-2 summarizes the coding parameters for the GPRS coding schemes [3GP00a].

Scheme	Code Rate	USF (bits)	Pre-coded USF bits	Radio Block (excluding USF and BCS)	BCS (bits)	Tail (bits)	Coded Bits	Punctured Bits	Data rate (kb/s)
CS-1	1/2	3	3	181	40	4	456	0	9.05
CS-2	2/3	3	6	268	16	4	588	132	13.4
CS-3	3/4	3	6	312	16	4	676	220	15.6
CS-4	1	3	12	428	16	-	456	-	21.4

Table 3-2 - Coding parameters for the GPRS coding schemes [Source: 3GP00a].

3.4 Simulations on GPRS Receiver Performance

3.4.1 Background to the Research on GPRS Receiver Performance

The research and development work of various wireless infrastructure manufacturers and operators during the standardization process has led to the performance characterization of the GPRS coding schemes. Both the 900 and 1800 MHz (European counterparts to the U.S. 800 and 1900 MHz bands) bands have been investigated, so as to define the link performance of the proposed schemes under different levels of interference, propagation environments and mobile speeds.

The simulation results presented herein (Figures 3-3 thru 3-13) are the compilation of the contributions by Alcatel (France), Ericsson (Sweden), Telecom Italia Laboratories (Italy) and GIE CEGETEL (France) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). The complete set of simulation results is presented in [3GP01a]. The results obtained independently by these contributors are in agreement, having led to the definition of the recommended performance values presented in that document.

3.4.2 GPRS Link Performance in Noise Limited Environments

Downlink system performance in noise-limited environments has been simulated. The results of Block Error Rate (BLER) versus E_b/N_0 for the following propagation environments are presented [3GP01a]:

- Static AWGN channel (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (1800 MHz)
- Rural @ 250 Km/h (RA250) no FH (1800 MHz)

A block is considered to be in error if the cyclic redundancy check word fails for the data block.

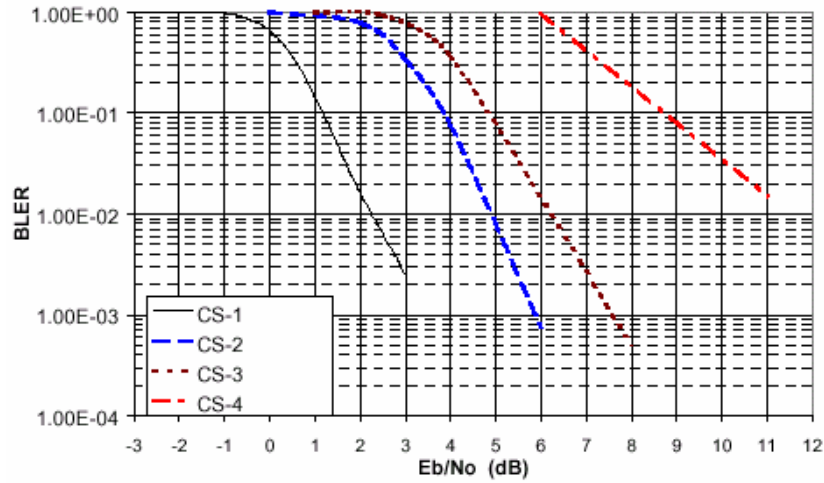


Figure 3-3 –Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus Eb/No performance, static AWGN channel, 900 MHz. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

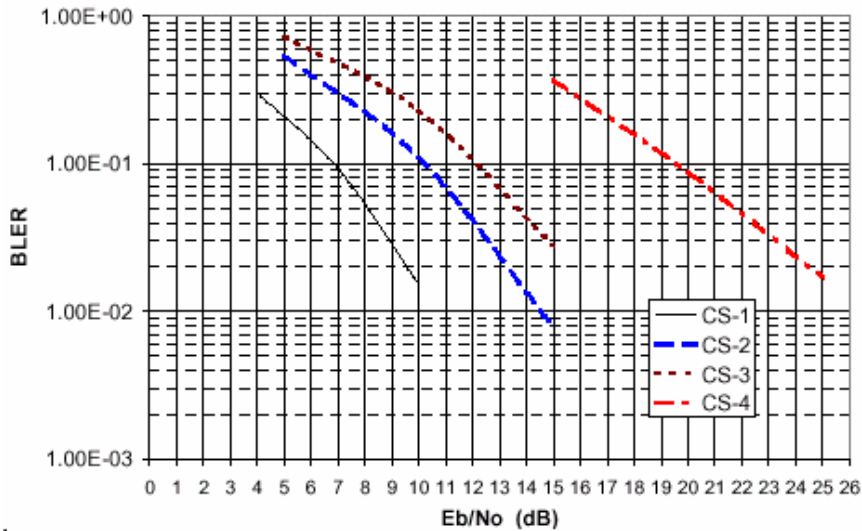


Figure 3-4 – Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus Eb/No performance, TU50 no FH, 900 MHz. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

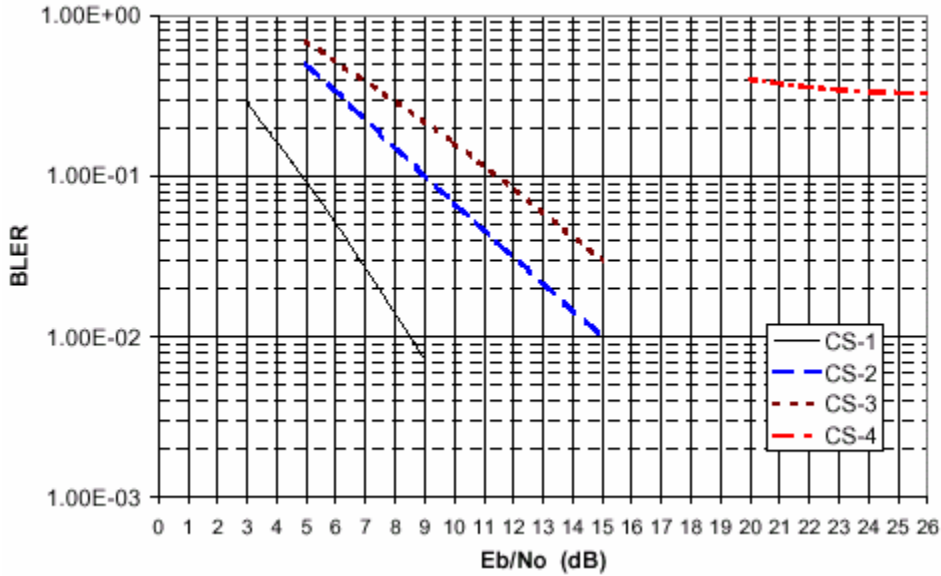


Figure 3-5 – Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus Eb/No performance, RA250 no FH, 900 MHz. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

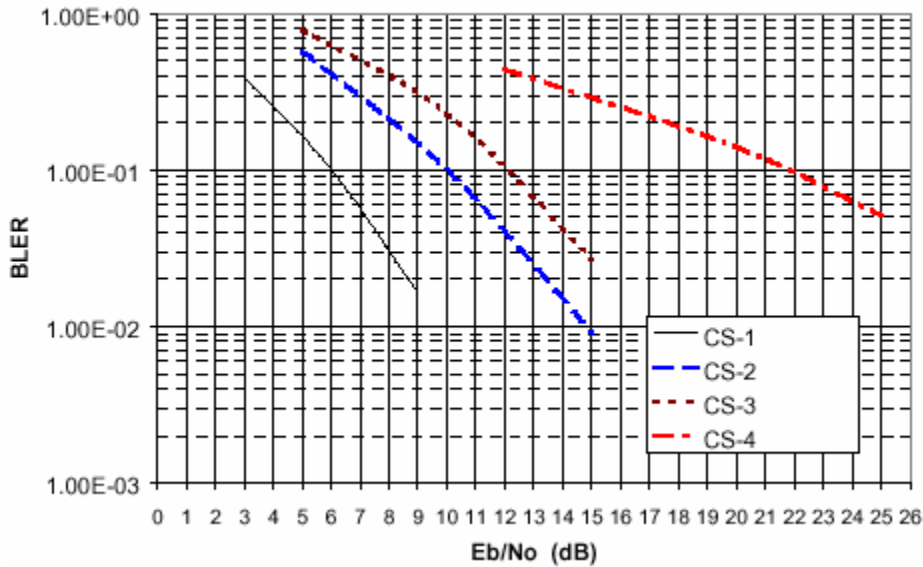


Figure 3-6 – Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus Eb/No performance, TU50 no FH, 1800 MHz. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

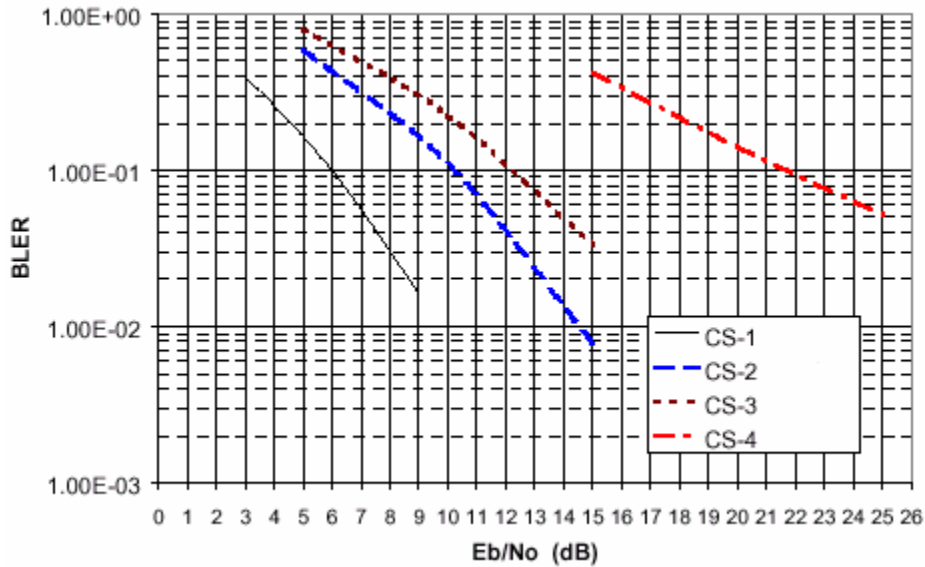


Figure 3-7 - Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus Eb/No performance, TU50 ideal FH, 1800 MHz. Varying fading occurring during one burst; independent fadings over consecutive bursts. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

Figure 3-7 shows that the improvement caused by frequency hopping over the non-frequency hopping case depicted in Figure 3-6 is marginal for the TU50 environment. The gain obtained with frequency hopping is generally between 2 and 3 dB. Such gain is generally realized at slow speeds, when the fading durations affect the data blocks more severely. In such cases frequency hopping improves de-interleaving performance, resulting in a reduction of the block error rate for the same Eb/No.

3.4.3 GPRS Link Performance in Interference Limited Environments

Interference-limited downlinks have been simulated under the Typical Urban @ 3 Km/h (TU3), Typical Urban @ 50 Km/h (TU50) and Rural @ 250 Km/h (RA250) environments. The simulation models accounted for both non-hopping and ideal hopping scenarios, given the original GSM capability to support frequency hopping (FH). When FH is simulated, independent fadings over consecutive bursts were assumed. Varying

fading during one burst was considered. Additionally, no antenna diversity was considered. A block is considered to be in error if the cyclic redundancy check word fails for the data block.

The C/I performance simulations assumed one single interfering signal with variable-mean lognormal distribution and standard deviation of 7 dB [3GP01a]. Simulation times and simulator complexity for multiple interfering signals encouraged the use of a single interfering signal. Such approximation should not affect the results presented herein. In general, interference is characterized by a predominant source. When multiple strong interferers are present their combined behavior can be represented by a single signal without significant loss of accuracy.

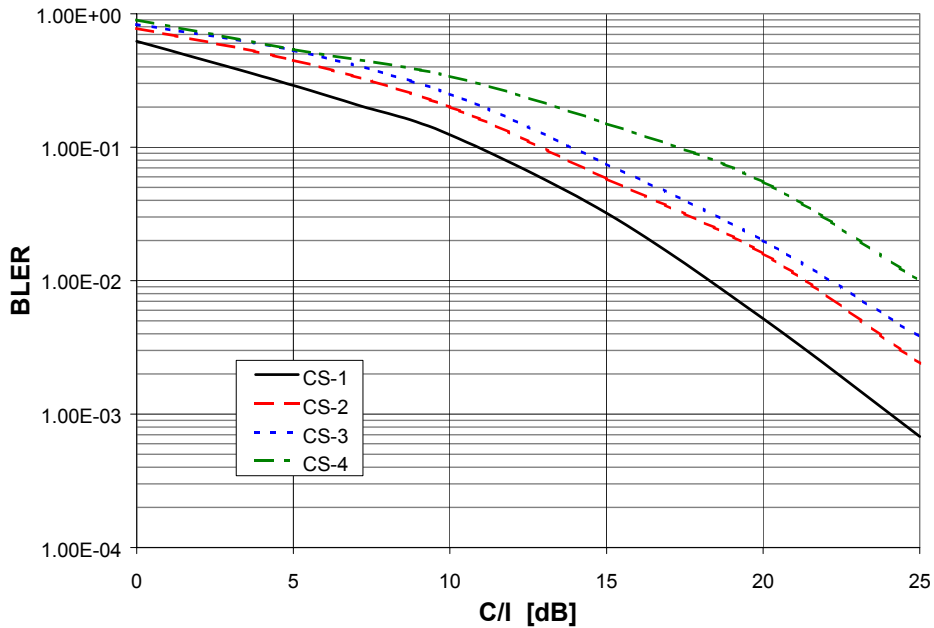


Figure 3-8 – Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU3 without FH, 900 MHz. One single interfering signal. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

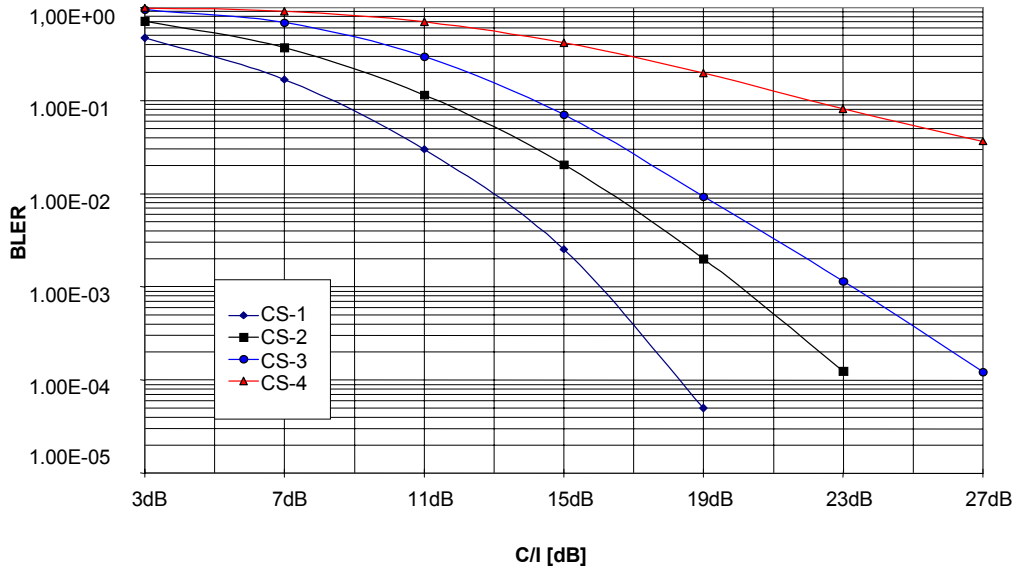


Figure 3-9 - Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU50 without FH, 900 MHz. One single interfering signal. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

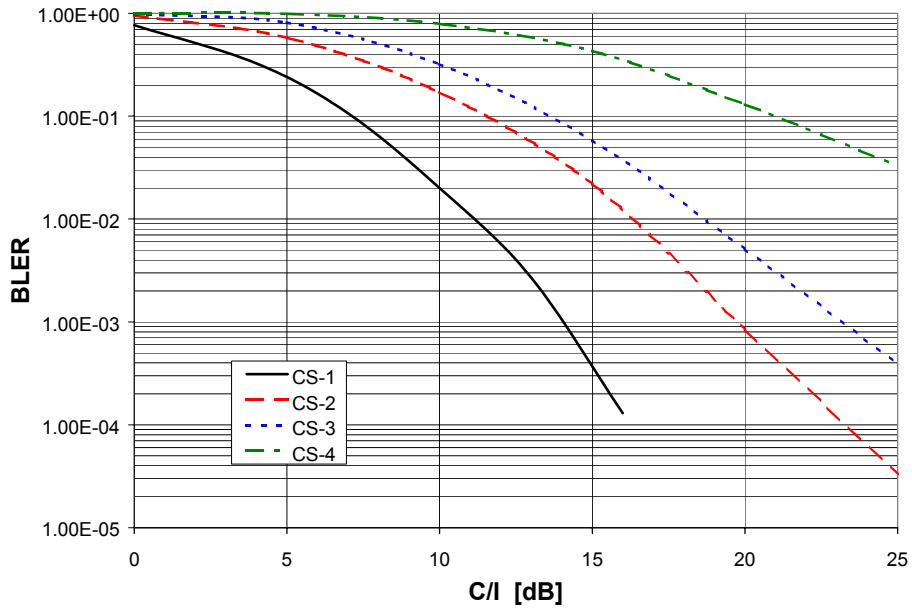


Figure 3-10 – Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU50 with ideal FH (900 MHz). One single interfering signal. Varying fading occurring during one burst; independent fadings over consecutive bursts. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

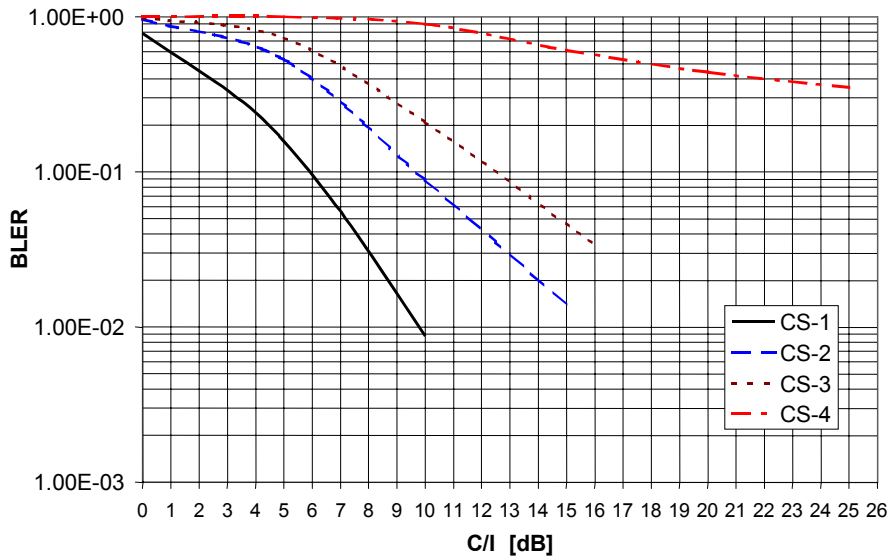


Figure 3-11 - Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for RA250 without FH, 900 MHz. One single interfering signal. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

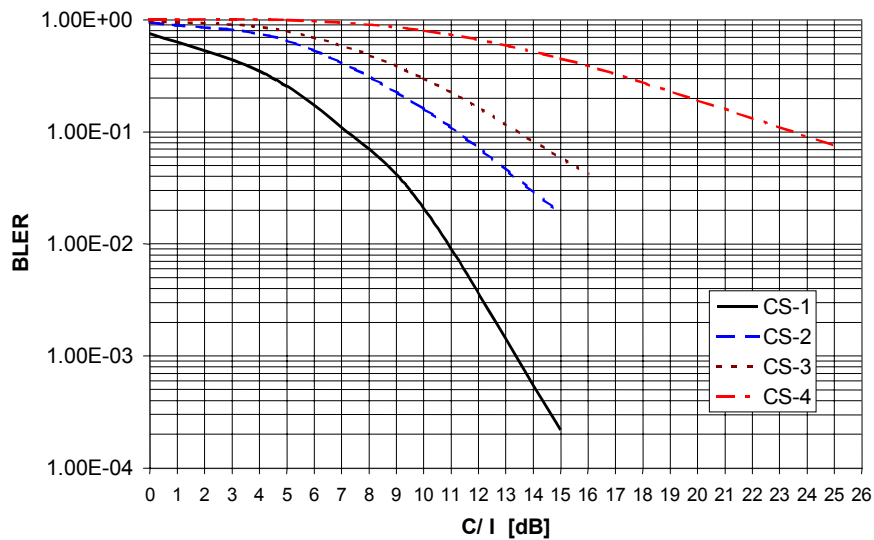


Figure 3-12 - Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU50 without FH (1800 MHz). One single interfering signal. Varying fading occurring during one burst. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

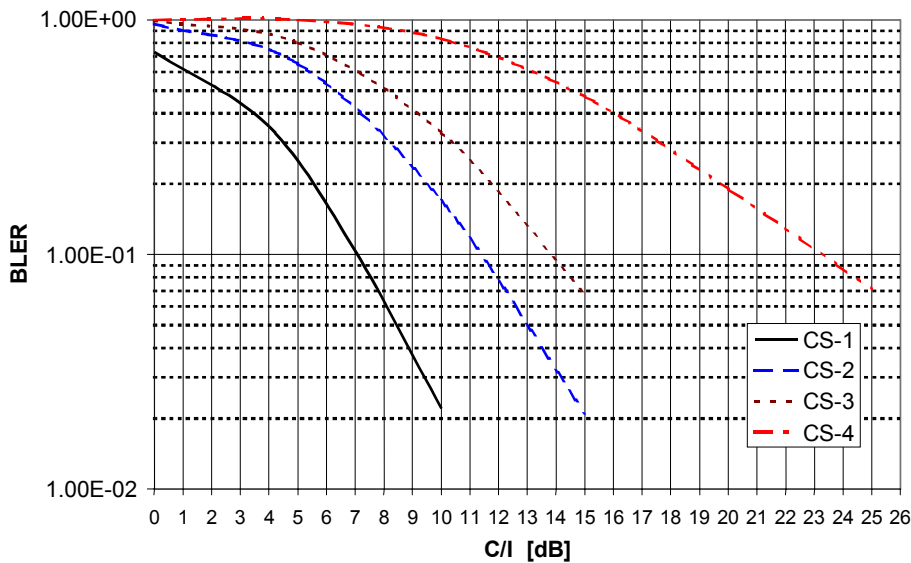


Figure 3-13 - Downlink General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU50 with ideal FH, 1800 MHz. Varying fading occurring during one burst; independent fadings over consecutive bursts. No antenna diversity. Burst synchronization recovery based on the cross-correlation properties of the training sequence. Soft output equalizer. Channel decoding: FIRE decoding and correction for CS-1; CRC only for CS-2, CS-3 and CS-4. 40,000 radio blocks per coding scheme. Data block size=456 bits [Source: 3GP01a].

3.5 GPRS Uplink Throughput

The simulation results presented herein (Figures 3-14 thru 3-18) are the compilation of the contributions by Telecom Italia Laboratories (Italy) and GIE CEGETEL (France) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). The complete set of simulation results is presented in [3GP01a]. The results obtained independently by these contributors are in agreement, having led to the definition of the recommended performance values presented in that document.

Uplink GPRS throughput performance versus C/I has been evaluated for CS-1 to CS-4 under the assumptions listed below [3GP01a]. Downlink throughput simulation results are not presented, for they are equivalent to those obtained for the uplink.

- Compliance with the GPRS MAC/RLC protocol
- Single interfering signal
- Variable mean lognormal C/I distribution with standard deviation of 7 dB
- Single-slot Mobile Stations
- Single Packet Data Channel (PDCH) dedicated to data traffic
- Response time between mobile station and base station is 2 TDMA frames
- Traffic Model: Poisson distribution of packet inter-arrival time and Railway traffic model for packet length

The results for TU3 without FH, TU50 without FH and TU50 with ideal FH are presented below. The points where BLER=10% are highlighted.

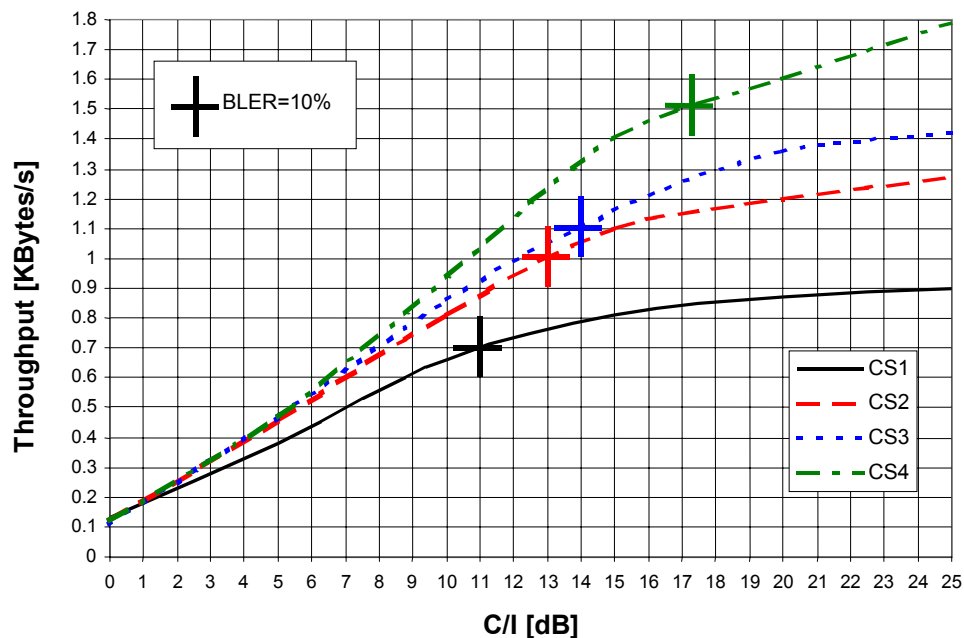


Figure 3-14 - General Radio Packet Services (GPRS) uplink throughput versus C/I for TU3 without FH. The crosses correspond to the points where BLER=10%. One single interfering signal. Variable mean lognormal C/I distribution with standard deviation of 7 dB. Single - slot mobile stations. Single Packet Data Channel (SPDC) dedicated to data traffic. Traffic model: Poisson distribution of packet of packet inter-arrival time and Railway traffic model for packet length. In compliance with the GPRS MAC/RLC protocol. Throughput in kbytes/s (1byte=8 bits). Response time between mobile station and base station is 2 TDMA frames [Source: 3GP01a].

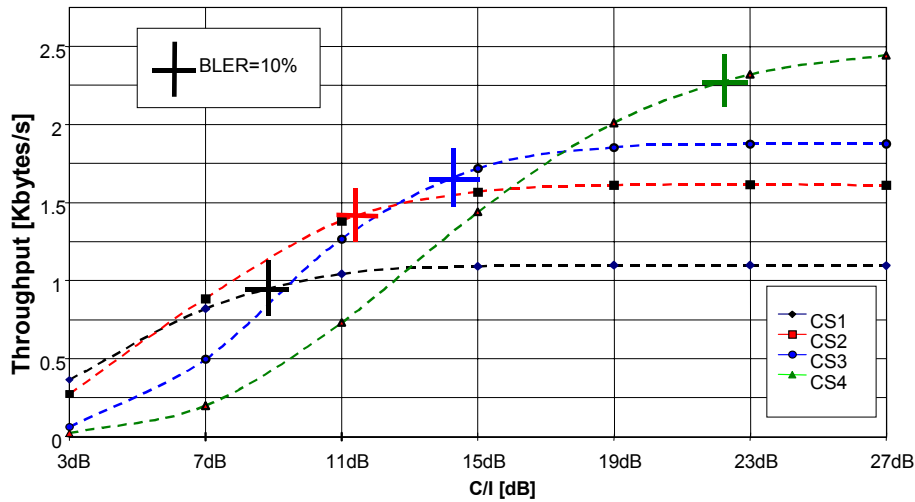


Figure 3-15 - General Radio Packet Services (GPRS) uplink throughput versus C/I for TU50 without FH. The crosses correspond to the points where BLER=10%. One single interfering signal. Variable mean lognormal C/I distribution with standard deviation of 7 dB. Single - slot mobile stations. Single Packet Data Channel (SPDC) dedicated to data traffic. Traffic model: Poisson distribution of packet of packet inter-arrival time and Railway traffic model for packet length. In compliance with the GPRS MAC/RLC protocol. Throughput in kbytes/s (1byte=8 bits). Response time between mobile station and base station is 2 TDMA frames [Source: 3GP01a].

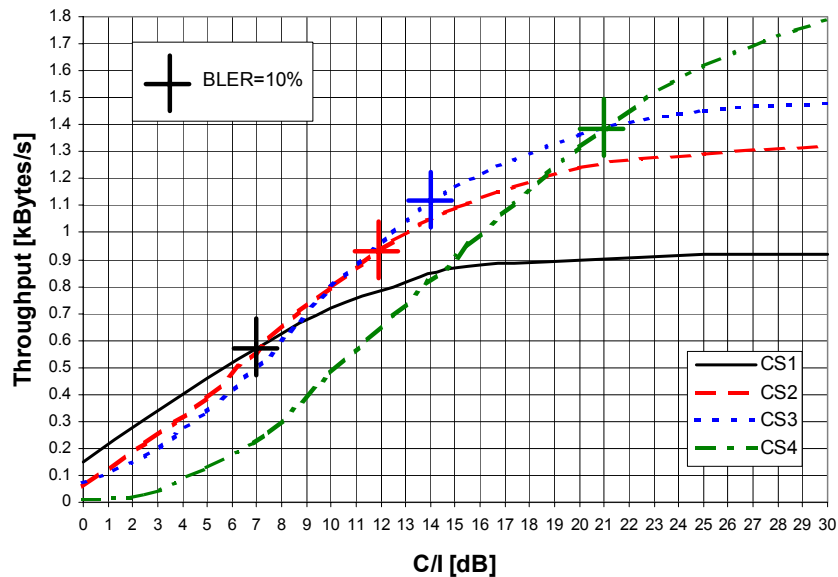


Figure 3-16 - General Radio Packet Services (GPRS) uplink throughput versus C/I for TU50 with ideal FH. The crosses correspond to the points where BLER=10%. One single interfering signal. Variable mean lognormal C/I distribution with standard deviation of 7 dB. Single - slot mobile stations. Single Packet Data Channel (SPDC) dedicated to data traffic. Traffic model: Poisson distribution of packet of packet inter-arrival time and Railway traffic model for packet length. In compliance with the GPRS MAC/RLC protocol. Throughput in kbytes/s (1byte=8 bits). Response time between mobile station and base station is 2 TDMA frames [Source: 3GP01a].

Figures 3-17 and 3-18 show the ranges each coding scheme yields the highest throughput as a function of C/I for TU3 without frequency hopping and TU50 with ideal frequency hopping, respectively.

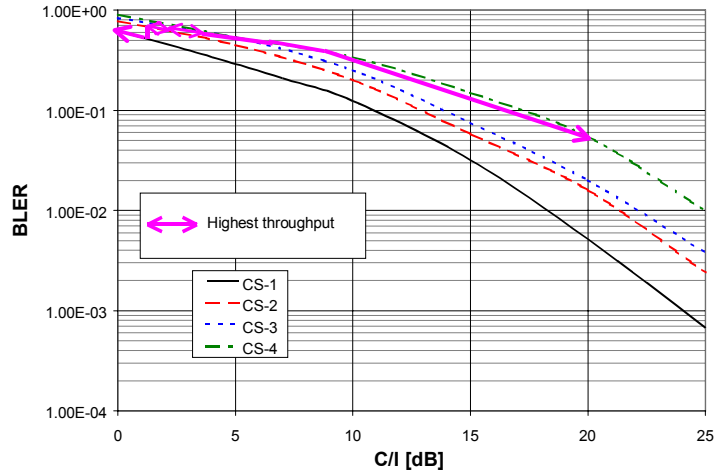


Figure 3-17 - General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU3 without FH (900 MHz). The arrows indicate the highest throughput range of each coding scheme. One single interfering signal. Variable mean lognormal C/I distribution with standard deviation of 7 dB. Single - slot mobile stations. Single Packet Data Channel (SPDC) dedicated to data traffic. Traffic model: Poisson distribution of packet of packet inter-arrival time and Railway traffic model for packet length. In compliance with the GPRS MAC/RLC protocol. Response time between mobile station and base station is 2 TDMA frames [Source: 3GP01a].

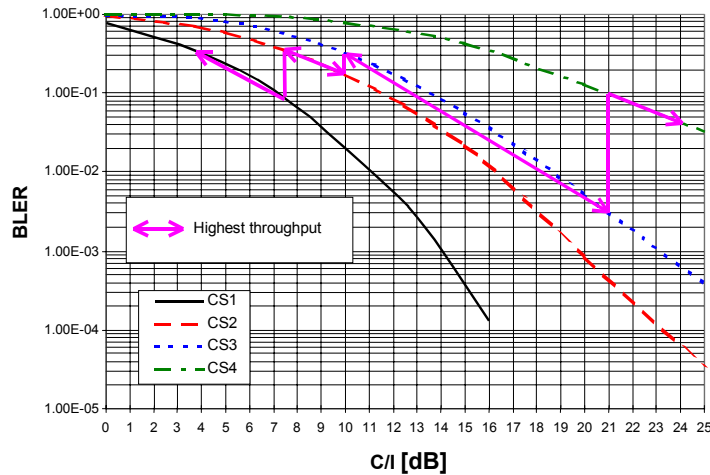


Figure 3-18 - General Radio Packet Services (GPRS) Block Error Rate (BLER) versus C/I performance for TU50 with ideal FH (900 MHz). The arrows indicate the highest throughput range of each coding scheme. One single interfering signal. Variable mean lognormal C/I distribution with standard deviation of 7 dB. Single - slot mobile stations. Single Packet Data Channel (SPDC) dedicated to data traffic. Traffic model: Poisson distribution of packet of packet inter-arrival time and Railway traffic model for packet length. In compliance with the GPRS MAC/RLC protocol. Response time between mobile station and base station is 2 TDMA frames [Source: 3GP01a].

An implementation margin of 2 dB is usually added to the values obtained from the previous charts, to account for receiver impairments not included in the simulations.

The BLER performance of 10% has been proposed as the reference level for GPRS systems. The use of Automatic Repeat Request (ARQ) in higher protocol layers allows for a reduced block error rate requirement, requesting retransmissions when blocks are received in error. The BLER reference level of 10% represents a compromise between coding complexity, which affect the data rate and required bandwidth, and throughput reduction caused by excessive retransmission requests by the ARQ protocol.

3.6 Discussion

The use of link adaptation to maintain the link quality allows for variable throughput given a certain interference condition. Intuitively, the system should always try to use the coding scheme that yields the highest throughput at any given time. However, having satisfactory link quality (C/I), a data session may not require the highest allowable throughput. In such cases the choice of a less “efficient” coding scheme should be considered for that connection, for it will allow a reduction in the transmitted power (through downlink/uplink power control), contributing for the minimization of the overall system interference. This has particular importance in the uplink, since the mobile terminal presents more severe power constraints.

The combination of the four CS's allows for the smooth variation of the throughput as C/I changes. The transition between them occurs in real time, during the data session, as the system dynamically estimates the link quality of every burst to decide on the most suitable coding scheme for the existing conditions [3GP01c].

Chapter 4 – Enhanced Data Rates for the GSM Evolution (EDGE) Link Performance

4.1 EDGE Modulations and Data Rates

The EDGE (Enhanced Data Rates for the GSM Evolution) air interface extends the functionality of GPRS by allowing increased data rates over the same channel bandwidth. It introduces a new modulation – 8 PSK (Phase Shift Keying), a linear high-level scheme that offers improved spectral efficiency with moderate implementation complexity. EDGE employs linearized GMSK (Gaussian Minimum Shift Keying) pulse shaping in order to allow the 8 PSK signal to fit into the original GSM spectrum mask [Fur98]. The original GMSK modulation is still used for lower data rates (up to 22.8 kbps), with 8 PSK taking over for higher rates. The maximum EDGE data rate per time slot is 69.2 kbps [3GP00a]. Figure 15 shows the 8PSK signal constellation.

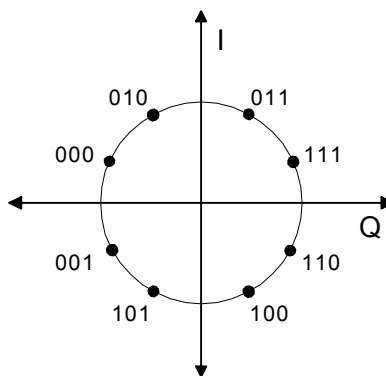


Figure 4-1 – 8PSK signal constellation (Grey coded) [Fur98].

Nine different modulation and coding schemes, MCS-1 to MCS-9, are defined for the packet-switched mode of EDGE (EGPRS). Table 4-1 shows the main characteristics of each one [3GP00a].

Coding Scheme	Modulation	Code Rate	Data Rate per Time Slot (kbps)
MCS-1	GMSK	0.53	8.8
MCS-2	GMSK	0.66	11.2
MCS-3	GMSK	0.80	14.8 (13.6) ¹
MCS-4	GMSK	1	17.6
MCS-5	8PSK	0.37	22.4
MCS-6	8PSK	0.49	29.6 (27.2) ²
MCS-7	8PSK	0.76	44.8
MCS-8	8PSK	0.92	54.4
MCS-9	8PSK	1	59.2

Table 4-1 - EDGE channel modulation and coding schemes [3GP00a].

4.2 Link Quality Control

The higher data rates involved in EDGE require improved link quality control mechanisms. EGPRS uses a combination of Link Adaptation (LA) and Incremental Redundancy (IR). The LA scheme regularly estimates the link quality, subsequently selecting the most appropriate modulation and coding scheme for coming transmissions, so as to maximize the data rate. With LA the link performance is dependent on the individual performance of each packet, coded in a particular coding scheme [Mol00].

In the IR mode, the first data block in a session is transmitted with very little or no redundant information, yielding a high data rate. If decoding fails, the next retransmission will occur with more redundant information, using a different puncturing scheme of the same data block. There are three puncturing schemes named P1, P2 and P3. MCS-1, MCS-2, MCS-5 and MCS-6 use P1 and P2, whereas the remaining MCS's use all of them.

¹ The lower data rate figure within brackets is the result of the insertion of 3 padding octets to the data octets when switching from MCS-8.

² The lower data rate figure within brackets is the result of the insertion of 6 padding octets to the data octets when switching from MCS-8.

The erroneous blocks are stored (in LA the erroneous blocks are discarded) and combined with each new retransmission, until the data block is successfully decoded. In IR the link performance is dependent on the combination of the packets coded in a particular coding scheme. The code combining results in a given coding scheme having lower BLER, when compared with LA at a similar $C/(I+N)$ [Mol00].

The link quality control solution employed in EDGE benefits from the robustness and high throughput of incremental redundancy while taking advantage of the lower delays and lower memory requirements enabled by link adaptation [Fur98].

4.3 EDGE Channel Coding

The MCS's are divided into families A, B and C. Each family has a different basic unit payload of 37 (and 34), 28 and 22 octets, respectively. Different codes rates within a family are achieved by transmitting a different number of payload units within one Radio Block. For families A and B, 1,2 or 4 payload units are transmitted, whereas family C transmits 1 or 2 payload units. Figure 4-2 illustrates the three families [3GP00a]. Figure 4-2 illustrates the block structure of all the families. Figures 4-3 to 4-11 show the detailed coding and puncturing structure of each MCS.

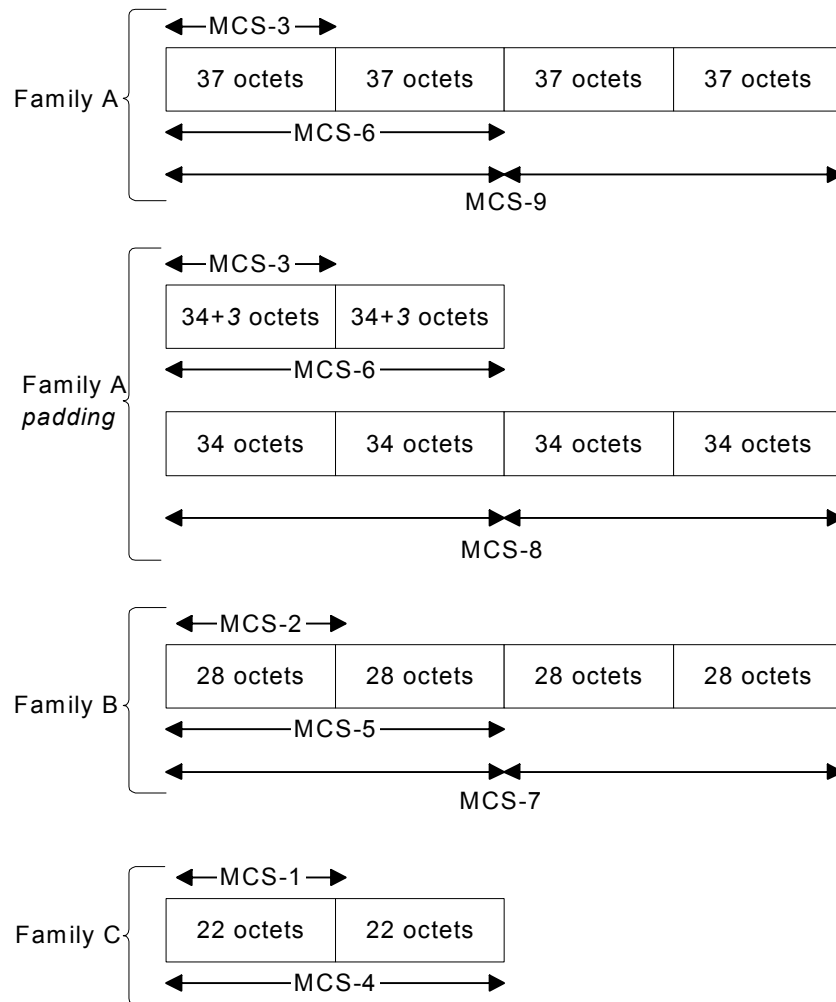


Figure 4-2 - EGPRS Modulation and Coding Schemes. Three families - A, B and C have been defined. Family A applies to MCS-6, MCS-8 and MCS-9. Family B applies to MCS-5 and MCS-7. Family C applies to MCS-1 and MCS-4. [3GP00a].

When 4 payload units are transmitted (MCS-7, MCS-8 and MCS-9), they are splitted into two RLC blocks, with separate sequence numbers and BCS's. MCS-8 and MCS-9 are interleaved over two bursts, whereas MCS-7 is interleaved over four bursts. When switching from MCS-8 to MCS-3 or MCS-6, 3 or 6 padding octets, respectively, are added to the data octets, as shown indicated in Figure 16 [3GP00a].

The header of the Radio Block is coded independently from the data, in order to ensure strong header protection. Three header formats are used: one for MCS-7, MCS-8 and

MCS-9 (MCS's with four payload units), one for MCS-5 and MCS-6 and one for MCS-1 to MCS-4. The first and second formats are for 8PSK modulation, with the third one dedicated to the GMSK MCS's. The main difference is the number of Sequence Numbers carried in the header – 2 for MCS-7, MCS-8 and MCS-9, 1 for MCS-5 and MCS-6. Unlike the data part, the header is always interleaved over four bursts. Figures 4-3 to 4-11 detail the coding and puncturing for the EDGE MCS's [3GP00a].

The USF has 8 states, represented by 3-bit field in the MAC header. It is encoded to 12 symbols, resulting in 12 bits for GMSK modes and 36 bits for the 8PSK modes. The **Final Block Indicator (FBI)** bit and the **Extension (E)** bit do not require extra protection, being encoded along with the data part [3GP00a].

The first step of the coding process is the inclusion of the **Block Check Sequence (BCS)** for error detection. The second step consists of adding six **Tail Bits (TB)** and an R=1/3 mother convolutional code for error correction. For each modulation and coding scheme the data is punctured at the output of the convolutional encoder to produce the desired data rate [3GP00a].

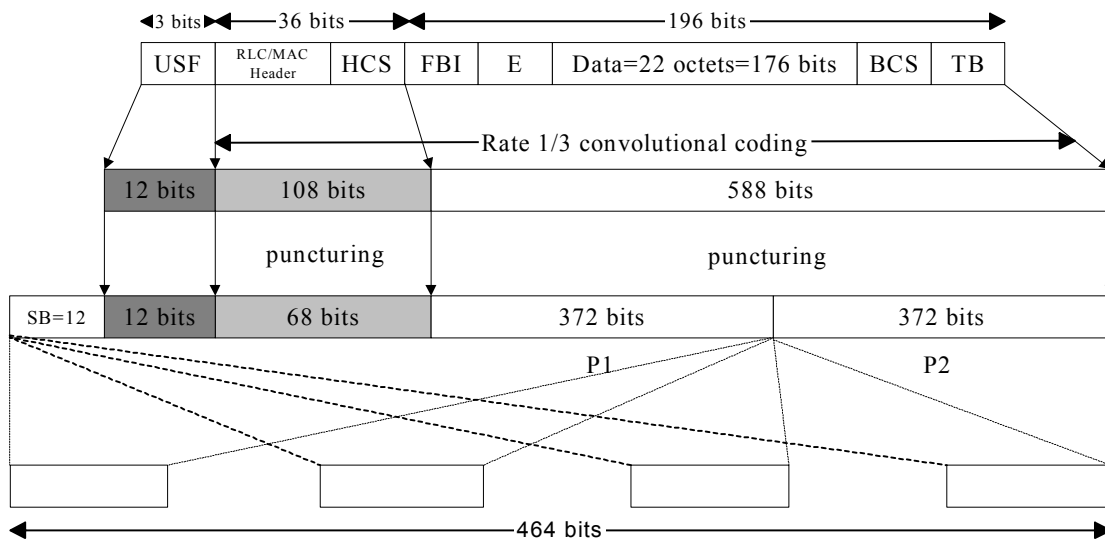


Figure 4-3 - Coding and Puncturing for MCS-1. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

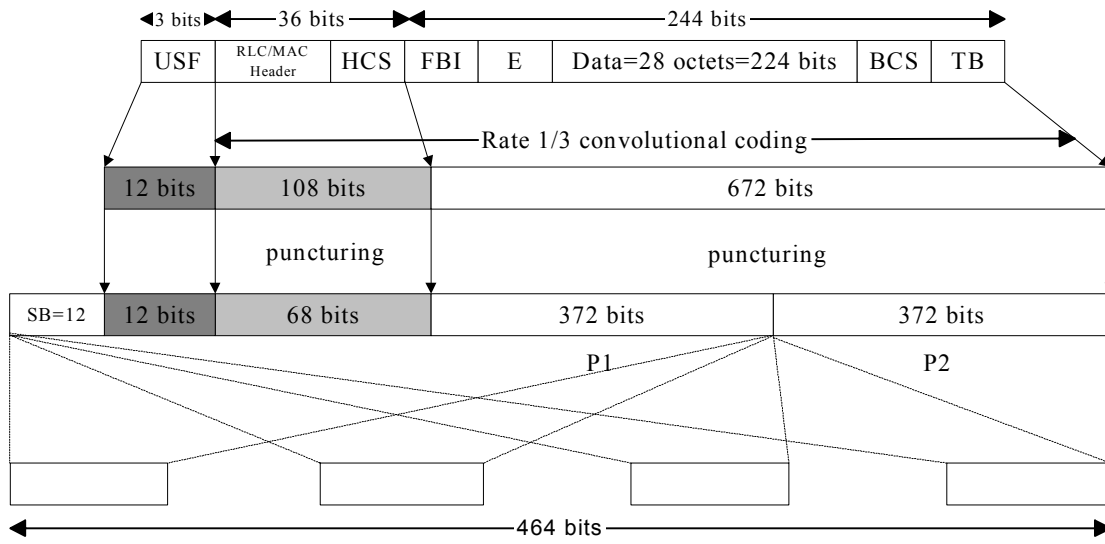


Figure 4-4 - Coding and Puncturing for MCS-2. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

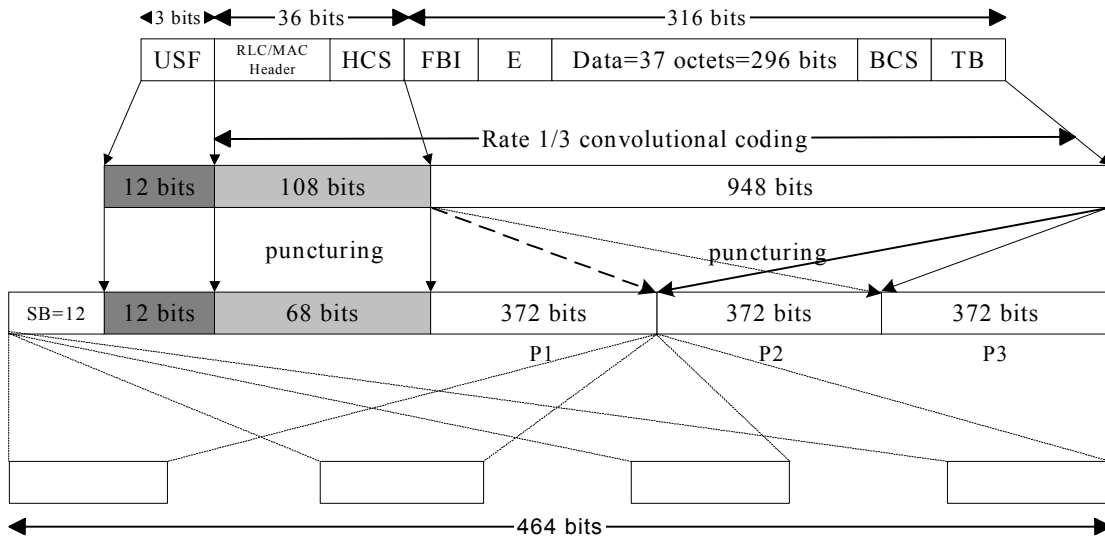


Figure 4-5 - Coding and Puncturing for MCS-3. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

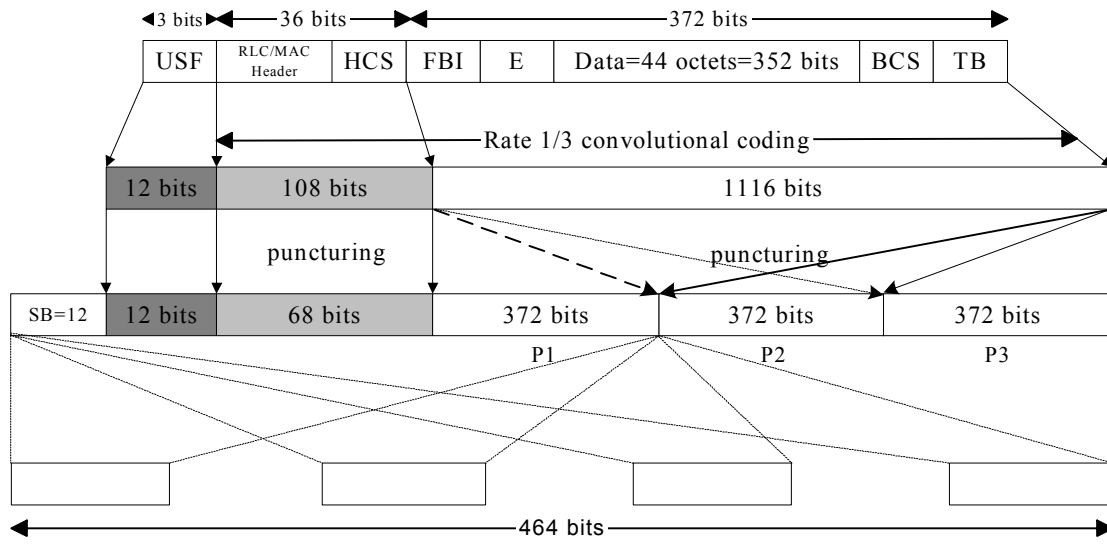


Figure 4-6 - Coding and Puncturing for MCS-4. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

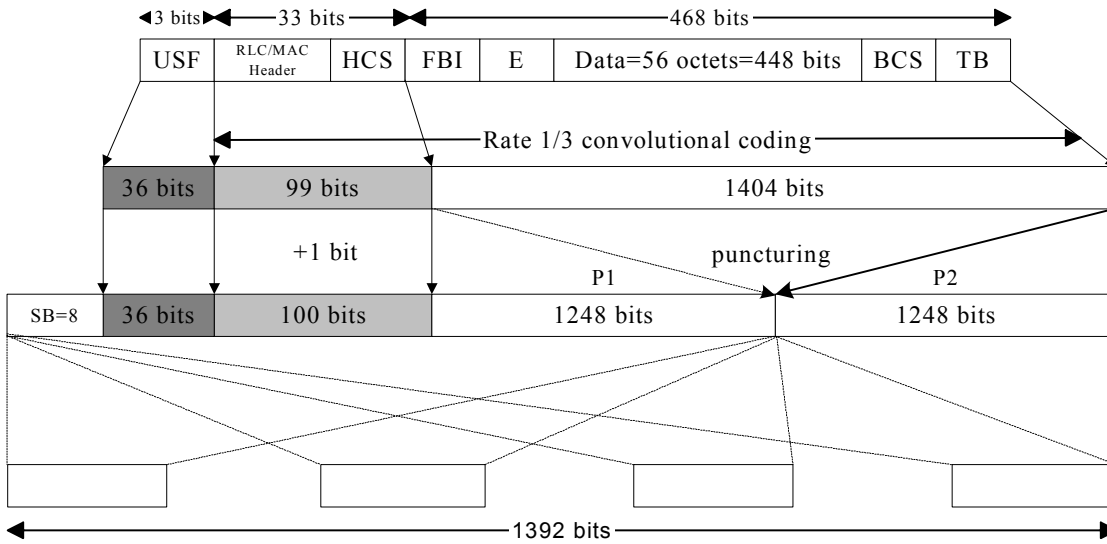


Figure 4-7 - Coding and Puncturing for MCS-5. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

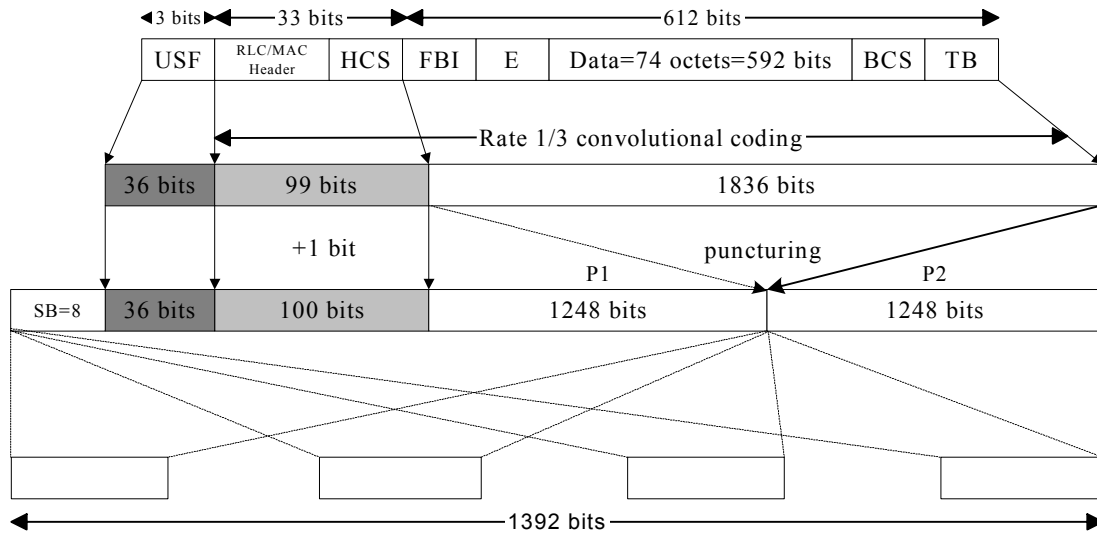


Figure 4-8 - Coding and Puncturing for MCS-6. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

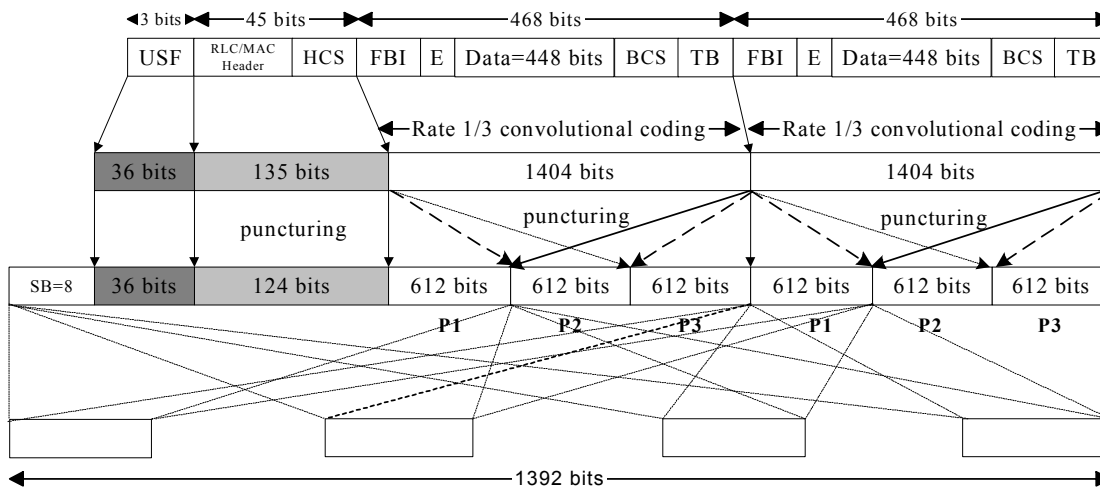


Figure 4-9 - Coding and Puncturing for MCS-7. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

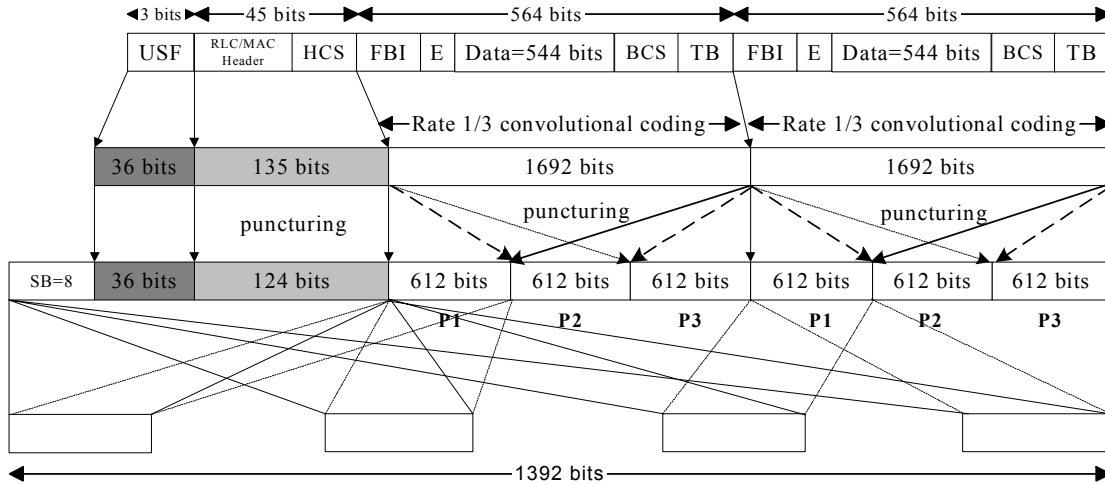


Figure 4-10 - Coding and Puncturing for MCS-8. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

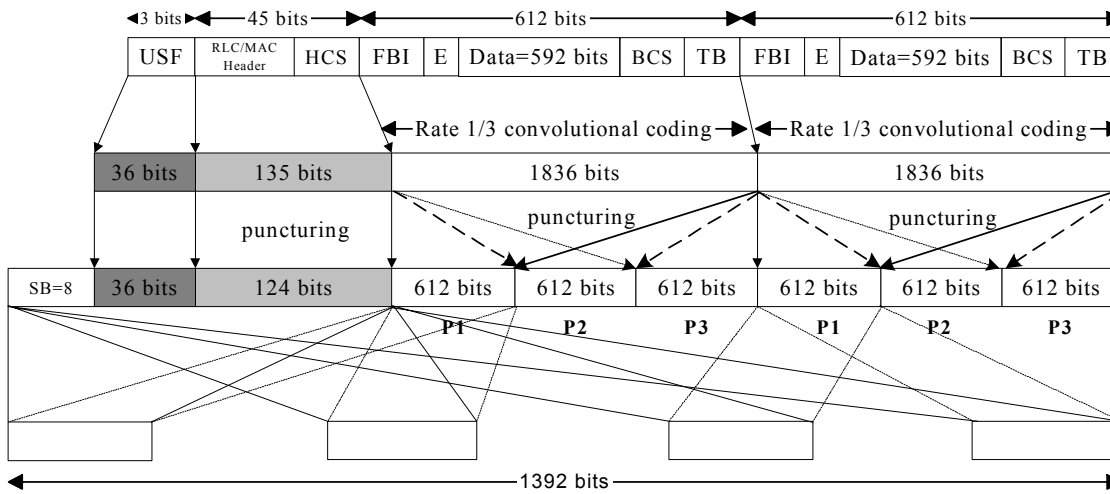


Figure 4-11 - Coding and Puncturing for MCS-9. USF=Uplink Sate Flag; BCS=Block Check Sequence; TB=Tail Bits; E=Extension bit ;RLC=Radio Link Control; MAC=Media Access Layer; FBI=Final Block Indicator [3GP00a].

The details of each EDGE modulation and coding scheme are shown in Table 4-2.

Scheme	Code Rate	Header Code Rate	Modulation	RLC blocks per Radio Block	Raw Data within one Radio Block (bits)	Family	BCS (bits)	Tail payload (bits)	HCS (bits)	Data rate (kbps)
MCS-1	0.53	0.53	GMSK	1	176	C	12	6	8	8.8
MCS-2	0.66	0.53	GMSK	1	224	B	12	6	8	11.2
MCS-3	0.80	0.53	GMSK	1	272+24 ³ 296	A	12	6	8	13.6 14.8
MCS-4	1	0.53	GMSK	1	352	C	12	6	8	17.6
MCS-5	0.37	1/3	8PSK	1	448	B	12	6	8	22.4
MCS-6	0.49	1/3	8PSK	1	544+48 ⁴ 592	A	12	6	8	27.2 29.6
MCS-7	0.76	0.36	8PSK	2	2X448	B	2X12	2X6	8	44.8
MCS-8	0.92	0.36	8PSK	2	2X544	A	2X12	2X6	8	54.4
MCS-9	1	0.36	8PSK	2	2X592	A	2X12	2X6	8	59.2

Table 4-2 - Coding parameters for the EDGE modulation and coding schemes [3GP00a].

4.4 Simulations on EDGE (EGPRS) Receiver Performance

4.4.1 Background on the Research of EDGE Receiver Performance

As in GPRS, the research effort of several wireless infrastructure manufacturers during the standardization process has led to the performance characterization of the EDGE (EGPRS) coding schemes. Both the 900 and 1800 MHz (European counterparts to the U.S. 800 and 1900 MHz bands) bands have been investigated, so as to define the link performance of the proposed schemes under different levels of interference, propagation environment and mobile speed.

³ 24 bits of padding.

⁴ 48 bits of padding.

The simulation results presented herein (Figures 4-12 thru 4-25) are the compilation of the contributions by Ericsson (Sweden) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Lucent Technologies (United States), Nortel Network (Canada) and Nokia (Finland) have been researched, but are not included in this document for they are aligned with the results presented by Ericsson. The contributions by Ericsson can be found in [ET99a], Nokia's contributions are in [ET99b], Lucent's contributions are in [ET99c] and Nortel's contributions are in [ET99d].

4.4.2 EDGE Bit Error Rate (BER) Link Performance

4.4.2.1 EDGE Bit Error Rate (BER) Link Performance in Noise Limited Environments

System performance in noise-limited environments has been simulated. Bit Error Rate (BER) versus E_b/N_0 curves are presented for the following propagation environments, for MCS-1 to MCS-4 (GMSK) and MCS-5 to MCS-9 (8PSK) [ET99a]:

- Static AWGN channel (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (1800 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (1800 MHz)

These curves show downlink simulation results for a receiver with no impairments. Additional curves accounting for impairments caused by frequency offset and error vector magnitude (EVM) are presented in section 4.4.4. Uplink simulations have not been performed, for they are expected to yield equivalent results. BER in the following figures

refer to bit error(s) in the data field and/or in the header field, including CRC bits, after decoding.

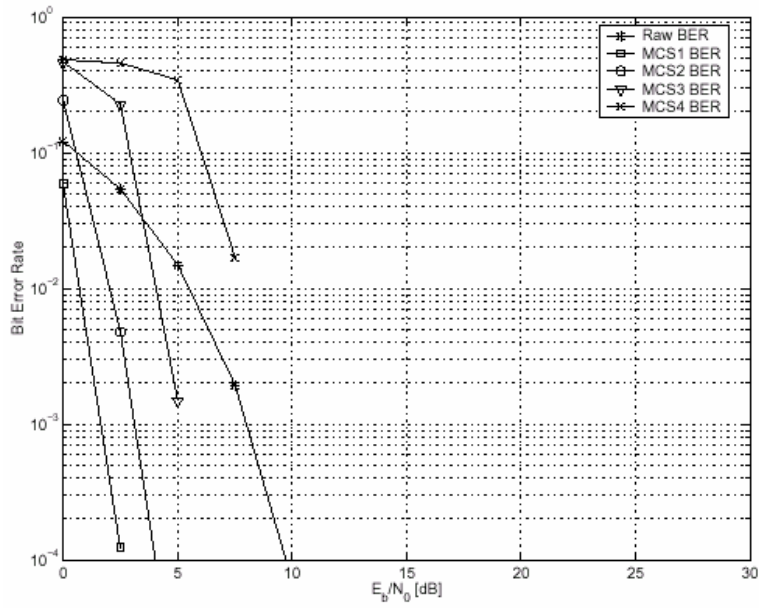


Figure 4-12 – Downlink Bit Error Rate (BER) for MCS-1 to MCS4 (GMSK), static AWGN channel, 900 MHz, no frequency hopping, no antenna diversity. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

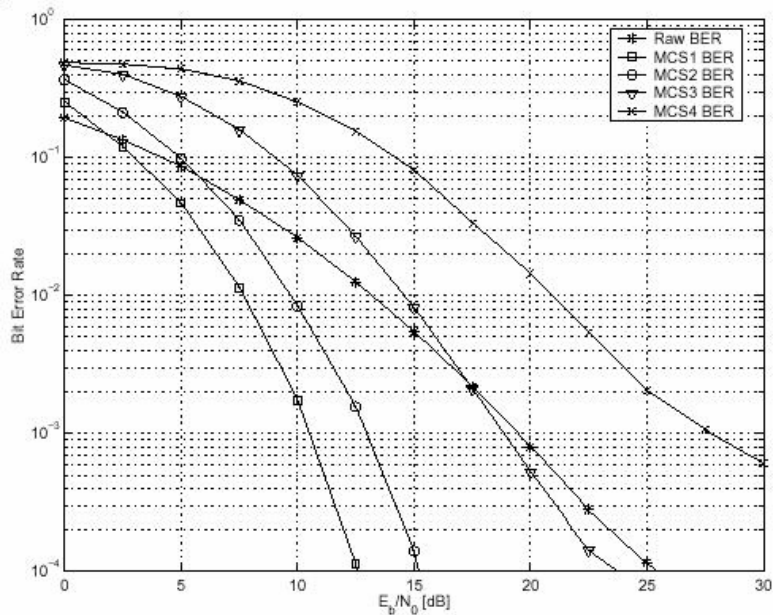


Figure 4-13 – Downlink Bit Error Rate (BER) for MCS-1 to MCS4 (GMSK), TU50 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

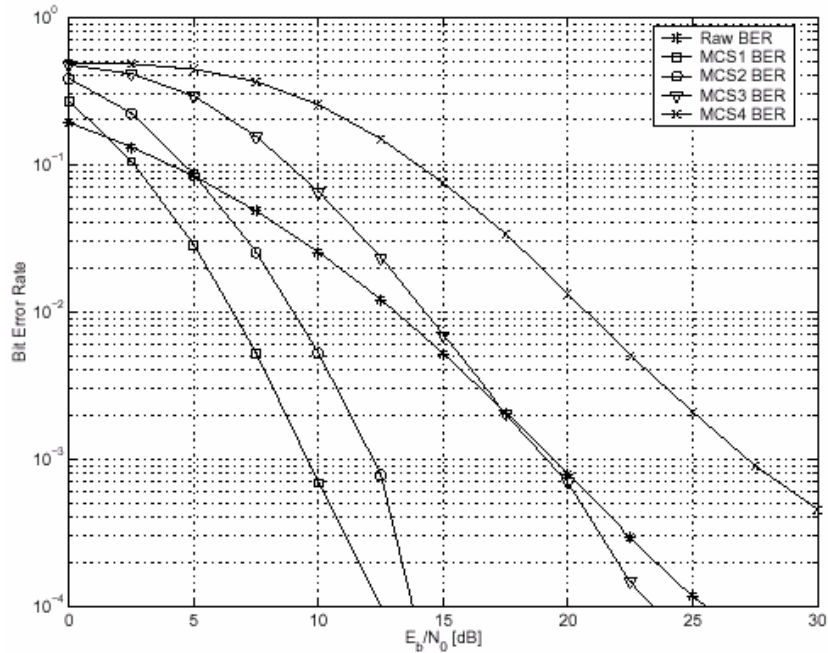


Figure 4-14 - Downlink Bit Error Rate (BER) for MCS-1 to MCS-4 (GMSK), TU50 ideal Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. [ET99a]

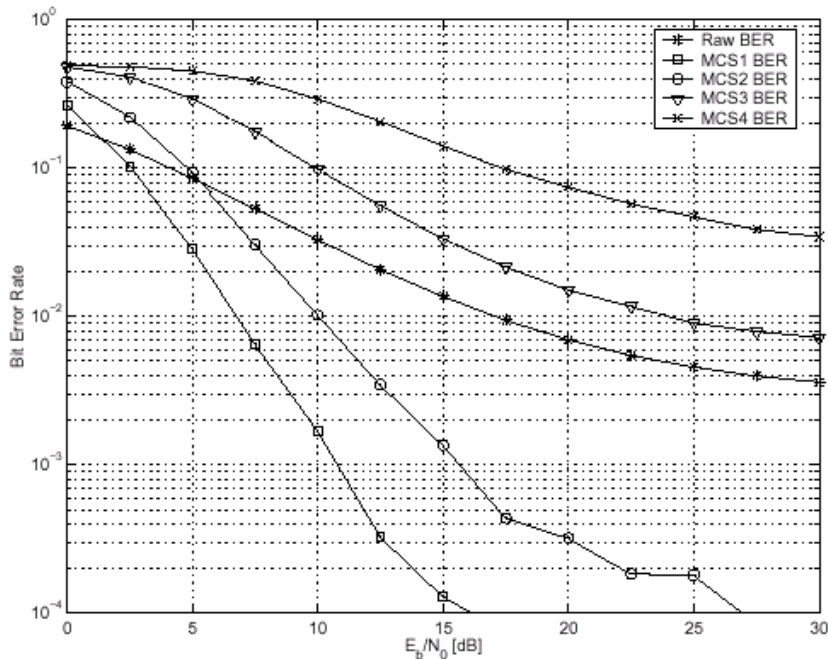


Figure 4-15 - Downlink Bit Error Rate (BER) for MCS-1 to MCS-4 (GMSK), RA250 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

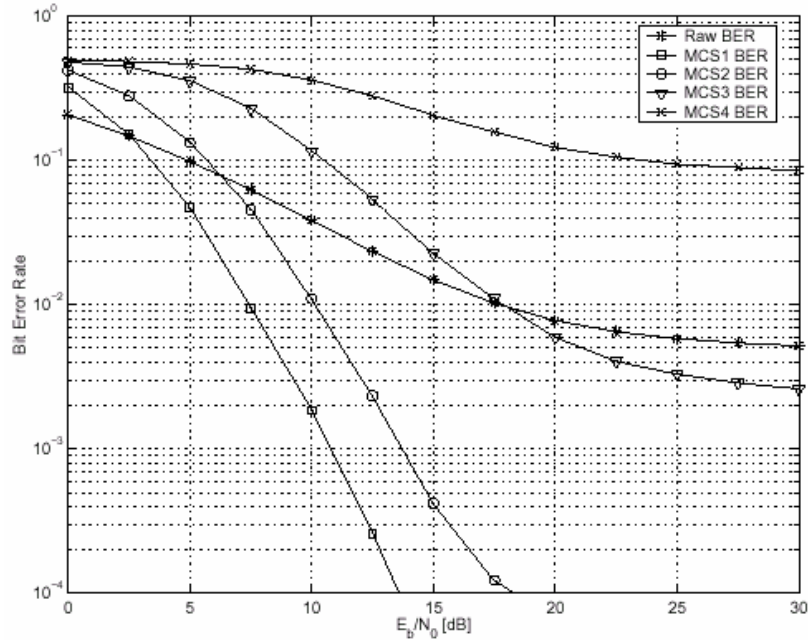


Figure 4-16 – Downlink Bit Error Rate (BER) for MCS-1 to MCS-4 (GMSK), HT100 no Frequency Hopping, no antenna diversity, 900 MHz. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

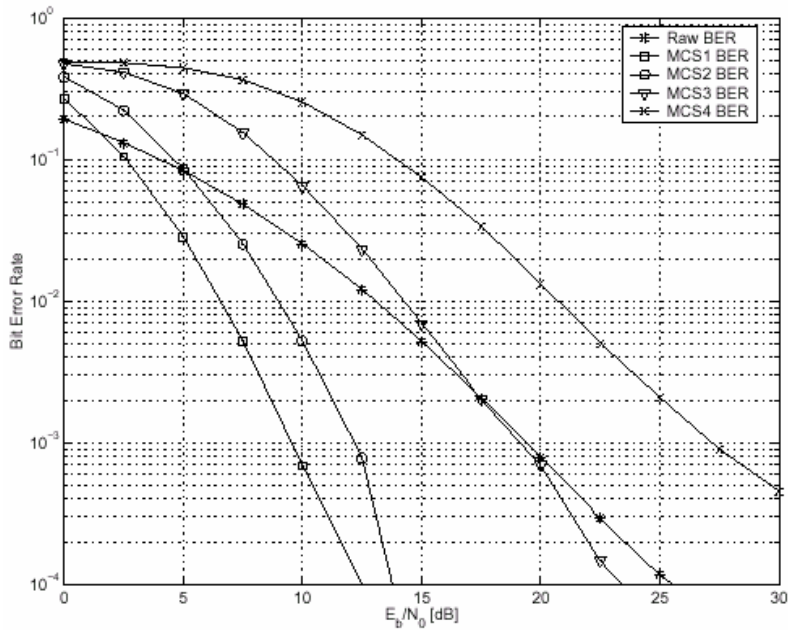


Figure 4-17 – Downlink Bit Error Rate (BER) for MCS-1 to MCS-4 (GMSK), TU50 ideal Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. [ET99a]

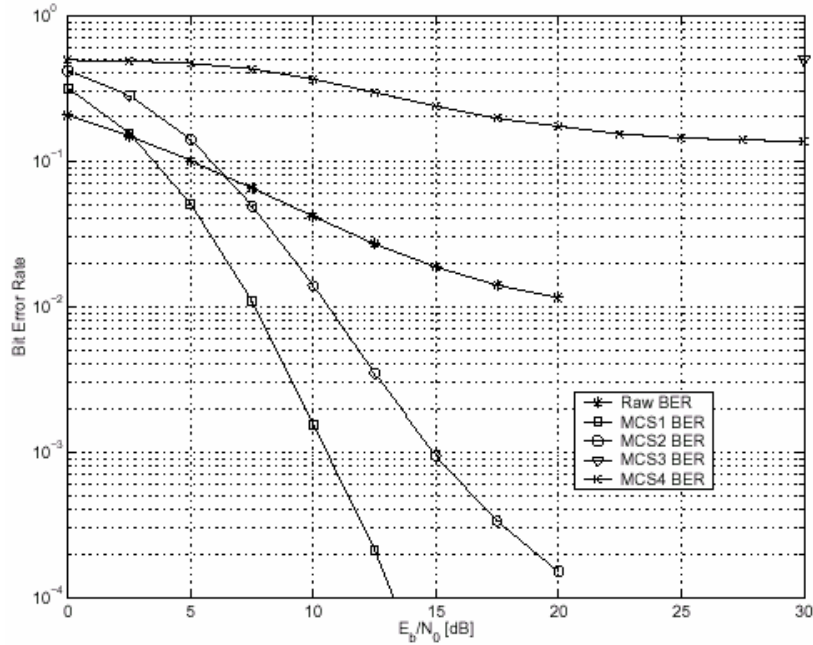


Figure 4-18 – Downlink Bit Error Rate (BER) for MCS1 to MCS-4 (GMSK), HT100 no Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

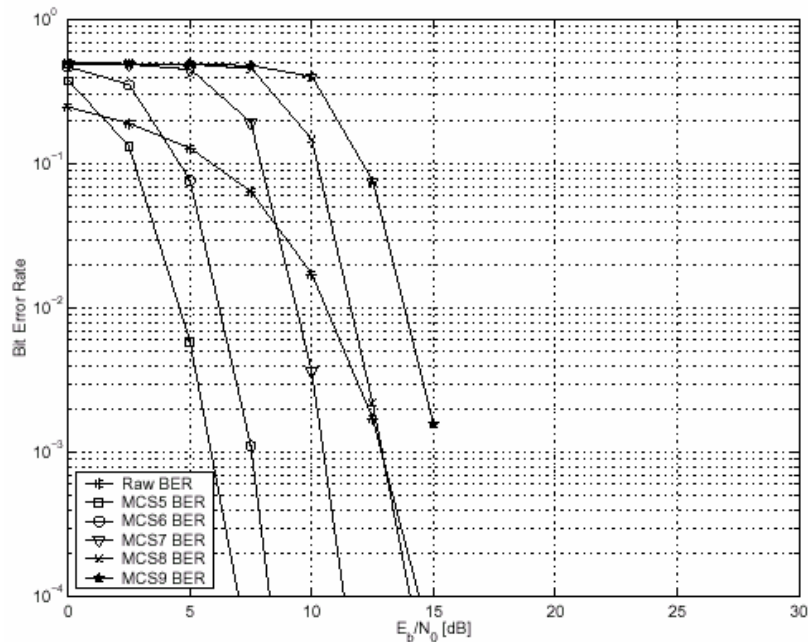


Figure 4-19 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), static AWGN channel, no Frequency Hopping, 900 MHz, no antenna diversity. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one time slot per frame. [ET99a]

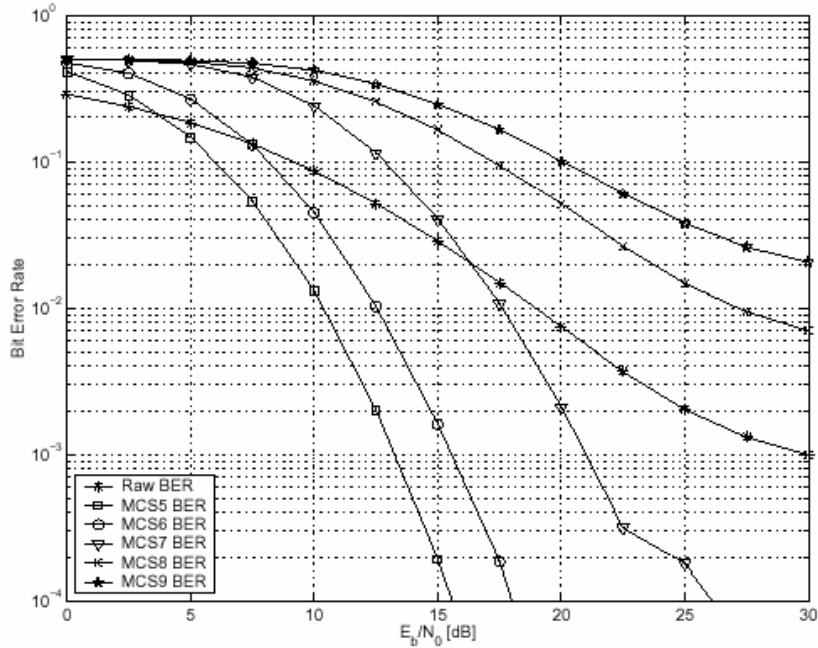


Figure 4-20 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), TU50 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one time slot per frame. [ET99a]

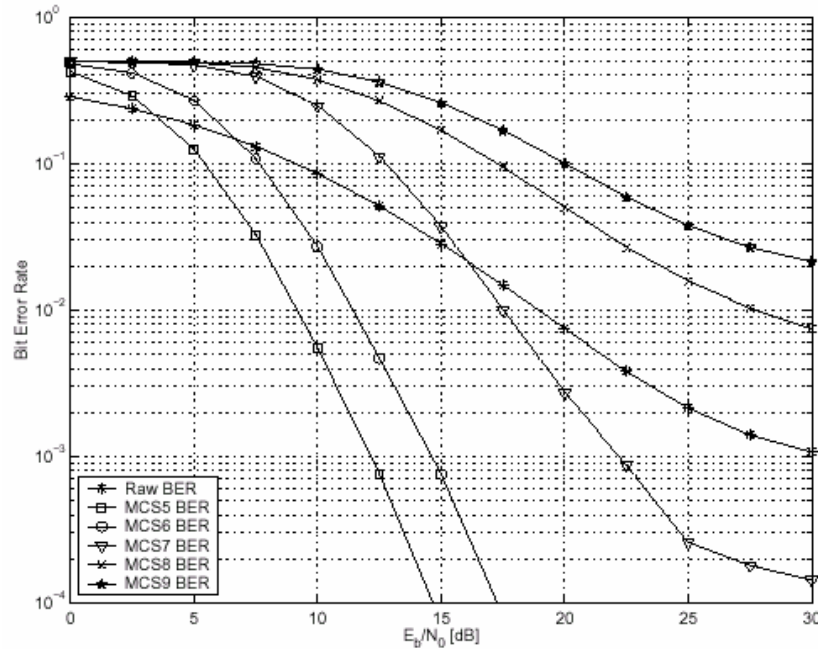


Figure 4-21 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), TU50 ideal Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. [ET99a]

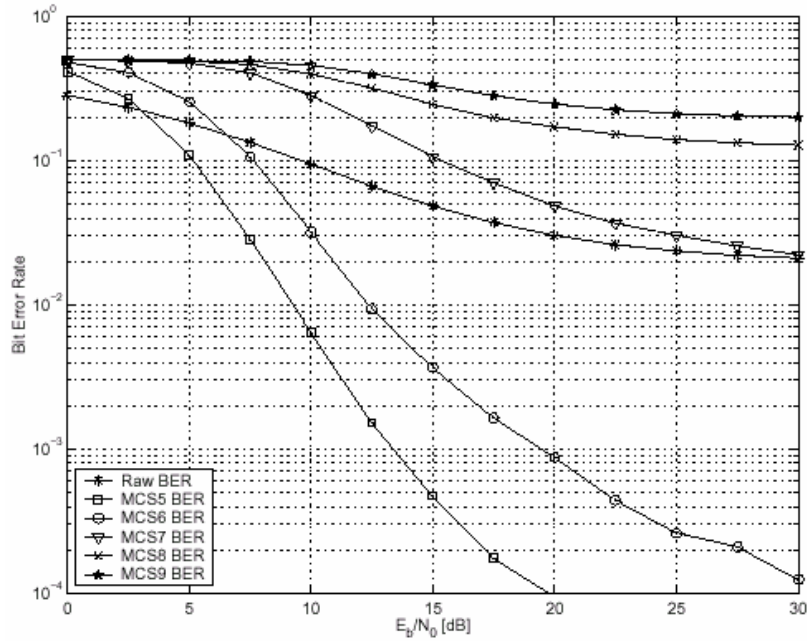


Figure 4-22 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), RA250 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one time slot per frame. [ET99a]

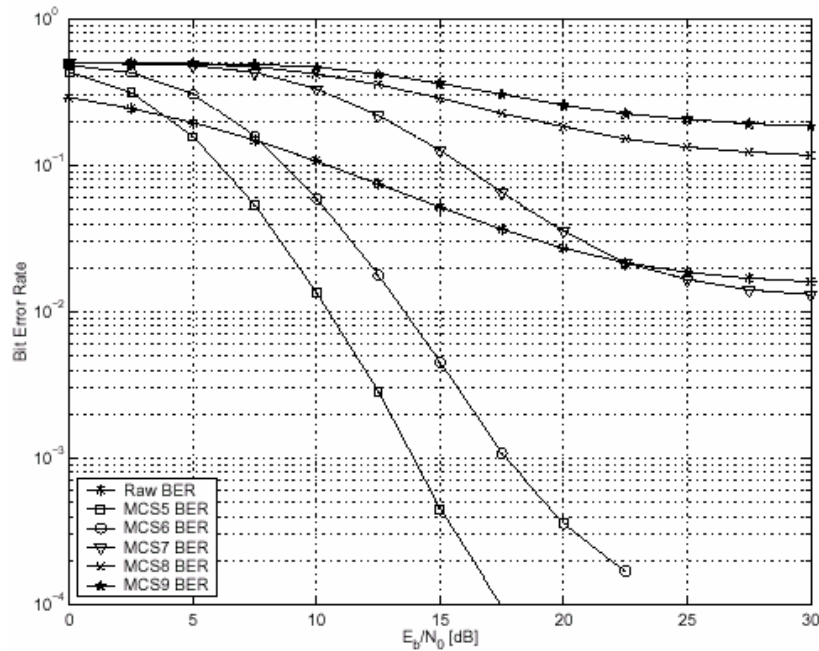


Figure 4-23 -Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), HT100 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one time slot per frame. [ET99a]

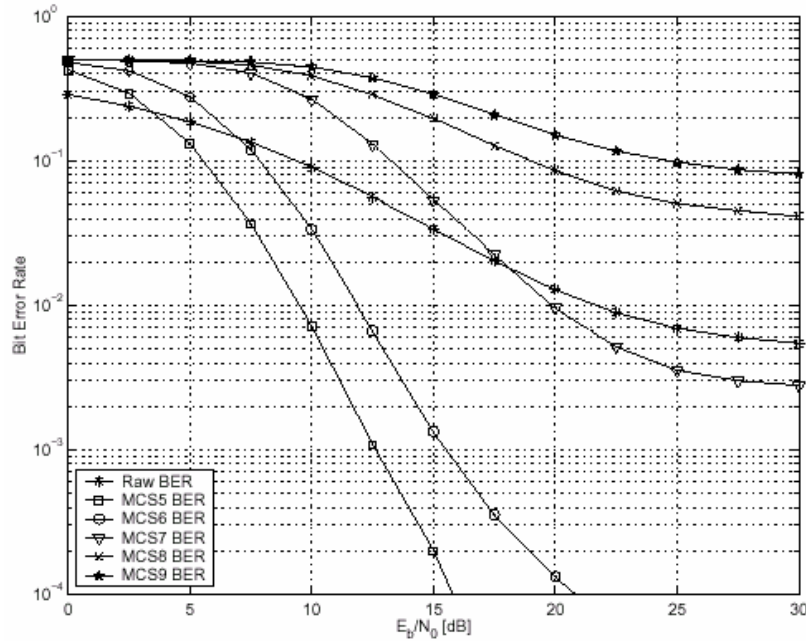


Figure 4-24 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), TU50 ideal Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. [ET99a]

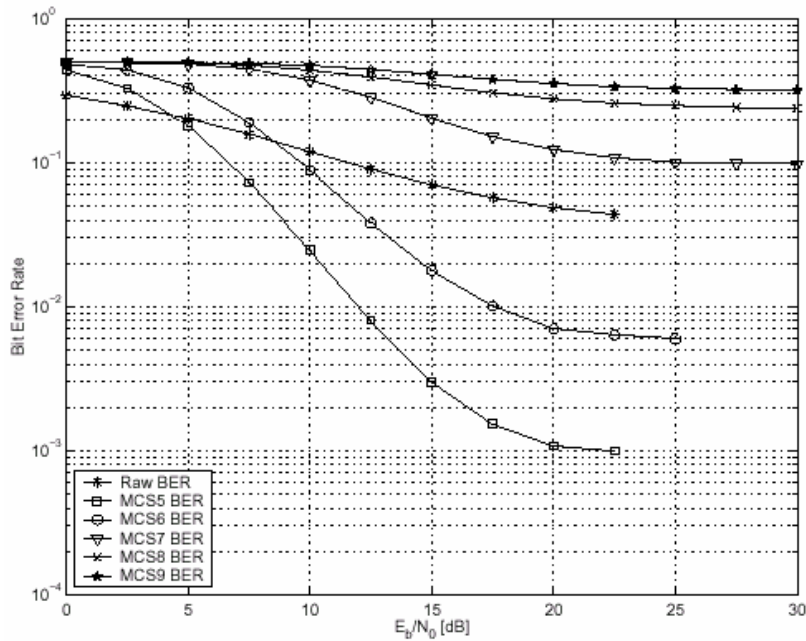


Figure 4-25 – Downlink Bit Error Rate (BER) for MCS-5 to MCS-9 (8PSK), TU50 ideal Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. [ET99a]

4.4.2.2 EDGE Bit Error Rate (BLER) Link Performance in Interference Limited Environments

The simulation results presented herein (Figures 4-26 thru 4-37) are the compilation of the contributions by Ericsson (Sweden) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Lucent Technologies (United States), Nortel Network (Canada) and Nokia (Finland) have been researched, but are not included in this document for they are aligned with the results presented by Ericsson. The contributions by Ericsson can be found in [ET99a]. Nokia's contributions are in [ET99b], Lucent's contributions are in [ET99c] and Nortel's contributions are in [ET99d].

Downlink Bit Error Rate (BER) versus C/I performance is presented for the propagation environments listed below. Uplink simulations have not been performed, for they are expected to yield equivalent results.

- Typical Urban @ 3 Km/h (TU3) no FH (900 MHz)
- Typical Urban @ 3 Km/h (TU3) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (1800 MHz)

The C/I simulation results presented in the subsequent pictures are based on the following assumptions [ET99a, ET99c]:

- Downlink, no reception diversity
- One source of co-channel interference, de-correlated in time and with 0 frequency offset
- One source of adjacent channel interference, de-correlated in time and with 200 KHz of frequency offset

- Ideal frequency hopping, when simulated. One time slot per frame when no hopping is used
- Automatic Frequency Offset Correction (AFC) applied for 8PSK modes. Not used for GMSK

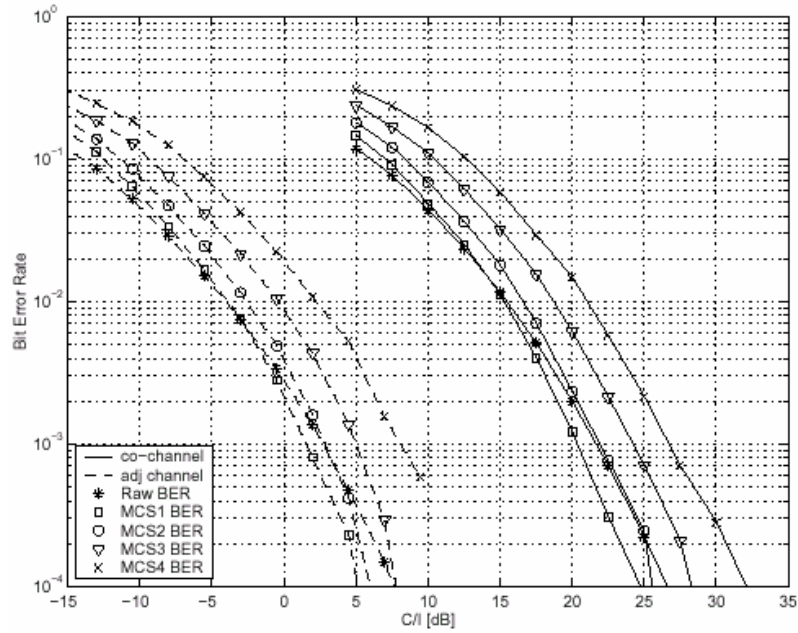


Figure 4-26 – Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU3 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst .One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

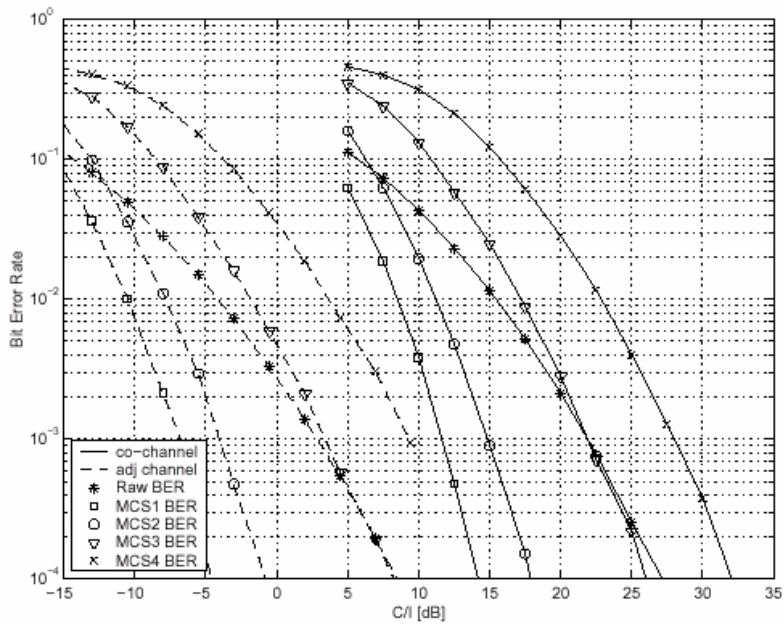


Figure 4-27 - Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU3 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst .One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

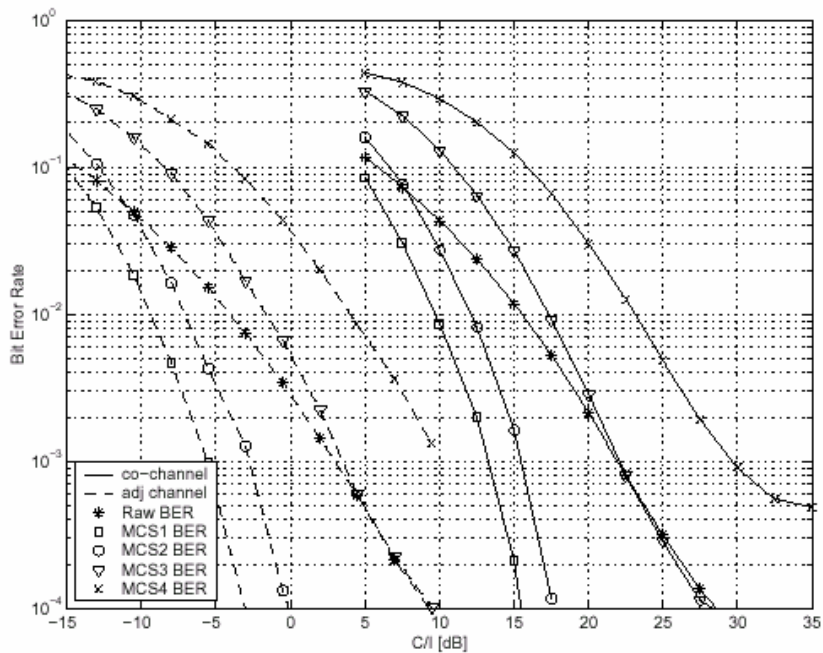


Figure 4-28 – Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst .One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

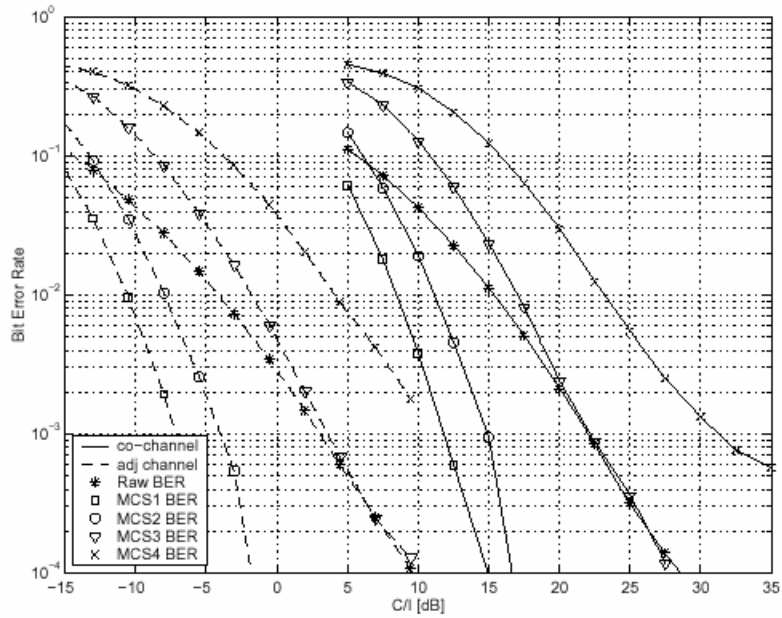


Figure 4-29 – Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

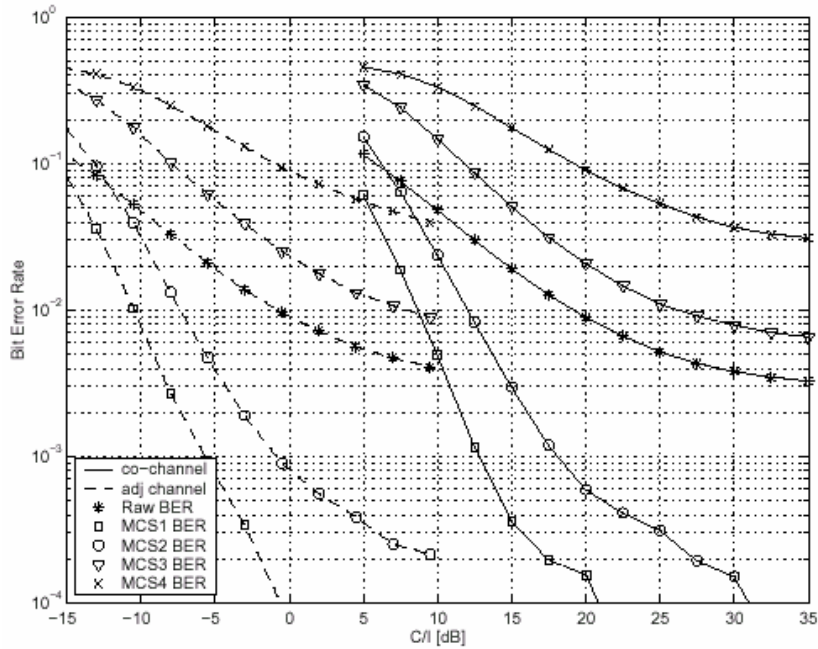


Figure 4-30 – Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), RA250 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

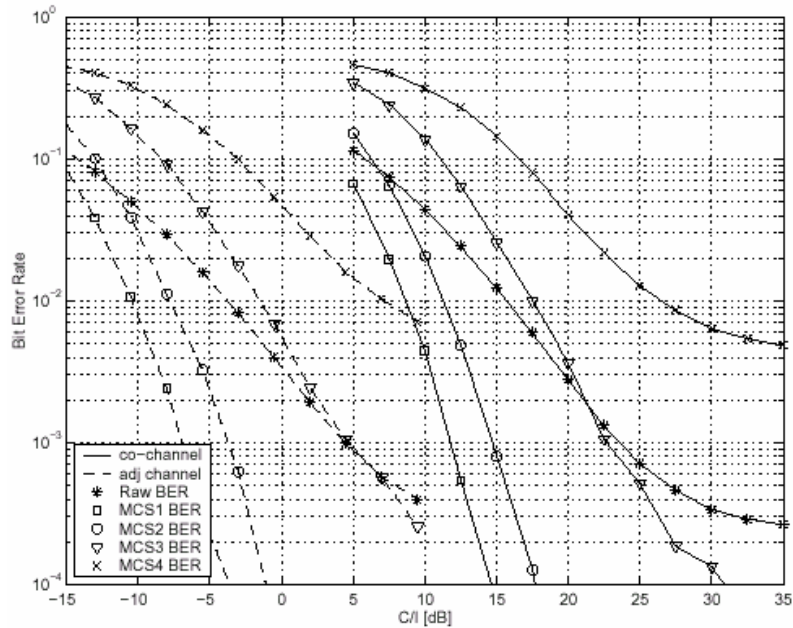


Figure 4-31 – Downlink Bit Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 ideal FH, 1800 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

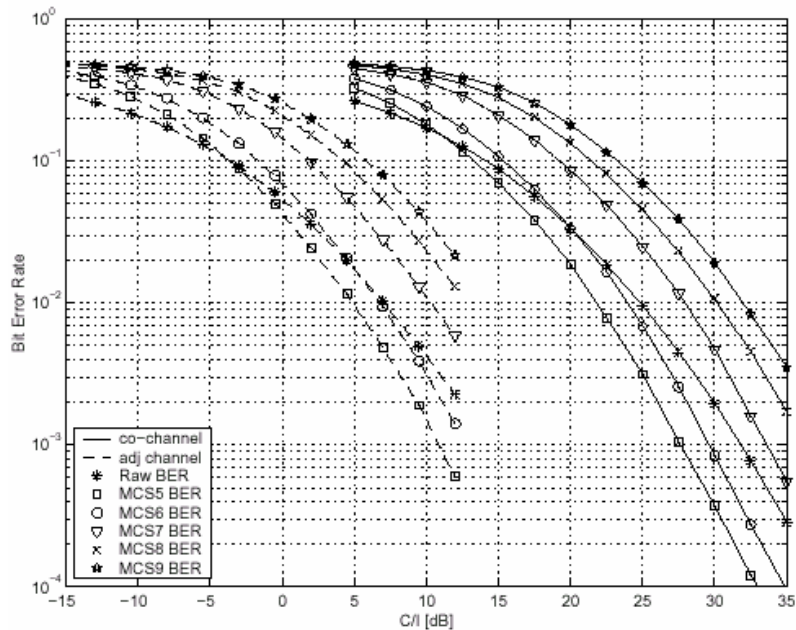


Figure 4-32 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU3 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

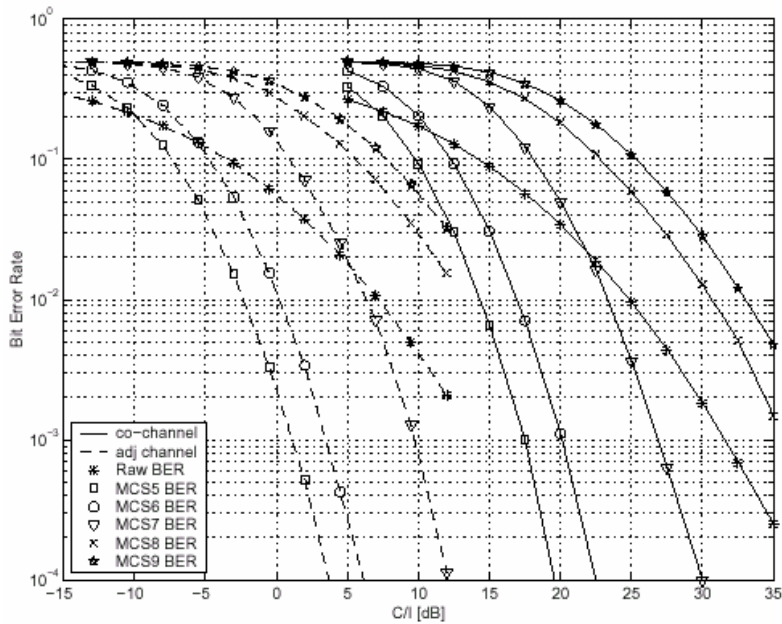


Figure 4-33 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU3 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

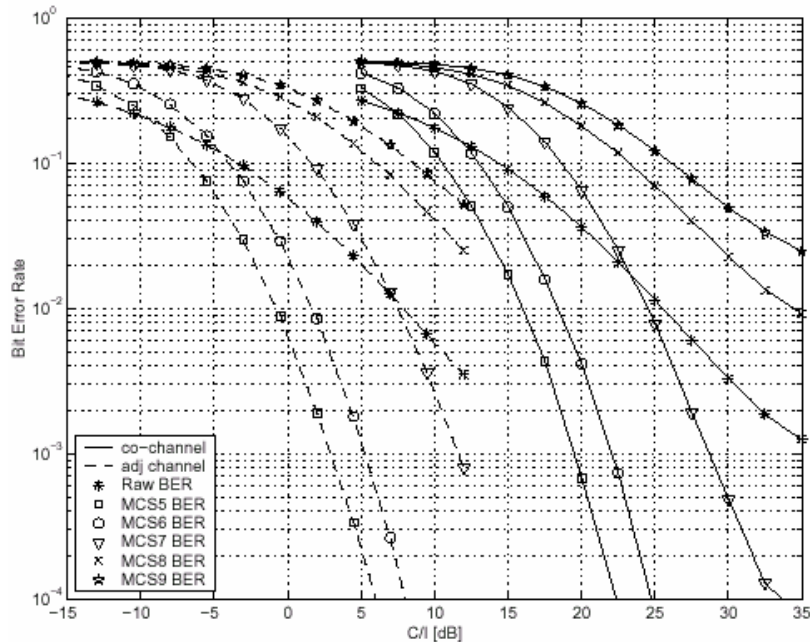


Figure 4-34 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

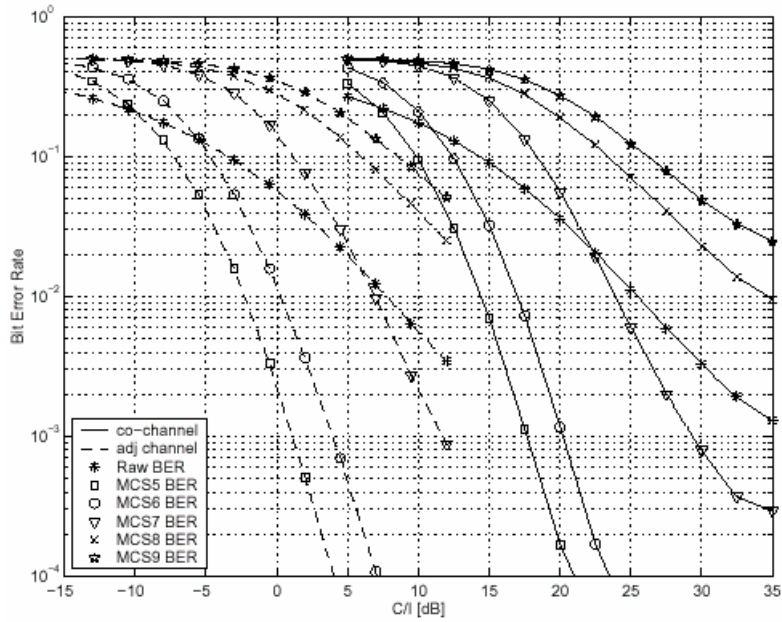


Figure 4-35 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

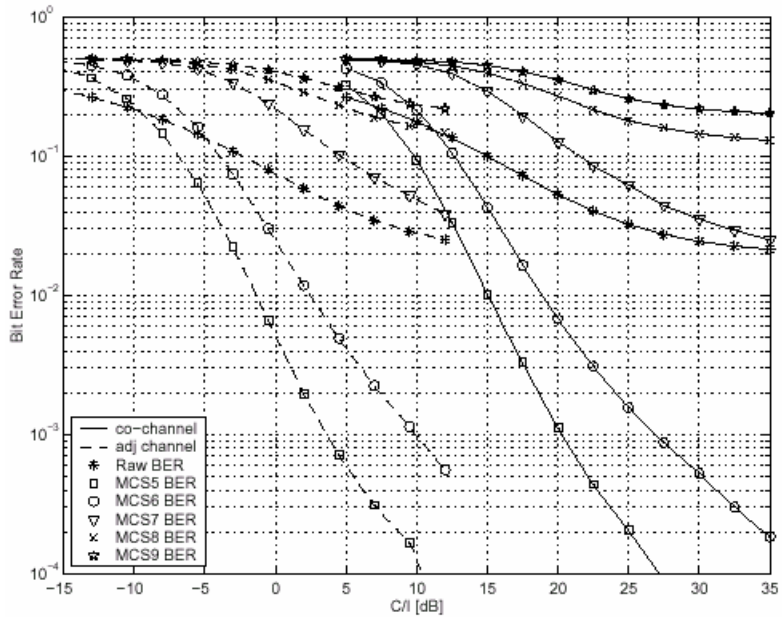


Figure 4-36 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), RA250 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. [ET99a]

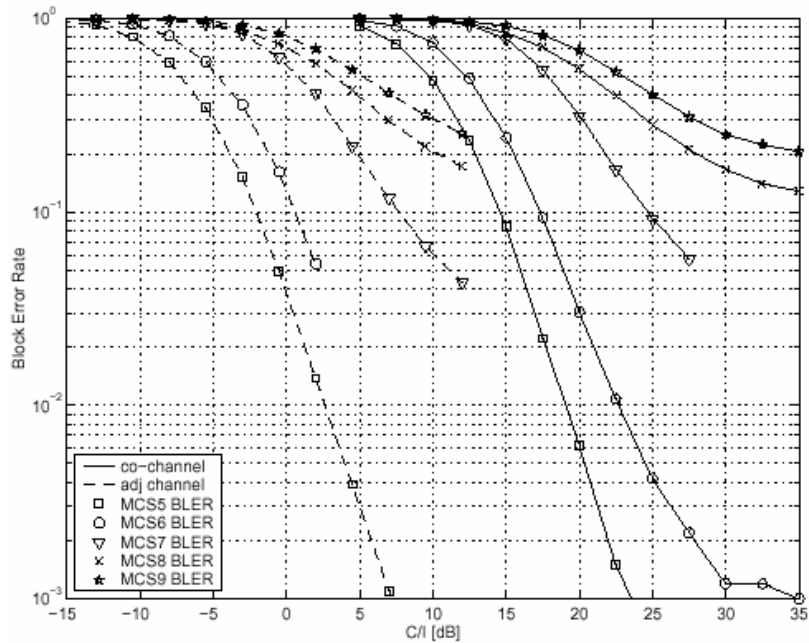


Figure 4-37 – Downlink Bit Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 ideal FH, 1800 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a]

4.4.3 EDGE Block Error Rate (BLER) Link Performance

4.4.3.1 EDGE Block Error Rate (BLER) Link Performance in Noise Limited Environments

The simulation results presented herein (Figures 4-38 thru 4-51) are the compilation of the contributions by Ericsson (Sweden) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Lucent Technologies (United States), Nortel Network (Canada) and Nokia (Finland) have been researched, but are not included in this document for they are aligned with the results presented by Ericsson. The contributions by Ericsson can be found in [ET99a]. Nokia’s contributions are in [ET99b], Lucent’s contributions are in [ET99c] and Nortel’s contributions are in [ET99d].

The Downlink Block Error Rate (BLER) versus E_b/N_0 curves presented in the subsequent figures result from EDGE (EGPRS) simulations in noise-limited environments. They assumed a block being counted as erroneous if at least one of the following errors occurred [ET99a, ET99b, and ET99c]:

- Bit error in data field after decoding (including CRC bits)
- Bit error in the header field after decoding (including CRC bits)
- Erroneous modulation format (blind detection error)
- Erroneous decoded stealing flag word

Uplink simulations have not been performed, for they are expected to yield equivalent results. The receiver did not use any a priori information about channel conditions or modulation. Curves are presented for the following propagation environments, for MCS-1 to MCS-4 (GMSK) and MCS-5 to MCS-9 (8PSK):

- Static channel (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (1800 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (1800 MHz)

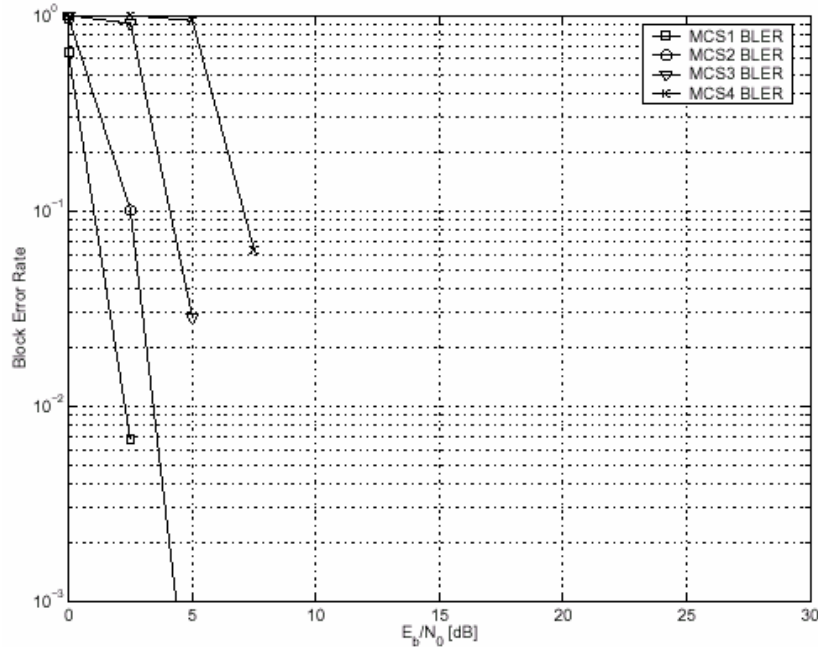


Figure 4-38 – Downlink Block Error Rate (BLER) for MCS1-to MCS4 (GMSK), static AWGN channel, 900 MHz, no frequency hopping, no antenna diversity. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one slot per time frame. [ET99a].

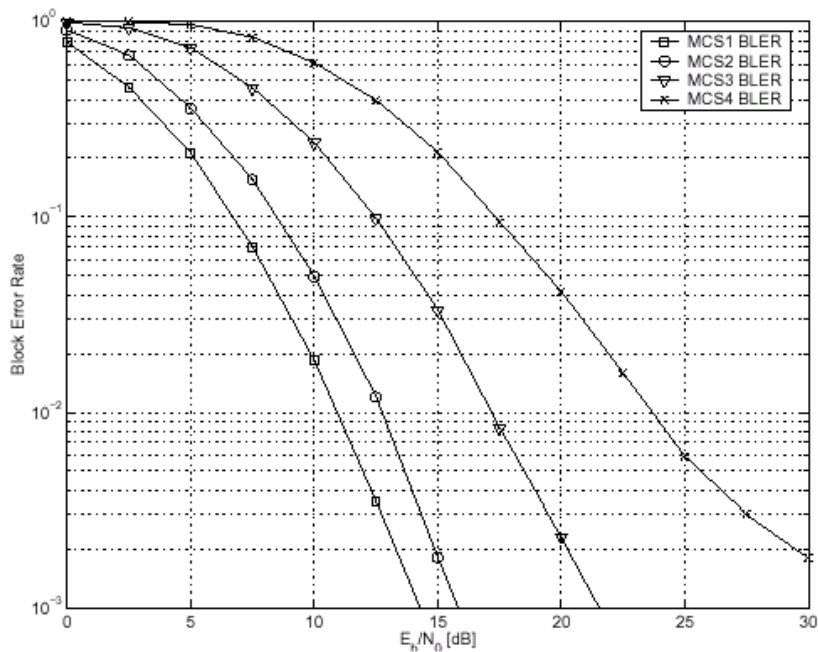


Figure 4-39 – Downlink Block Error Rate (BLER) for MCS-1 to MCS-4 (GMSK), TU50 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

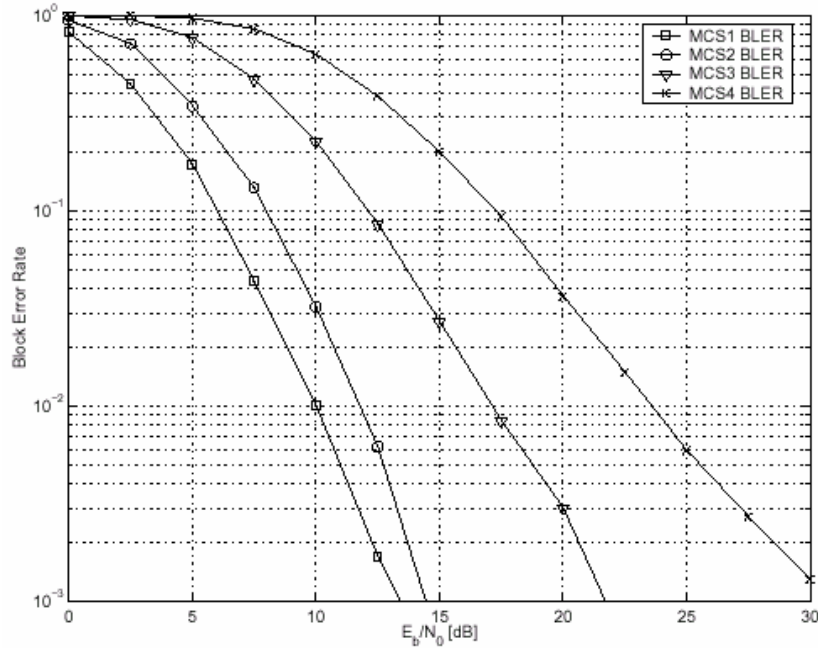


Figure 4-40 – Downlink Block Error Rate (BLER) for MCS-1 to MCS-4 (GMSK), TU50 ideal Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. [ET99a]

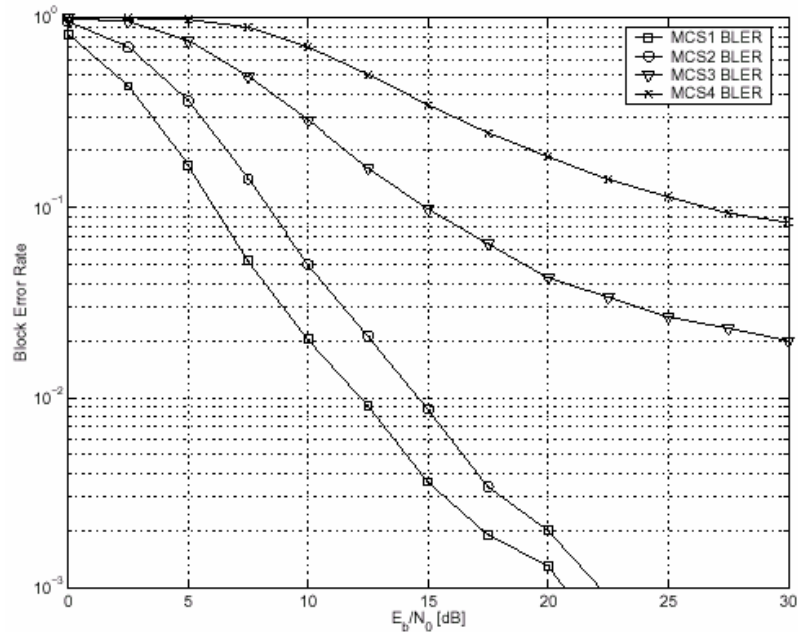


Figure 4-41 – Downlink Block Error Rate (BLER) for MCS-1 to MCS-4 (GMSK), RA250 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

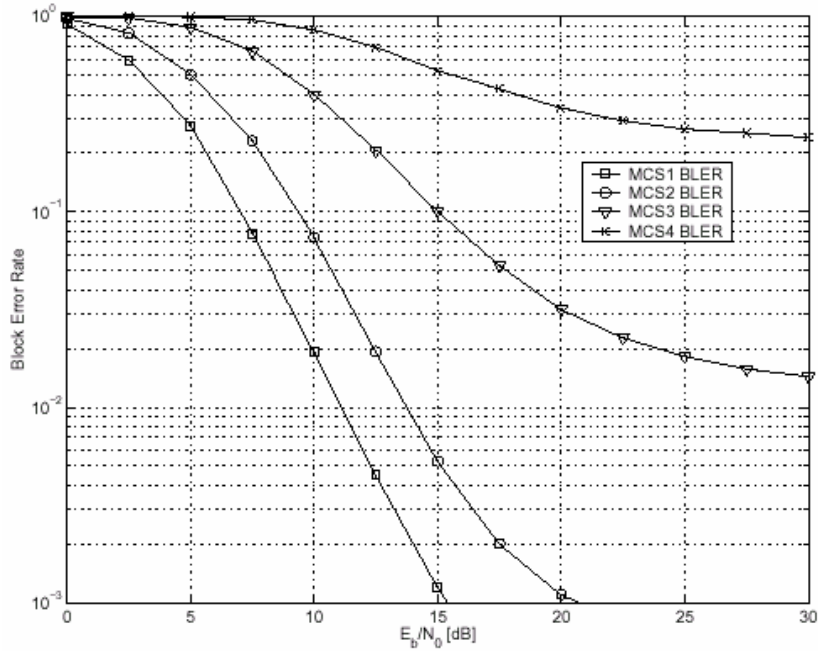


Figure 4-42 – Downlink Block Error Rate (BLER) for MCS-1 to MCS-4 (GMSK), HT100 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

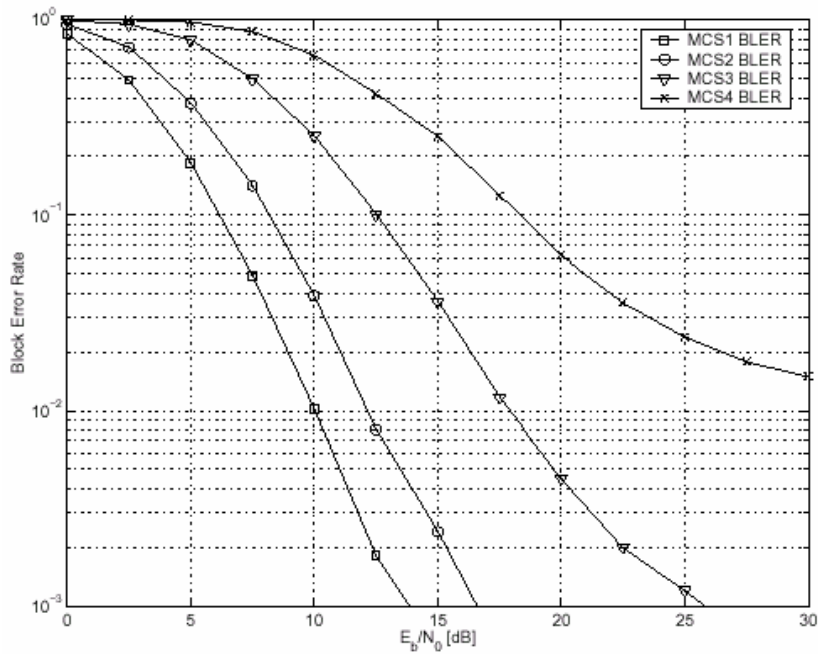


Figure 4-43 – Downlink Block Error Rate for MCS-1 to MCS-4 (GMSK), TU50 ideal Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. [ET99a]

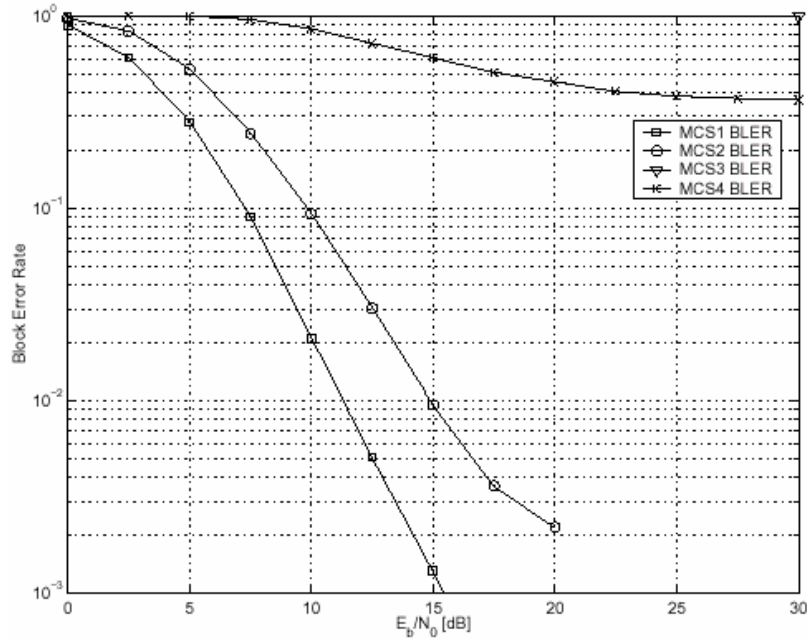


Figure 4-44 – Downlink Block Error Rate (BLER) for MCS-1 to MCS-4 (GMSK), HT100 no Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst Automatic Frequency Control (AFC) not applied. Interleaving over four data blocks. Measurements for one time slot per frame. [ET99a]

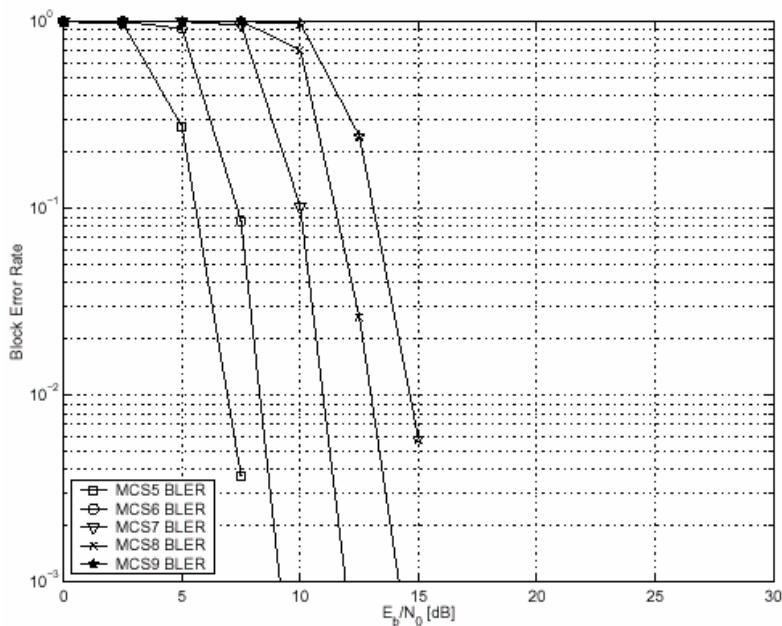


Figure 4-45 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), static AWGN channel, 900 MHz, no antenna diversity. Varying fading occurring during one burst Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one time slot per frame. [ET99a]

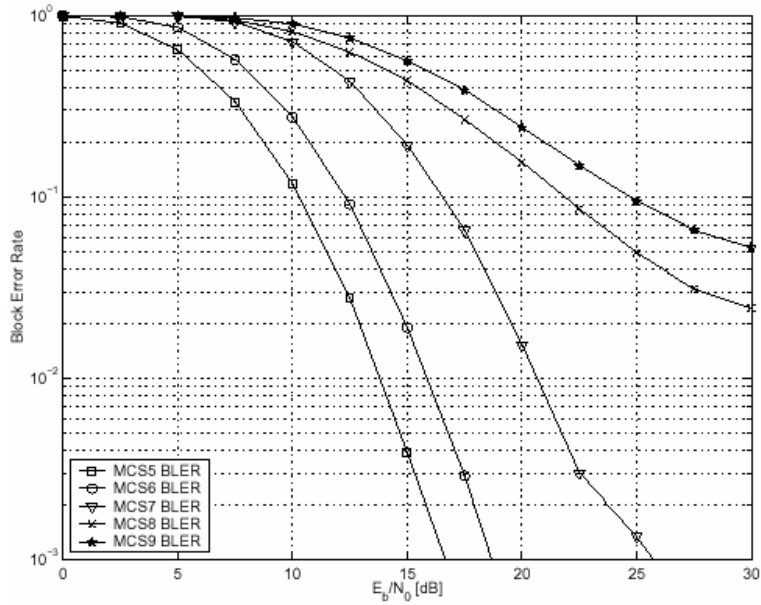


Figure 4-46 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), TU50 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one slot per time frame. [ET99a]

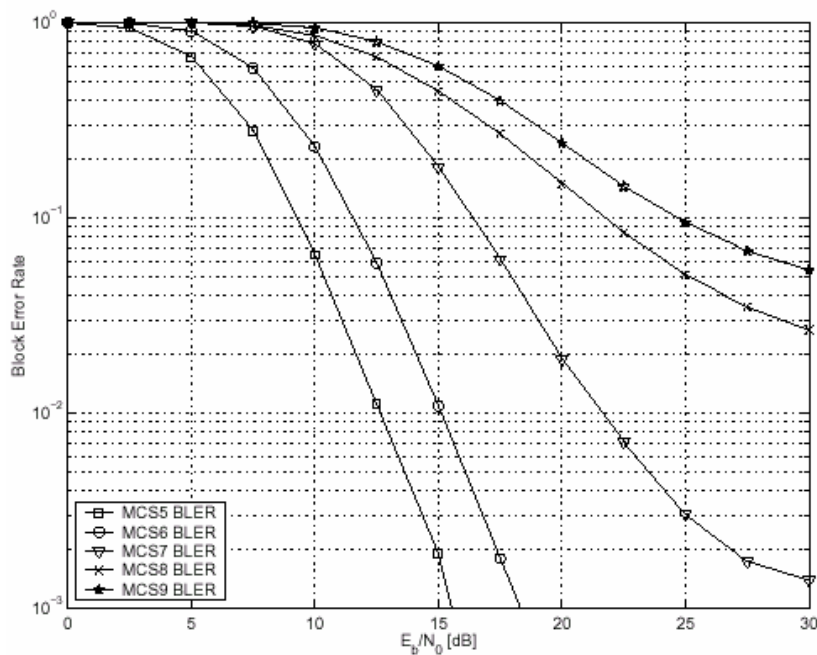


Figure 4-47 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), TU50 ideal Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. [ET99a]

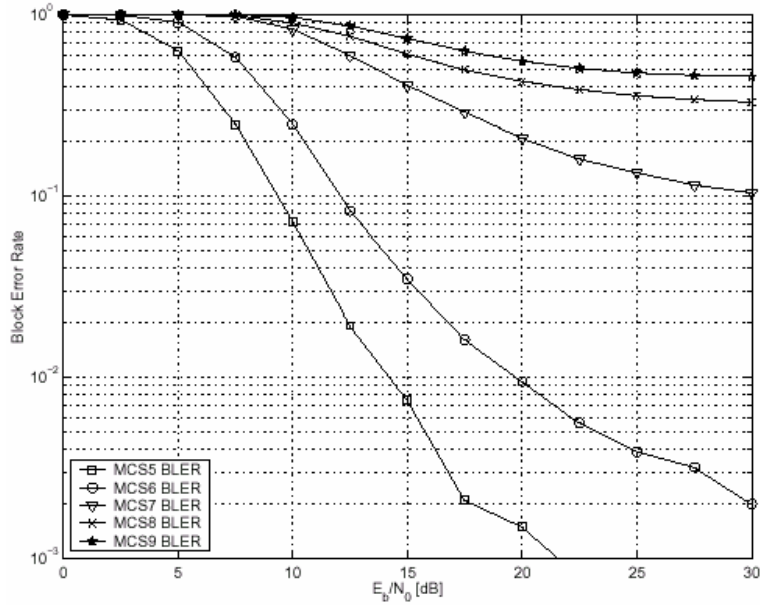


Figure 4-48 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), RA250 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one slot per time frame. [ET99a]

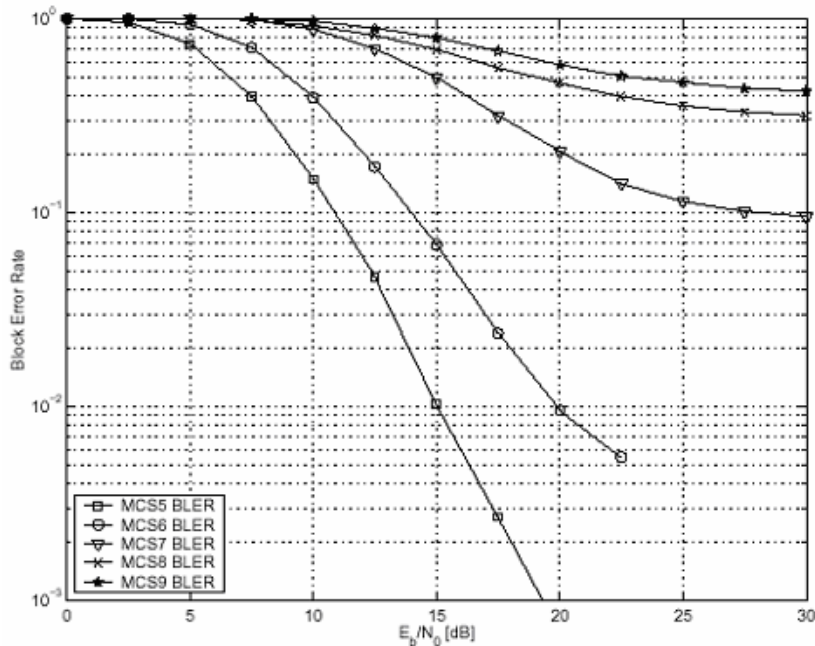


Figure 4-49 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), HT100 no Frequency Hopping, 900 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one slot per time frame. [ET99a]

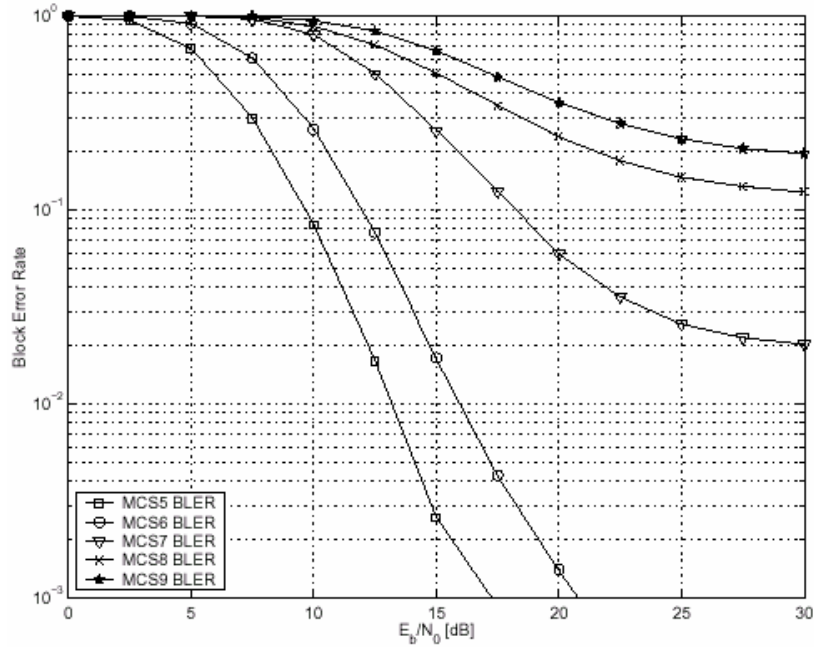


Figure 4-50 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), TU50 ideal Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. [ET99a]

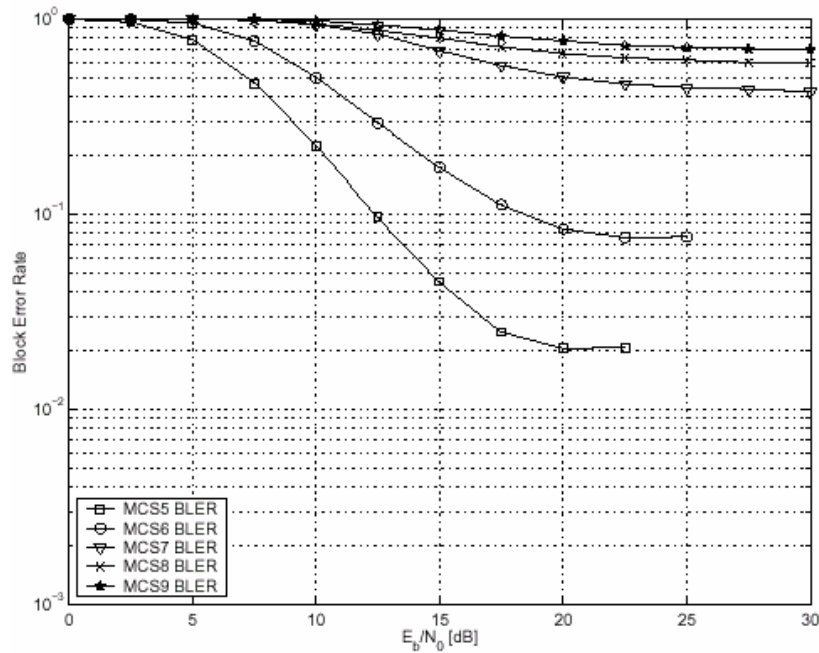


Figure 4-51 – Downlink Block Error Rate (BLER) for MCS-5 to MCS-9 (8PSK), HT100 no Frequency Hopping, 1800 MHz, no antenna diversity. Varying fading occurring during one burst. Ideal Automatic Frequency Control (AFC) assumed. Interleaving over two data blocks. Measurements for one slot per time frame. [ET99a]

4.4.3.2 EDGE Block Error Rate (BLER) Link Performance in Interference Limited Environments

The simulation results presented herein (Figures 4-38 thru 4-51) are the compilation of the contributions by Ericsson (Sweden) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Lucent Technologies (United States), Nortel Network (Canada) and Nokia (Finland) have been researched, but are not included in this document for they are aligned with the results presented by Ericsson. The contributions by Ericsson can be found in [ET99a]. Nokia's contributions are in [ET99b], Lucent's contributions are in [ET99c] and Nortel's contributions are in [ET99d].

The Downlink Bit Error Rate (BLER) versus C/I curves presented in the subsequent figures result from EDGE (EGPRS) simulations in interference-limited environments. They assumed a block being counted as erroneous if at least one of the following errors occurred [ET99a, ET99b, and ET99c]:

- Bit error in data field after decoding (including CRC bits)
- Bit error in the header field after decoding (including CRC bits)
- Erroneous modulation format (blind detection error)
- Erroneous decoded stealing flag word

Uplink simulations have not been performed, for they are expected to yield equivalent results. The receiver did not use any a priori information about channel conditions or modulation. Curves are presented for the following propagation environments, for MCS-1 to MCS-4 (GMSK) and MCS-5 to MCS-9 (8PSK): BLER versus C/I performance is presented for the propagation environments listed below [ET99a]:

- Typical Urban @ 3 Km/h (TU3) no FH (900 MHz)
- Typical Urban @ 3 Km/h (TU3) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)

- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (1800 MHz)

The C/I simulation results presented in the subsequent pictures are based on the following assumptions [ET99a, ET99c]:

- Downlink, no reception diversity
- One source of co-channel interference, de-correlated in time and with 0 frequency offset
- One source of adjacent channel interference, de-correlated in time and with 200 KHz of frequency offset
- Ideal frequency hopping, when simulated. One time slot per frame when no hopping is used
- Automatic Frequency Offset Correction (AFC) based on burst-by-burst estimation.
- P1 puncturing only

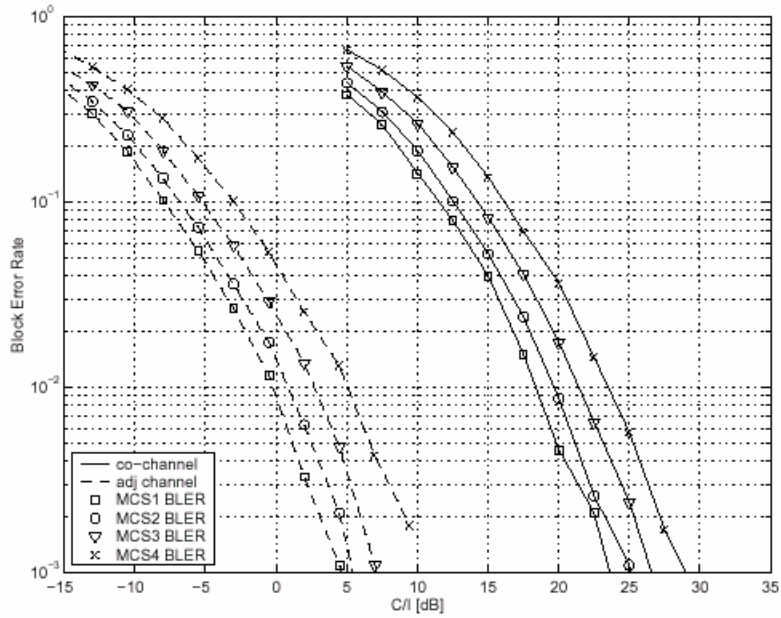


Figure 4-52 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU3 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame [ET99a].

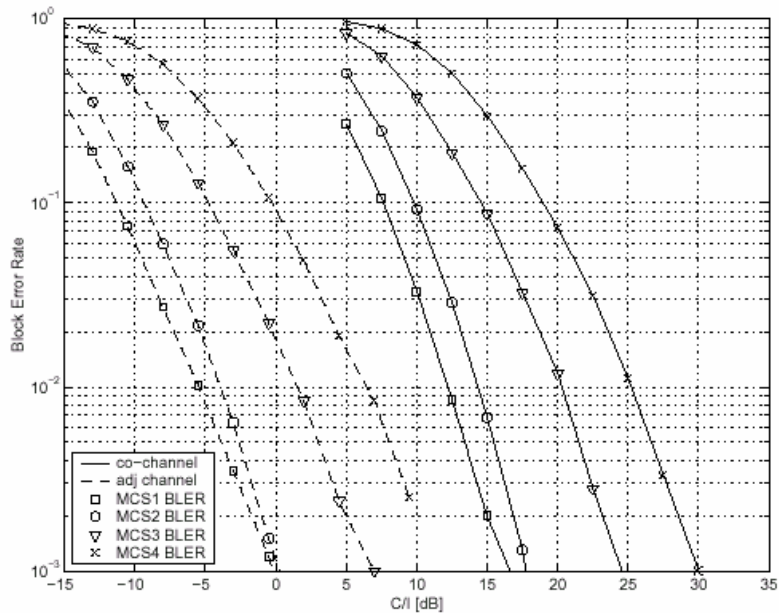


Figure 4-53 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU3 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a].

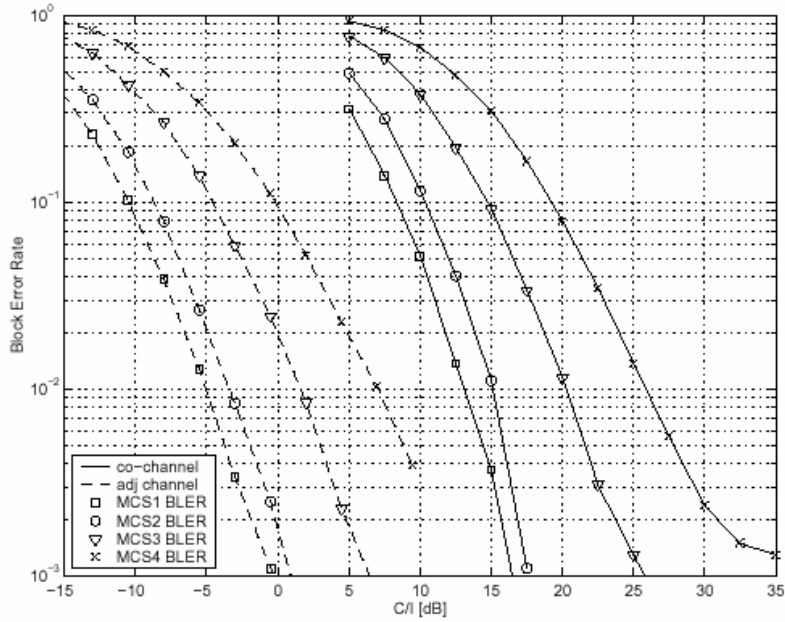


Figure 4-54 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame [ET99a].

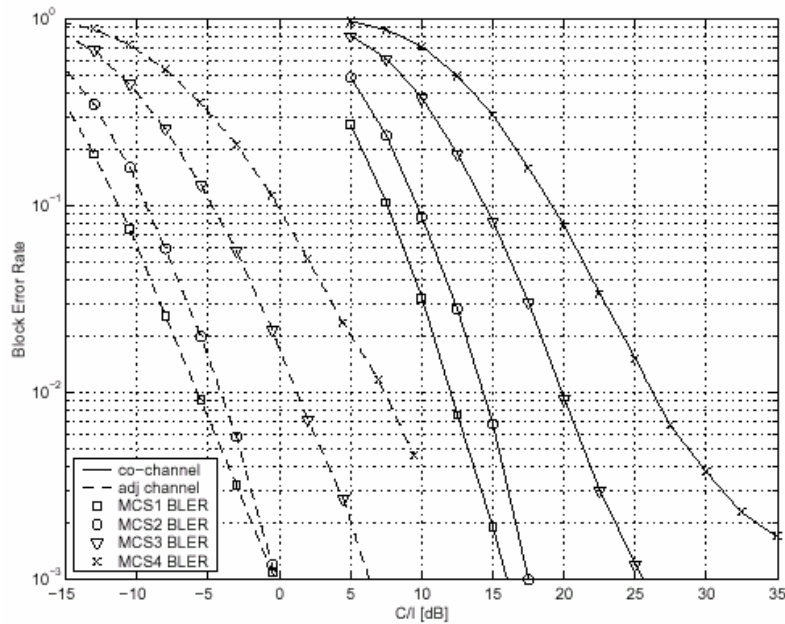


Figure 4-55 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a].

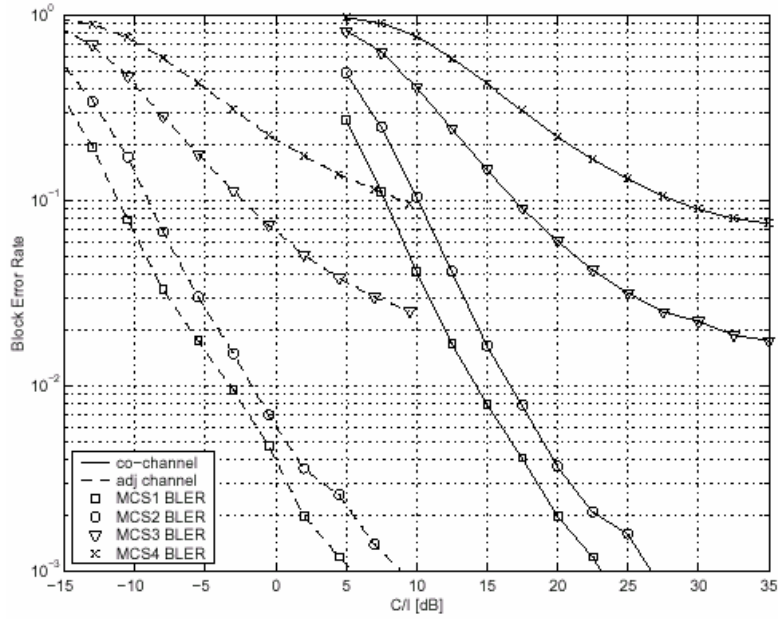


Figure 4-56 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), RA250 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame [ET99a].

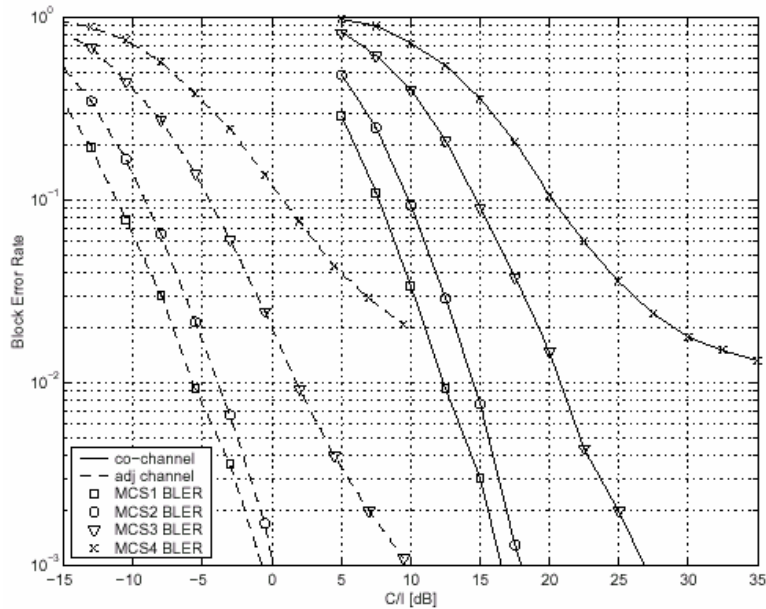


Figure 4-57 – Downlink Block Error Rate versus C/I for MCS-1 to MCS-4 (GMSK), TU50 ideal FH, 1800 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. [ET99a].

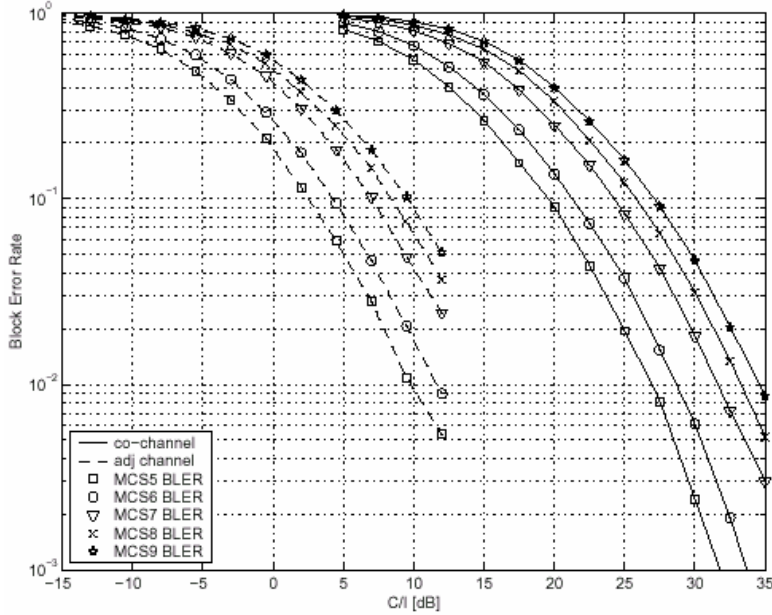


Figure 4-58 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU3 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

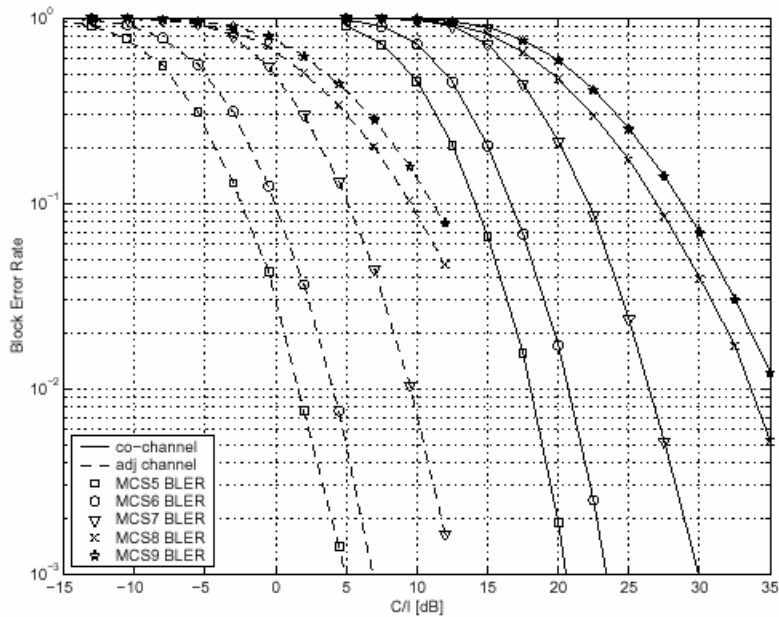


Figure 4-59 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU3 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

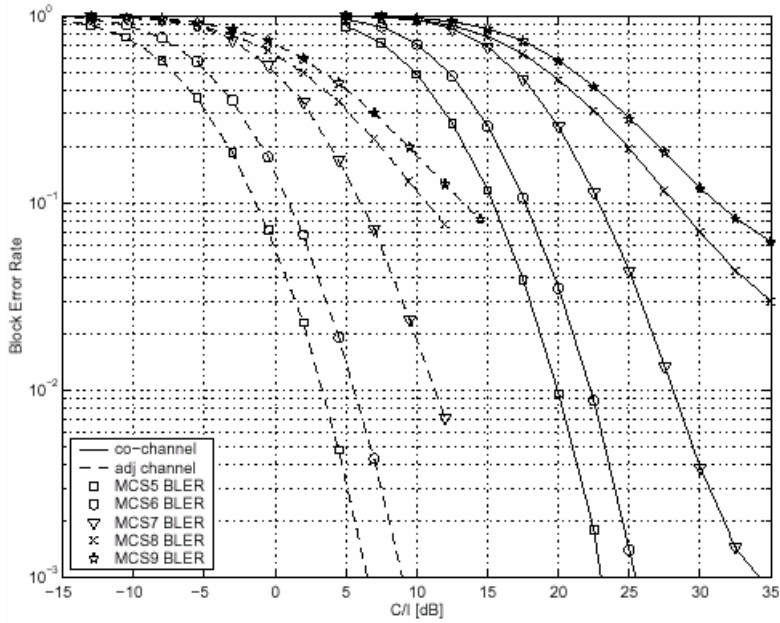


Figure 4-60 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

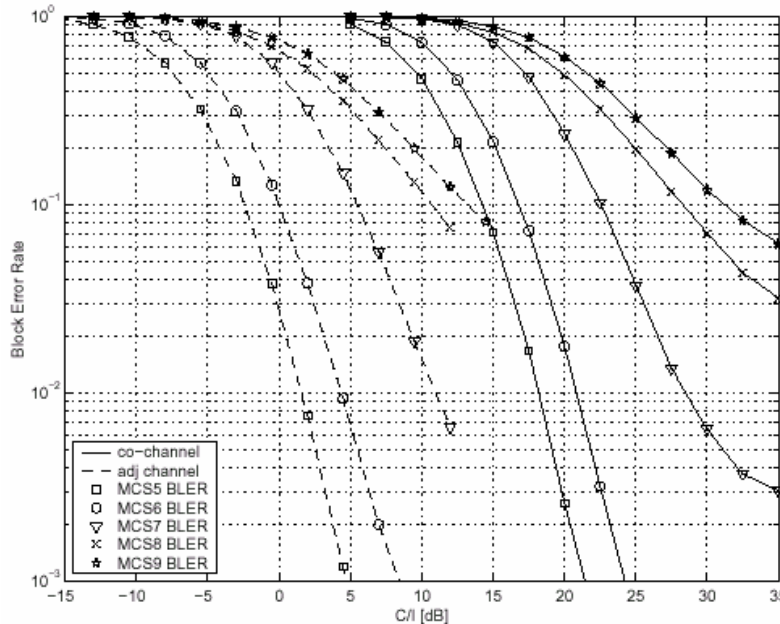


Figure 4-61 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 ideal FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

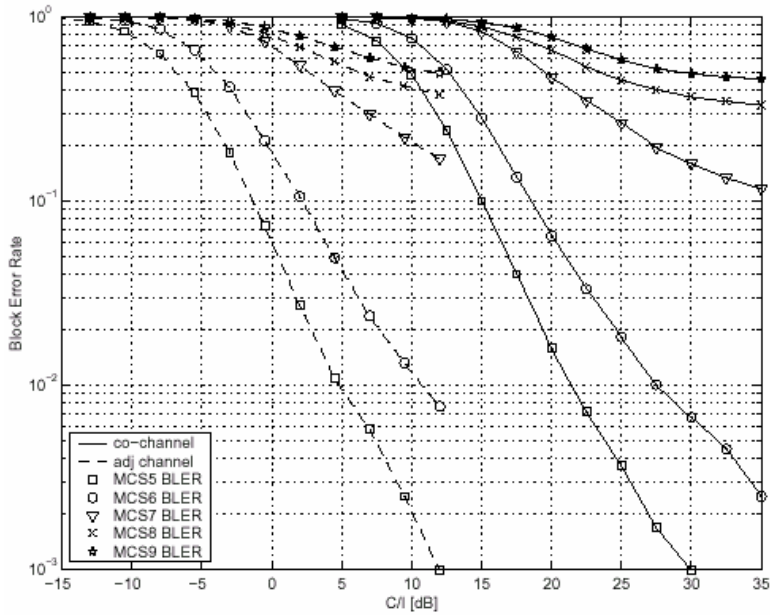


Figure 4-62 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), RA250 no FH, 900 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

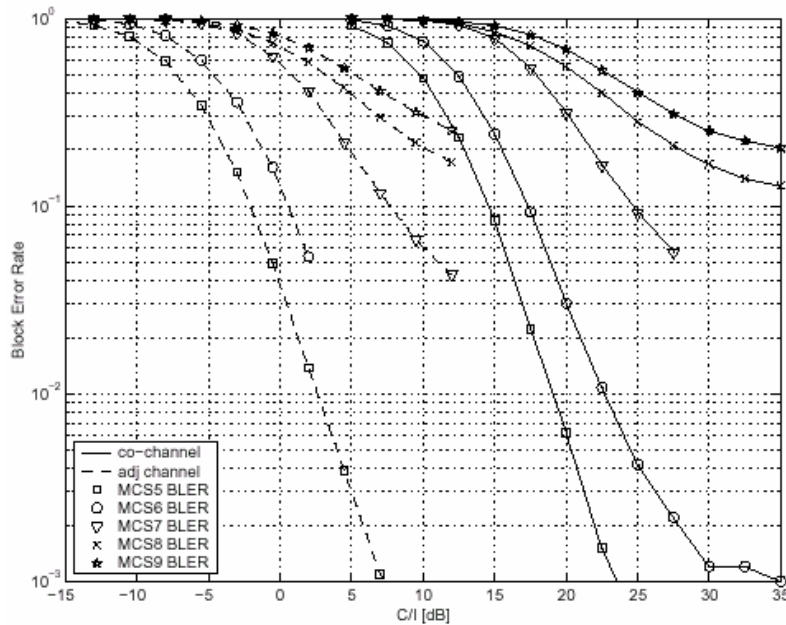


Figure 4-63 – Downlink Block Error Rate versus C/I for MCS-5 to MCS-9 (GMSK), TU50 ideal FH, 1800 MHz, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99a].

4.4.4 EDGE Link Performance with Receiver Impairments

The EDGE performance can be affected by implementation impairments that limit the receiver's ability to decode the signal. Examples of such sources of error are the phase noise of synthesizers, drifts in the I/Q demodulator and local oscillator frequency offsets [ET99a]. The 8PSK modulation used in MCS-5 to MCS-9 is particularly sensitive to these impairments, since it carries information on both the amplitude and phase components. Error Vector Magnitude (EVM) is commonly used as a figure of merit of the 8PSK modulation accuracy, representing the "distance" between the measured and ideal modulated signals [Pin00].

4.4.4.1 Error Vector Magnitude (EVM)

An 8PSK signal is defined by its magnitude and phase, as illustrated in Figure 4-64. The error vector represents the difference between the measured signal (the received signal) and a reference (the transmitted signal). EVM corresponds to the magnitude of the error vector. The magnitude and phase difference between the measured and the reference signals are also usually measured. The EVM can be expressed by equation [1], whereas the magnitude and phase errors are defined as in equations [2] and [3], respectively. I_{MEAS} and Q_{MEAS} are the quadrature components of the measured signal; I_{REF} and Q_{REF} are the quadrature components of the reference signals. Such variables are usually expressed in terms of their root-mean-square (RMS) values, with EVM and magnitude error being expressed in percentage and normalized to the reference signal magnitude. Figure 4-64 illustrates the above quantities [Pin00].

$$EVM = \sqrt{(I_{MEAS} - I_{REF})^2 + (Q_{MEAS} - Q_{REF})^2} \quad [1]$$

$$MagnitudeError = \sqrt{I_{MEAS}^2 + Q_{MEAS}^2} - \sqrt{I_{REF}^2 + Q_{REF}^2} \quad [2]$$

$$PhaseError = \arctan \frac{Q_{MEAS}}{I_{MEAS}} - \arctan \frac{Q_{REF}}{I_{REF}} \quad [3]$$

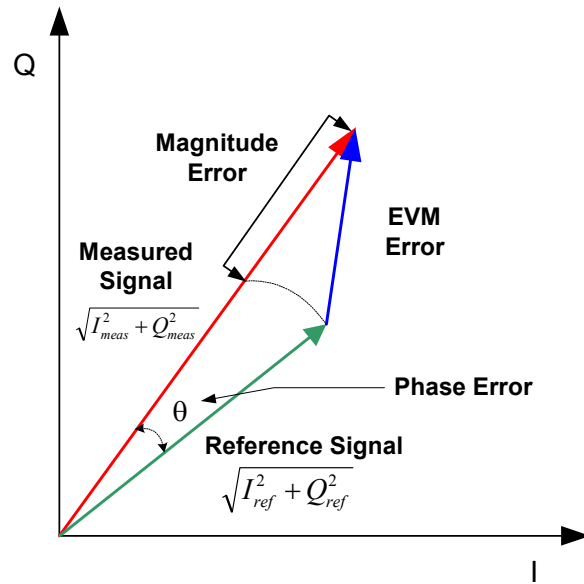


Figure 4-64 - Definition of Error Vector Magnitude (EVM), Magnitude Error and Phase Error [Pin00].

4.4.4.2 EDGE Block Error Rate (BLER) Link Performance in Noise Limited Environments with EVM and Frequency Offset

The simulation results presented herein (Figures 4-65 thru 4-77) are the compilation of the contributions by Nokia (Finland) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Ericsson (Sweden), Lucent Technologies (United States) and Nortel Network (Canada) have been researched, but are not included in this document for they are aligned with the results presented by Nokia. The contributions by Nokia can be found in [ET99b]. Ericsson's contributions are in [ET99a], Lucent's contributions are in [ET99c] and Nortel's contributions are in [ET99d].

The following curves show the Downlink Block Error Rate (BLER) versus E_b/N_0 performance of EDGE (EGPRS) in noise-limited environments. The impairments are 3.1% of EVM and +100 Hz of frequency offset for 900 MHz/ +200 Hz for 1800 MHz [ET99c]. The order of magnitude of the simulated impairments corresponds to that of real links. Uplink simulations have not been performed, for they are expected to yield equivalent results. The simulated environments are:

- Static channel (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) ideal FH (1800 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (900 MHz)
- Hilly Terrain @ 100 Km/h (HT100) no FH (1800 MHz)

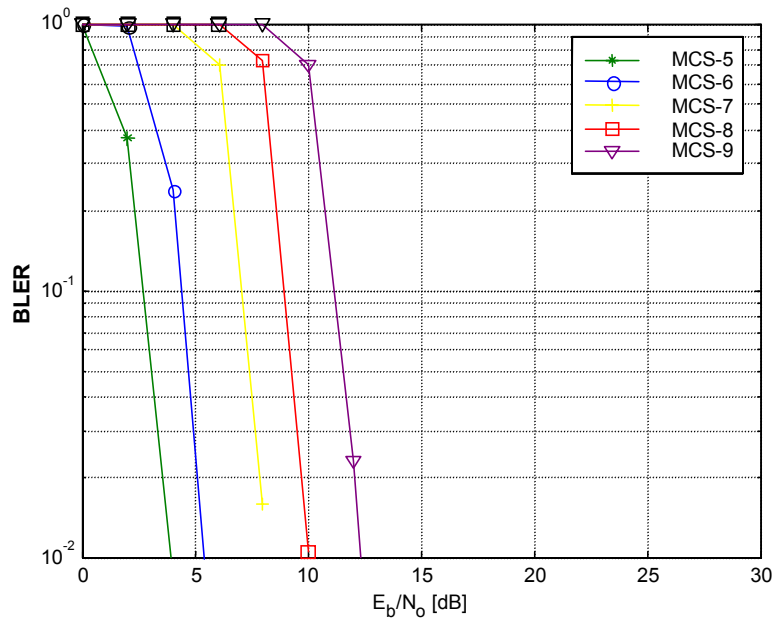


Figure 4-65 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), Static channel, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

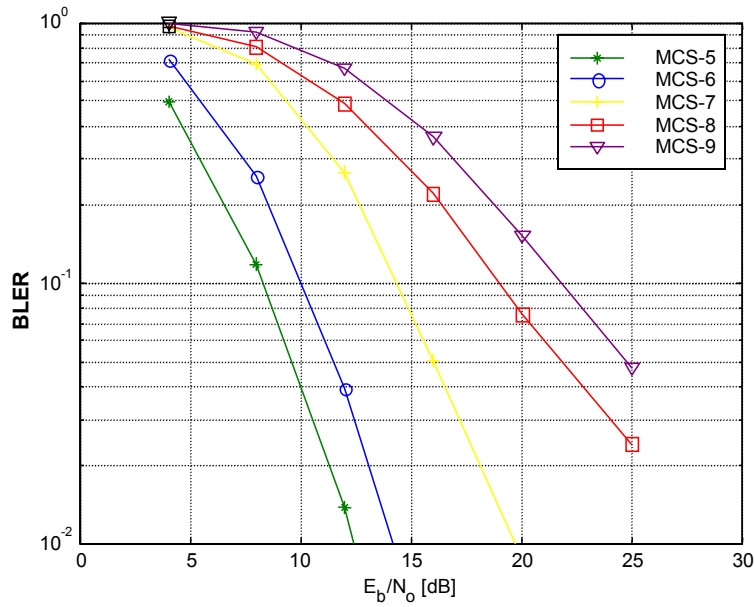


Figure 4-66 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), TU50 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

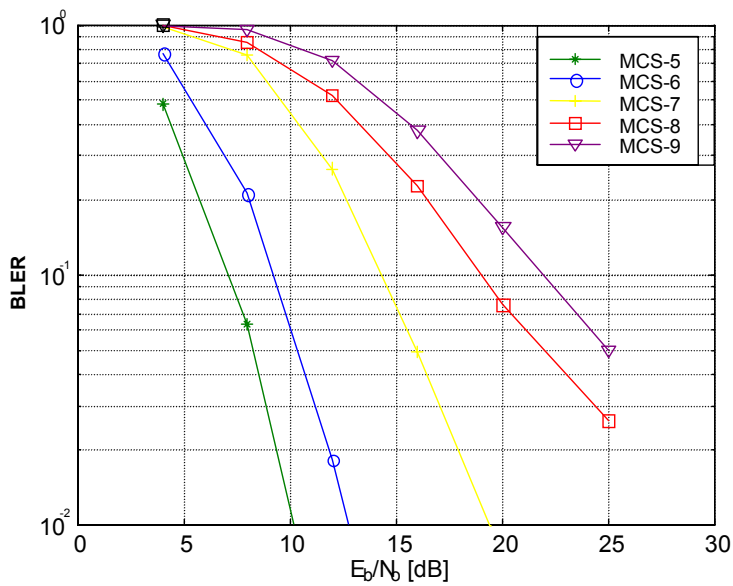


Figure 4-67 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), TU50 ideal FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

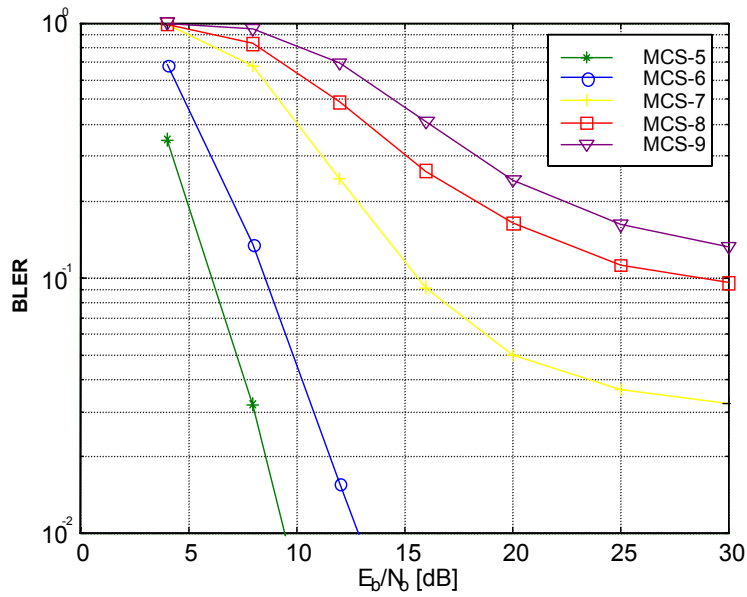


Figure 4-68 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), RA250 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

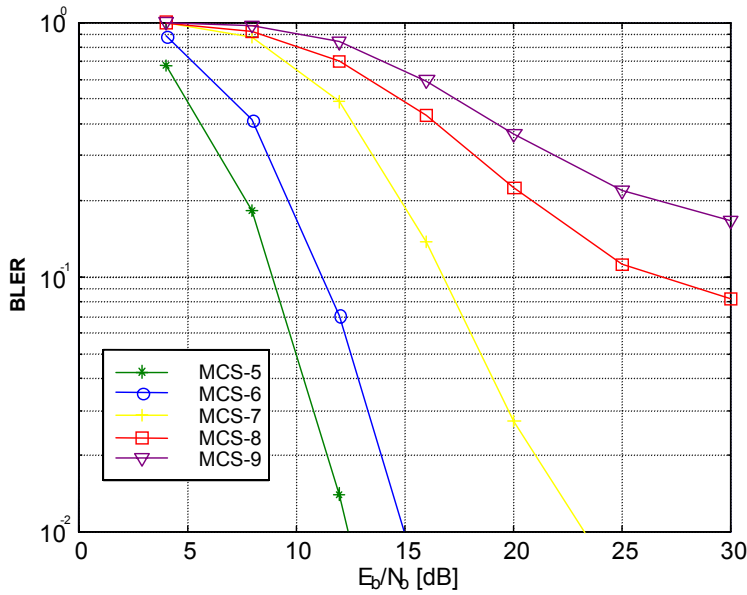


Figure 4-69 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), HT100 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

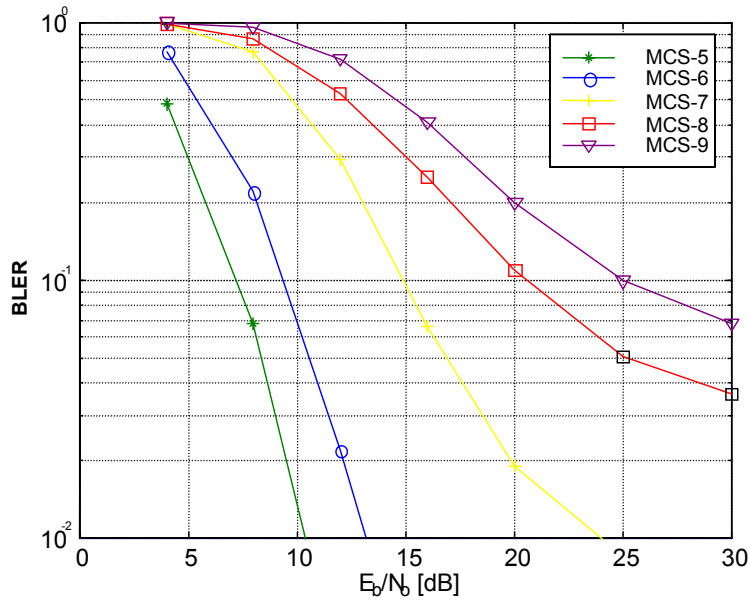


Figure 4-70 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), TU50 ideal FH, 1800 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

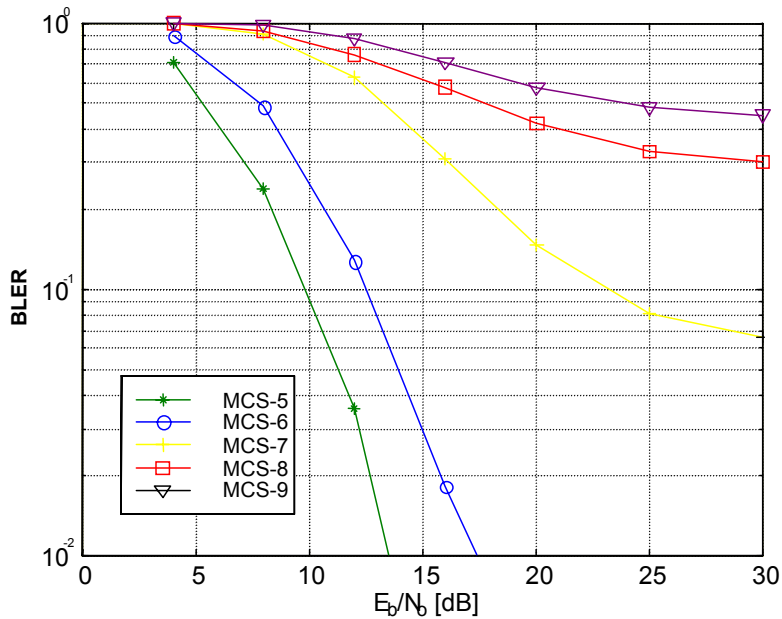


Figure 4-71 – Downlink Block Error Rate (BLER) versus E_b/N_0 for MCS-5 to MCS-9 (8PSK), HT100 ideal FH, 1800 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

When compared to Figures 4-45 to 4-51, Figures 4-65 to 4-71 show that the degradation caused by the Error Vector Magnitude (EVM) has little impact at low speeds, becoming more pronounced at high speeds. Also, its impact is less apparent in lower data rates (MCS-5, 6 and 7), but gains importance as the data rates increase (MCS-8 and 9).

4.4.4.3 Block Error Rate (BLER) Performance in Interference-Limited Environments with EVM and Frequency Offset

The following curves show the Downlink Block Error Rate (BLER) versus C/I performance of EDGE (EGPRS) in interference-limited environments (AWGN). The impairments are 3.1% of EVM and +100 Hz of frequency offset [ET99c]. The order of magnitude of the simulated impairments corresponds to that of real links. Uplink simulations have not been performed, for they are expected to yield equivalent results. The simulated environments are:

- Static channel (900 MHz)
- Typical Urban @ 3 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 3 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) no FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) with ideal FH (900 MHz)
- Typical Urban @ 50 Km/h (TU50) ideal FH (1800 MHz)
- Rural @ 250 Km/h (RA250) no FH (900 MHz)

The simulations are based on the assumptions listed below [ET99c]:

- Downlink, no reception diversity
- One source of co-channel interference, de-correlated in time and with 0 frequency offset
- One source of adjacent channel interference, de-correlated in time and with 200 KHz of frequency offset

- Ideal frequency hopping, when simulated. One time slot per frame when no hopping is used
- Automatic Frequency Offset Correction (AFC) based on burst-by-burst estimation
- P1 puncturing only

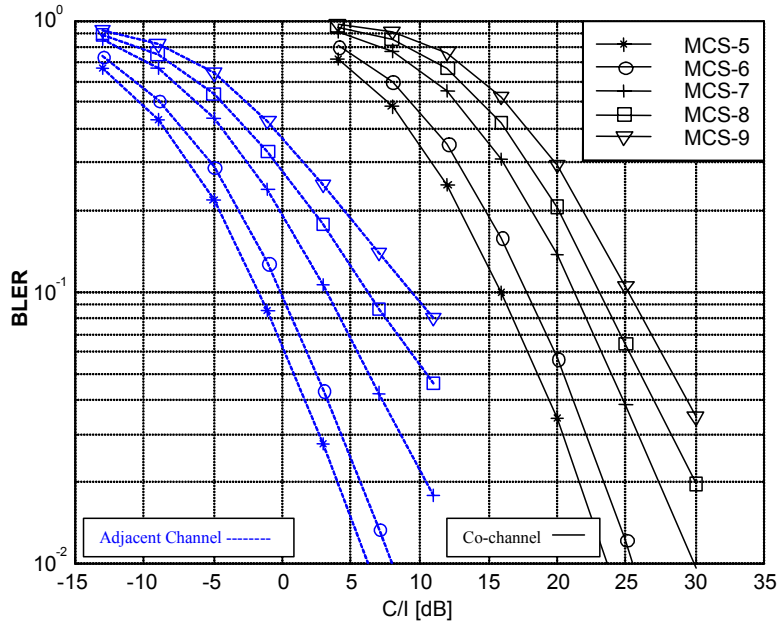


Figure 4-72 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), TU3 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

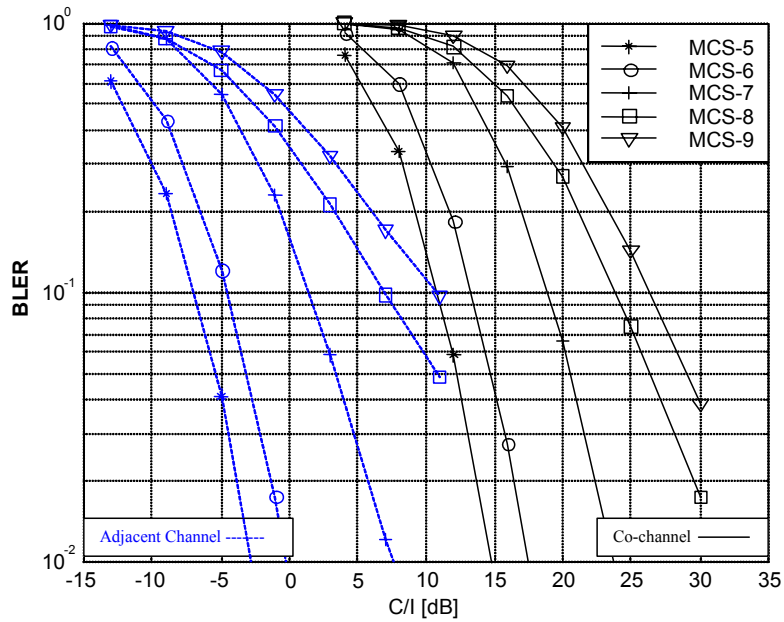


Figure 4-73 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), TU3 ideal FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception error. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

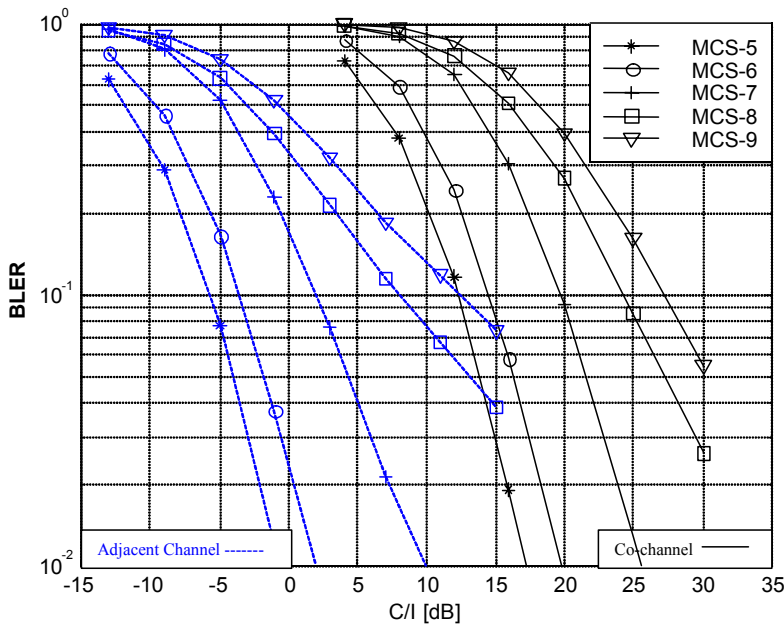


Figure 4-74 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), TU50 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

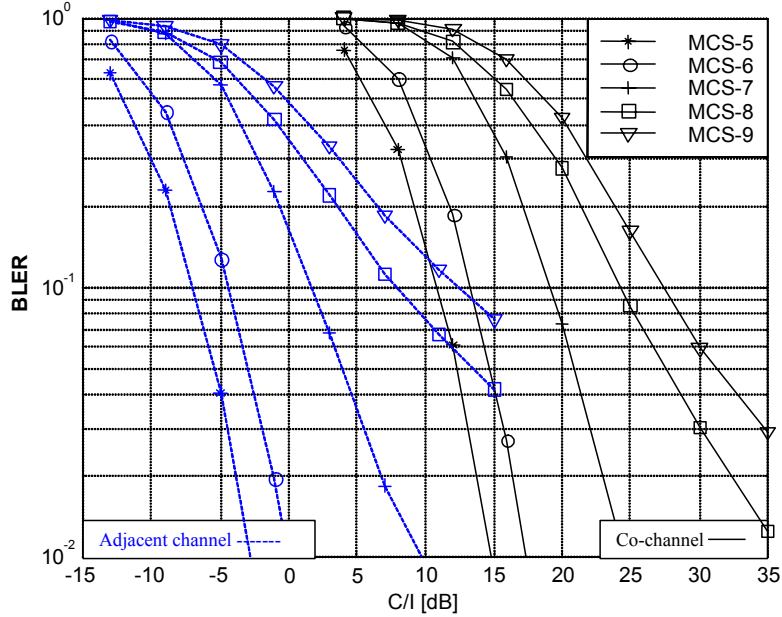


Figure 4-75 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), TU50 ideal FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

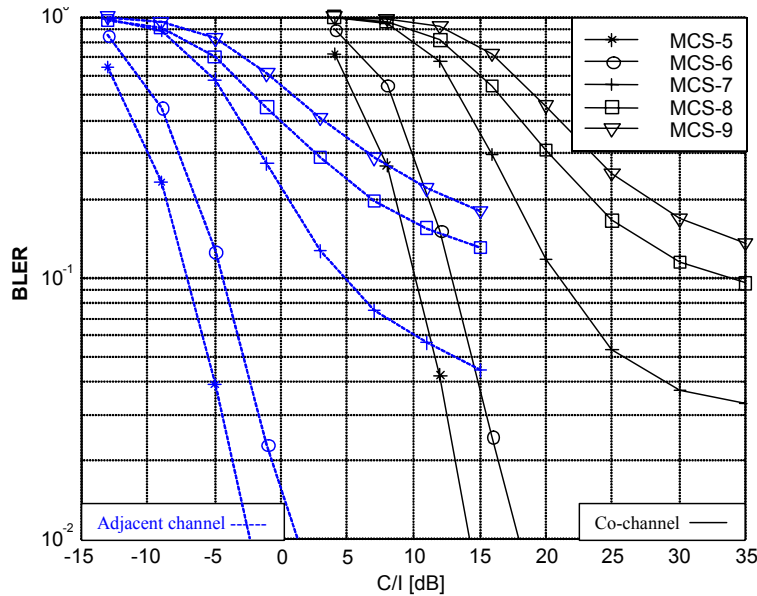


Figure 4-76 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), RA250 no FH, 900 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. One time slot per frame. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

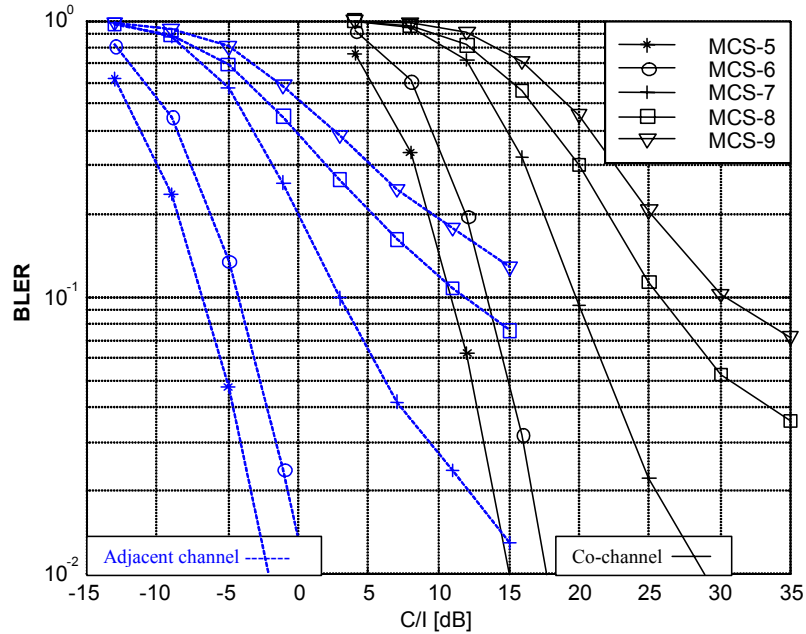


Figure 4-77 – Downlink Block Error Rate (BLER) versus C/I for MCS-5 to MCS-9 (8PSK), TU50 ideal FH, 1800 MHz, 3.1% EVM, +100 Hz frequency error, no reception diversity. Varying fading occurring during one burst. One source of co-channel interference, de-correlated in time with 0 frequency offset. One source of adjacent channel interference, de-correlated in time with 200 kHz of frequency offset. P1 puncturing. Burst-by-burst AFC estimation [ET99c].

When compared to Figure 4-58 to 4-63, Figures 4-72 to 4-77 show that the degradation caused by the Error Vector Magnitude (EVM) to the EDGE link performance in interference-limited environments is very small. In the presence of interference the link quality becomes most affected that element. The degrading effect of the frequency offset and/or phase rotation errors in the main carrier frequency are masked by the interfering signal.

4.5 EDGE (EGPRS) Downlink Throughput Simulations

The downlink throughput of EDGE (EGPRS) has been simulated in order to allow for the assessment of the improvement in performance caused by Link Adaptation (LA) and Incremental Redundancy (IR). Results in noise-limited scenarios - throughput versus E_b/N_0 and interference-limited scenarios - throughput versus C/I are presented.

The simulation results presented herein (Figures 4-78 thru 4-84) are the compilation of the contributions by Motorola (United States) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Ericsson (Sweden), Lucent Technologies (United States) and Siemens (Germany) have been researched, but are not included in this document for they are aligned with the results presented by Motorola. The contributions by Motorola can be found in [Mol00]. Ericsson's contributions are in [ET99a], Lucent's contributions are in [ET99c] and Siemens' contributions are in [Hal].

The simulator output throughput is defined as:

$$\text{Throughput} = [1 - BLER_{(E_b/N_o \text{ or } C/I)}] R_{MCS(X)}$$

where $R_{MCS(X)}$ is the user data rate of the simulated coding scheme, as presented in Table 4-2.

4.5.1 Downlink Throughput in Noise Limited Environments

Downlink throughput versus C/I simulation results are presented in the following figures. The transmitter and receiver are considered to have negligible phase noise, frequency phase and amplitude and phase imbalances. No reception diversity is considered and the receiver is capable of blind modulation detection, to distinguish between GMSK and 8PSK. Uplink throughput simulations have not been reported in the available literature, but are expected to yield equivalent results to those for the Downlink.

For each simulation scenario 5,000 blocks are transmitted. A block is considered to be in error if one or more of the following occurs:

- Modulation detection is wrong
- Wrong detection of SB flags
- Code redundancy check fails for the RLC/MAC header

- Code redundancy check fails for the data block

Figures 4-78 to 4-84 show the impact of frequency hopping on higher code rates at low speeds. They show that throughput performance tends to degrade as the code rate increases, because the diminished data protection makes the data block more vulnerable to interference. The enhanced protection of lower data rate MCS's causes frequency hopping to perform better, since de-interleaving spreads errored bits over the block, allowing the decoder to correct them. This effect can be seen in both the BLER versus E_b/N_0 and BLER versus C/I curves. As speed increases, the effects of interleaving are minimized, for the channel characteristics change more rapidly, increasing the de-correlation between bursts. In these scenarios the difference in performance due to frequency hopping becomes marginal, as shown in Figure 4-80 for TU50 with no FH. HT100 has a more detrimental impact on higher code rates, as shown in Figure 4-81, mainly due to the pronounced multipath environment [Mol00].

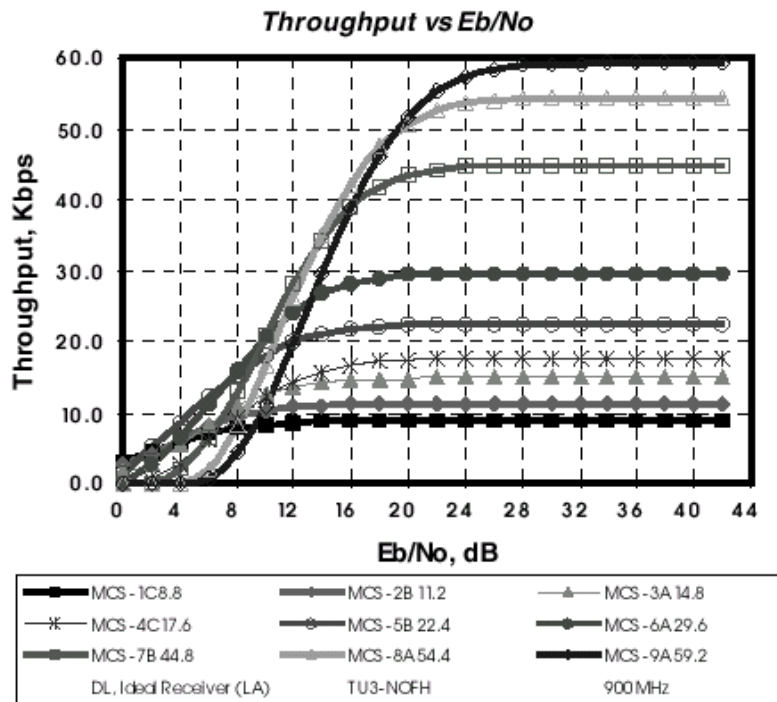


Figure 4-78 – EDGE Downlink throughput versus E_b/N_0 for TU3 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

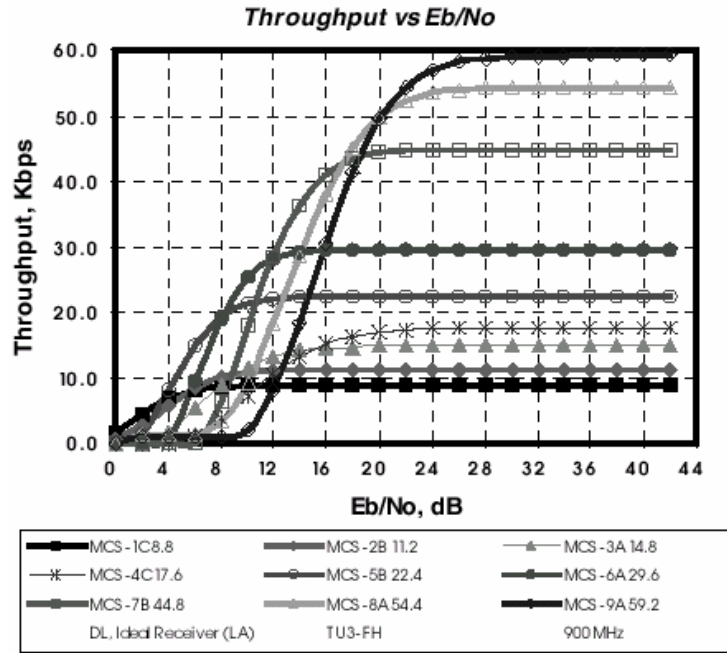


Figure 4-79 - EDGE Downlink throughput versus Eb/No for TU3 ideal FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

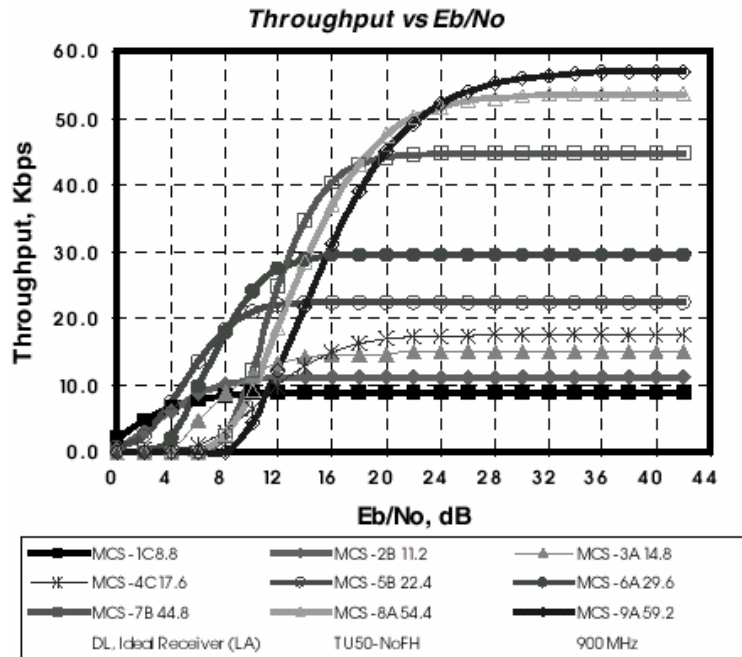


Figure 4-80 - EDGE Downlink throughput versus Eb/No for TU50 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

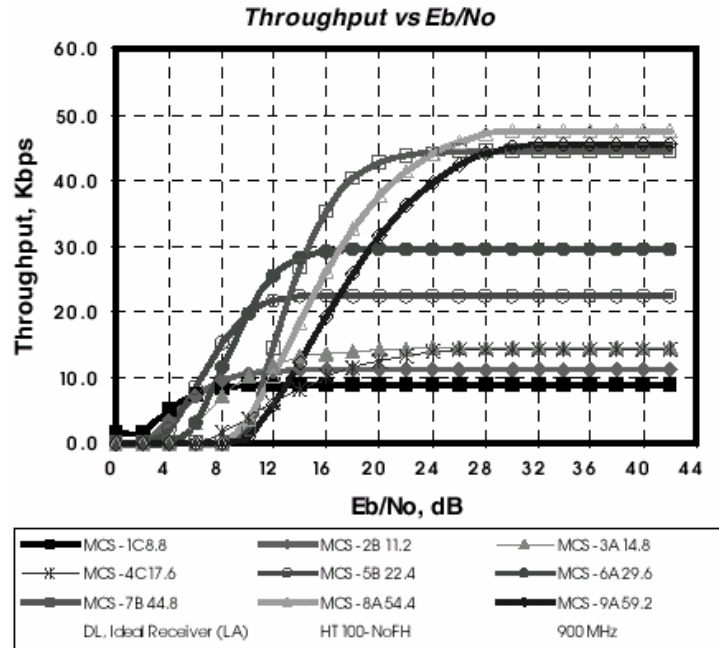


Figure 4-81 - EDGE Downlink throughput versus Eb/No for HT100 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mo100].

Figures 4-82 to 4-84 show how Incremental Redundancy improves throughput performance at lower values of Eb/No. Figure 4-82 clearly illustrates the gain obtained through IR for MCS-9 under TU3 with ideal FH. That happens because at lower Eb/No values there is an increase in the number of block retransmissions and puncturing effectively increases the net data rate. As Eb/No improves this benefit tends to disappear and IR converges to LA. Figure 4-83 shows similar comparison for HT100. In this case the gain is greater, because of the higher BLER experienced under this propagation environment. Figure 4-84 shows IR with P1+P2 for all MCS's, under HT100 with no FH [Mo100].

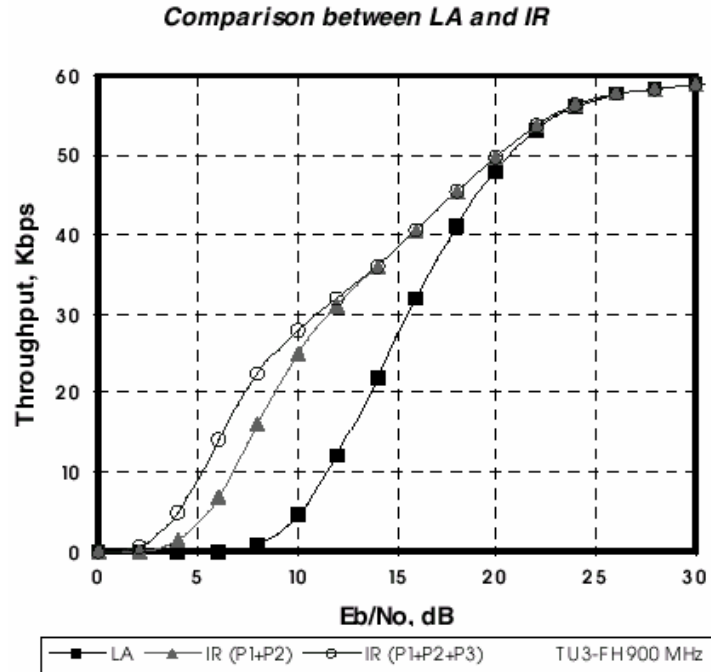


Figure 4-82 - Comparison between (LA) and (IR) for TU3 ideal FH, 900 MHz [Mol00]. 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

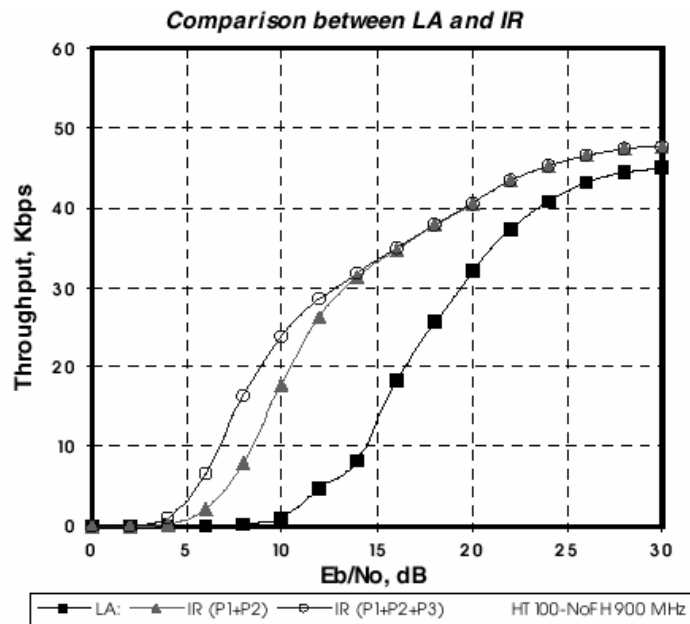


Figure 4-83 - Comparison between (LA) and (IR) for HT100 no FH, 900 MHz [Mol00]. 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

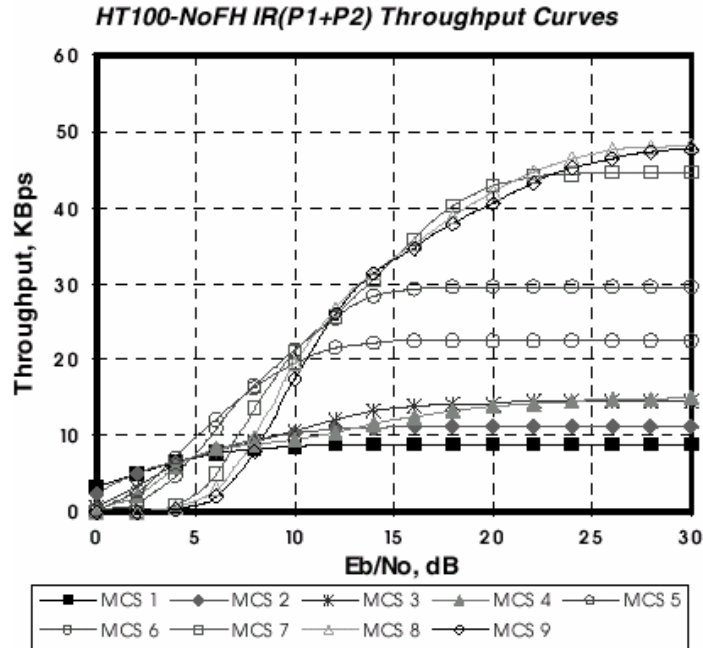


Figure 4-84 - Throughput for IR (P1+P2) for HT100, no FH, 900 MHz [Mol00]. 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

4.5.2 Downlink Throughput in Interference Limited Environments

The simulation results presented herein (Figures 4-85 thru 4-89) are the compilation of the contributions by Motorola (United States) to the standardization efforts promoted by the European Telecommunications Standards Institute (ETSI). Additional contributions by Ericsson (Sweden), Lucent Technologies (United States) and Siemens (Germany) have been researched, but are not included in this document for they are aligned with the results presented by Motorola. The contributions by Motorola can be found in [Mol00]. Ericsson's contributions are in [ET99a], Lucent's contributions are in [ET99c] and Siemens' contributions are in [Hal].

Downlink throughput versus C/I simulation results are presented in the following pictures. The transmitter and receiver are considered to have negligible phase noise, frequency phase and amplitude and phase imbalances. No reception diversity is

considered and the receiver is capable of blind modulation detection, to distinguish between GMSK and 8PSK.

For each simulation scenario 5,000 blocks are transmitted. A block is considered to be in error if one or more of the following occurs:

- Modulation detection is wrong
- Wrong detection of SB flags
- Code redundancy check fails for the RLC/MAC header
- Code redundancy check fails for the data block

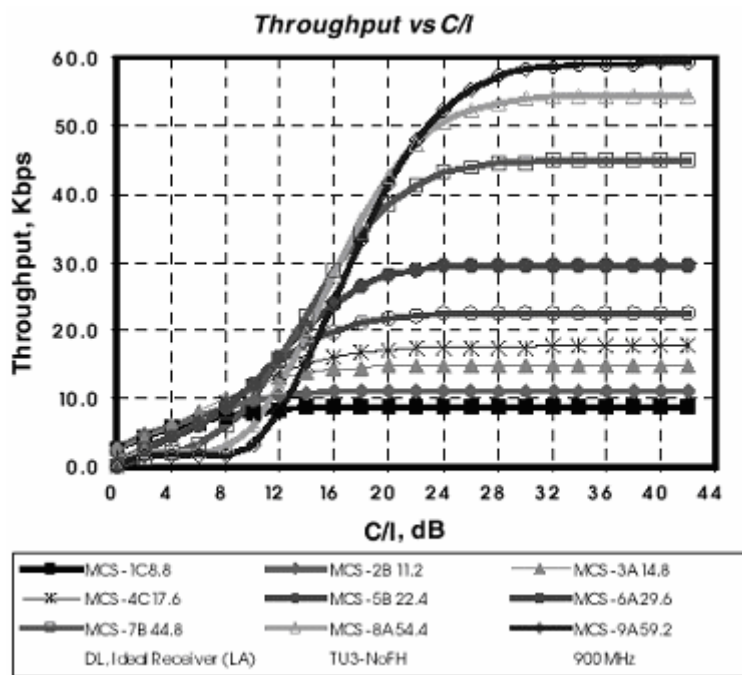


Figure 4-85 - EDGE Downlink throughput versus C/I for TU3 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

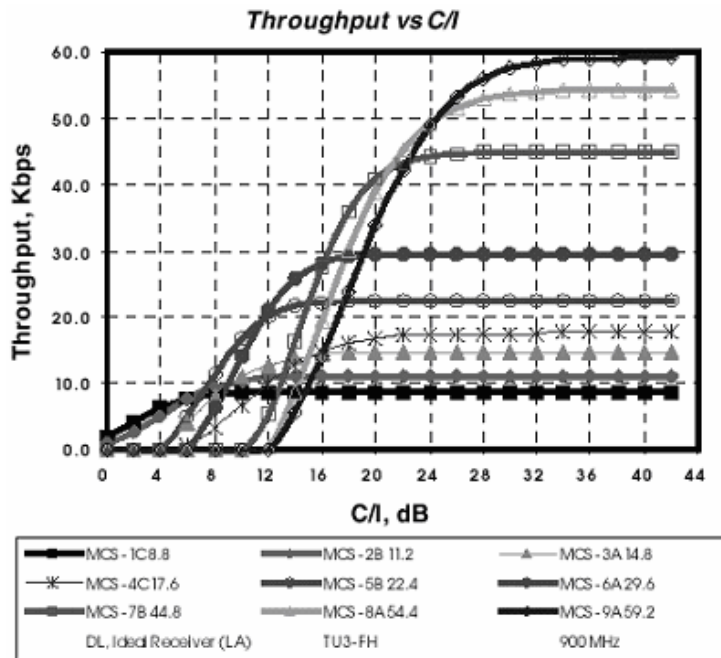


Figure 4-86 - EDGE Downlink throughput versus C/I for TU3 ideal FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset, and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

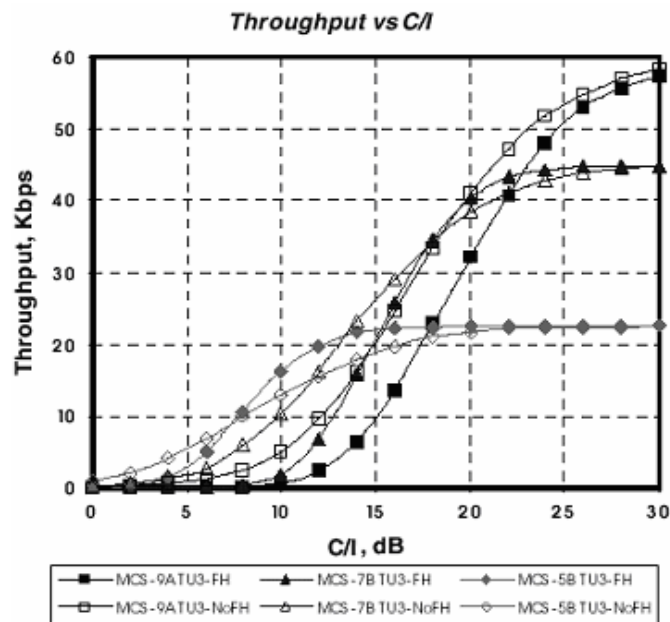


Figure 4-87 - Comparison of EDGE Downlink throughput vs. C/I between TU3 ideal FH and no FH, 900 MHz. 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset, and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

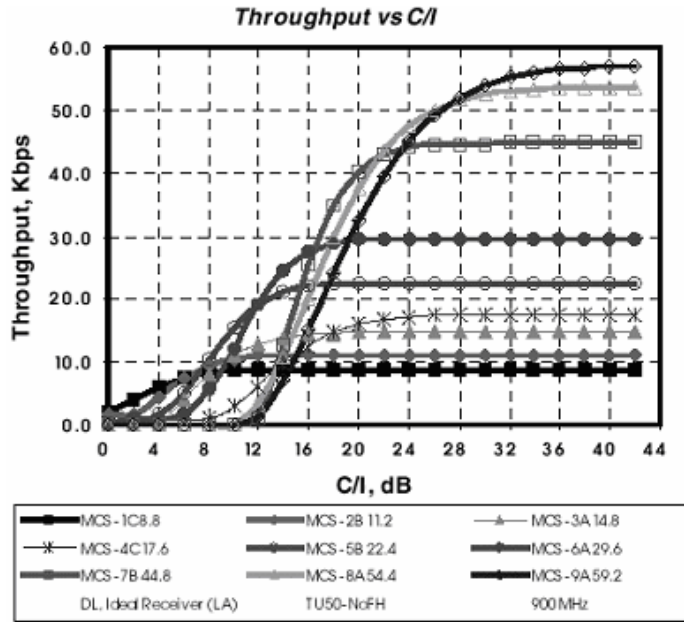


Figure 4-88 - EDGE Downlink throughput versus C/I for TU50 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset, and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

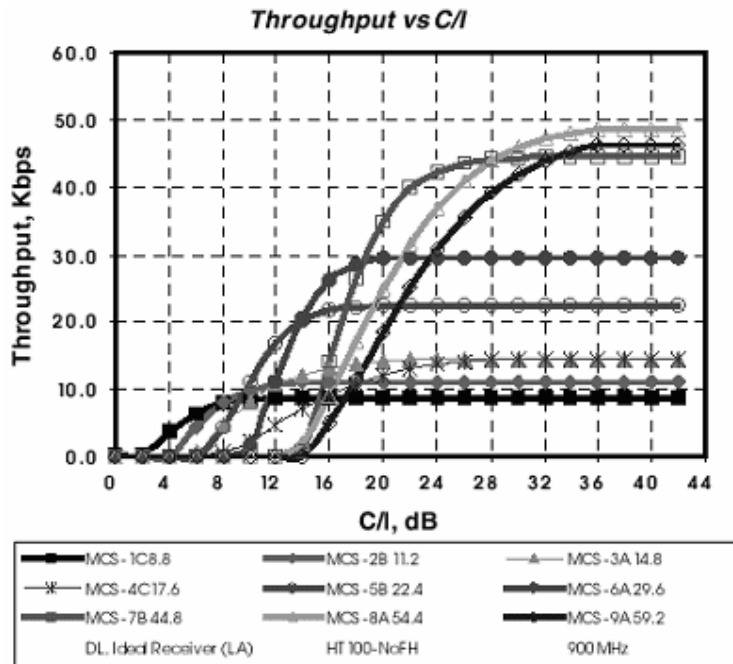


Figure 4-89 - EDGE Downlink throughput versus C/I for HT100 no FH, 900 MHz, Link Adaptation (LA). 5,000 data blocks are transmitted. Simulation assumes negligible phase noise, frequency offset, and amplitude and phase imbalances. No reception diversity. Viterbi equalizer is assumed. Blind modulation detection scheme [Mol00].

4.6 Discussion

The introduction of a more spectrum efficient modulation considerably improves EDGE's data rate capabilities, when compared with the GPRS technology. For the same bandwidth (200 kHz), EDGE offers up to 2.8 times more data rate capacity than GPRS per GSM time slot. EDGE was not designed to be a competitor of GPRS, but rather to be an evolution of it. It expands its spectrum efficiency, allowing for higher data rates within the same bandwidth. The improved data rates come at the expense of power. The new modulation and coding schemes based on the 8PSK modulation require increased signal-to-noise ratios to meet the quality requirements. This indicates that existing GSM networks that migrate to EDGE are likely to require re-design, since their service footprints, based on the conventional GSM modulation (GMSK), will be reduced once EDGE is implemented.

The finer granularity allowed by the three puncturing schemes employed in the incremental redundancy mechanism add important robustness EDGE, besides allowing for improved throughput. The combination of link adaptation and incremental redundancy adds valuable benefits to EDGE, particularly in poor link conditions.

At first glance the previous figures show that the system should always try to use the coding scheme that yields the highest throughput at any given time. However, having satisfactory link quality (C/I), a data session may not require the highest permissible throughput. In such cases the choice of a less "efficient" coding scheme should be considered for that connection, for it will allow a reduction in the transmitted power (through downlink/uplink power control), contributing for the minimization of the overall system interference. This has particular importance in the uplink, since the mobile terminal presents more severe power constraints.

Chapter 5 – Wideband CDMA (WCDMA) Link Performance

5.1 WCDMA Channel Structure

WCDMA (**W**ideband **C**ode **D**ivision **M**ultiple **A**ccess) supports bandwidth-on-demand, requiring the physical layer to have the ability to adapt the bit rate during the connection, besides carrying multiple services concurrently. In order to fulfill these requirements the data is carried over the air using *transport channels*, which are mapped to the physical channels. The concept of transport channels did not exist in second-generation technologies.

5.1.1 Transport Channels

The transport channels represent a link between the logical channels and the physical layer. The logical channels define the type of data to be transmitted, therefore acting above the MAC (**M**edia **A**ccess **C**ontrol) layer and the transport channels. The Physical channels are in the lowest layer of the structure, defining the characteristics of the radio channel.

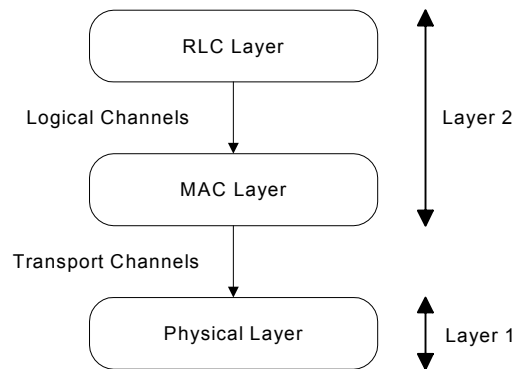


Figure 5-1 – Wideband CDMA (WCDMA) Channel Structure. [KOR01]

Each transport channel receives a Transport Format Indicator (TFI) whenever there is data from the higher logical layers addressed to it. Multiple transport channels are combined in the physical layer, receiving a Transport Format Combination Indicator (TCFI), as indicated in Figure 5-2.

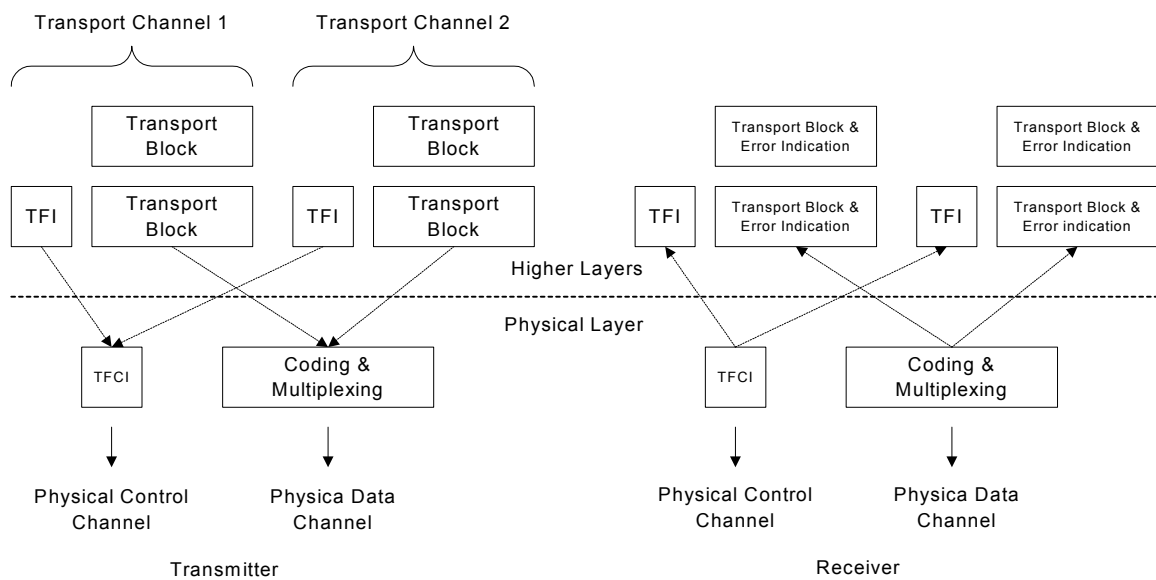


Figure 5-2 - Relation between Transport channels and the physical layer [Ho100].

There are two types of transport channels: the dedicated channel and the common channel. The common channel is divided between all users, or a group of users in a cell, whereas the dedicated channel is reserved for a single user [Ho100].

5.1.1.1 Dedicated Transport Channel (DCH)

This is the only dedicated channel specified in WCDMA. It is a bi-directional channel used to carry control information, such as handover commands and measurement reports, between the network and the mobile stations. It can also carry actual service data - speech

frames or data frames. The DCH supports variable data rates on a frame-by-frame basis, fast power control, soft handoff and beam shaping using adaptive antennas.

5.1.1.2 Common Transport Channels

Six common transport channels have been defined:

- Broadcast Channel (BCCH)
- Forward Access Channel (FACH)
- Paging Channel (PCH)
- Random Access Channel (RACH)
- Uplink Common Packet Channel (CPCH)
- Downlink Shared Channel (DSCH)

The common channels do not support soft handoff, but some of them support fast power control, as described below.

5.1.1.2.1 Broadcast Control Channel (BCH)

The BCH is a downlink point-to-multipoint channel used to broadcast system- and cell-specific information. It is transmitted over the entire cell, since all terminals located under the service area of the cell must be able to receive and decode this channel.

5.1.1.2.2 Forward Access Channel (FACH)

The FACH is a downlink channel used to carry control information to mobile stations with known cell locations. It supports user packet data, but its data rate must be low enough to allow its reception and decoding over the entire cell. There can be more than one FACH in a cell.

5.1.1.2.3 Paging Channel (PCH)

The PCH is a downlink channel used to carry information to mobile stations with unknown cell location. Its primary use is in the paging procedure, when the network wants to initiate communication with the terminal. The PCH must reach the entire service area of the cell.

5.1.1.2.4 Random Access Channel (RACH)

The RACH is an uplink channel used to carry control information from the mobile terminals, also being able to carry user data packets. Its data rates are low enough to allow its reception from the entire cell area. RACH does not support fast power control.

5.1.1.2.5 Uplink Common Packet Channel (CPCH)

The CPCH is an extension of the RACH and was designed to carry packet-based user data in the uplink direction. Unlike RACH, this channel does support fast power control, besides featuring a physical layer-based collision detection mechanism [Hol00].

5.1.1.2.6 Downlink Shared Channel (DSCH)

The DSCH is similar to the FACH, supporting both control information and user data. It does not require complete cell coverage, supporting variable bit rates on a frame-by-frame basis. The DSCH supports fast power control.

5.1.2 Physical Channels

The physical channels are defined by their frequency, spreading, scrambling and frame duration (the uplink also has the relative phase as a parameter). Spreading and scrambling are described in section 5.2.

WCDMA utilizes two types of physical channels: dedicated and common, or shared. Dedicated channels are used for single user and common channels can be allocated to all users within a cell, or a subgroup of that.

5.1.2.1 Uplink Physical Channels

5.1.2.1.1 Uplink Dedicated Physical Channels

Two types of uplink dedicated channels have been defined: The Dedicated Physical Data Channel (uplink DPDCH) and the uplink Dedicated Physical Control Channel (uplink DPCCH). The uplink DPDCH is used to carry the DCH transport channel. There may be none, one, or several uplink DPDCH's on each radio link. The uplink DPCCH is used to carry control information generated at higher protocol layers, such as Layer 1[KOR01].

5.1.2.1.2 Uplink Common Physical Channels

The Physical Random Access Channel (PRACH) and the Physical Common Packet Channel (PCPCH) operate as common uplink channel. The PRACH is used to carry the RACH transport channel while the PCPCH carries the CPCH.

5.1.2.2 Downlink Physical Channels

5.1.2.2.1 Downlink Dedicated Physical Channels

The Downlink Dedicated Physical Channel (downlink DPCH) is the only downlink dedicated physical channel. It carries multiplexed data from the DCH and control data from higher protocol layers.

5.1.2.2.2 Downlink Common Physical Channels

The following downlink common channels have been defined:

- Common Pilot Channel (CPICH): carries a fixed rate, pre-defined control signal used for acquisition and synchronization.
- Primary Common Control Physical Channel (PCCPCH): used to carry the BCH
- Secondary Common Control Physical Channel (S-PCCPCH): used to carry the FACH and PCH
- Synchronization Channel (SCH): Used for cell search
- Physical Downlink Shared Channel (PDSCH): used to carry the DSCH
- Acquisition Indicator Channel (AICH): use to carry the signatures for the random access procedures
- Page Indication Channel (PICH): carries page indicators to signal the presence of paging messages on the PCH
- Access Preamble Acquisition Indicator Channel (AP-AICH): carries acquisition indicators for the CPCH
- CPCH Status Indicator Channel (CSICH): carries the status of the CPCH;
- Collision-Detection/Channel Assignment Indicator Channel (CD/CA-ICH): carries collision-detection indicators only if the CA channel is not active, or both CD and CA indicators if the CA channel is active.

5.1.3 Mapping of Transport Channels to Physical Channels

The mapping of the transport channels to the physical channels, as described in the previous sections, is summarized in Figure 5-3.

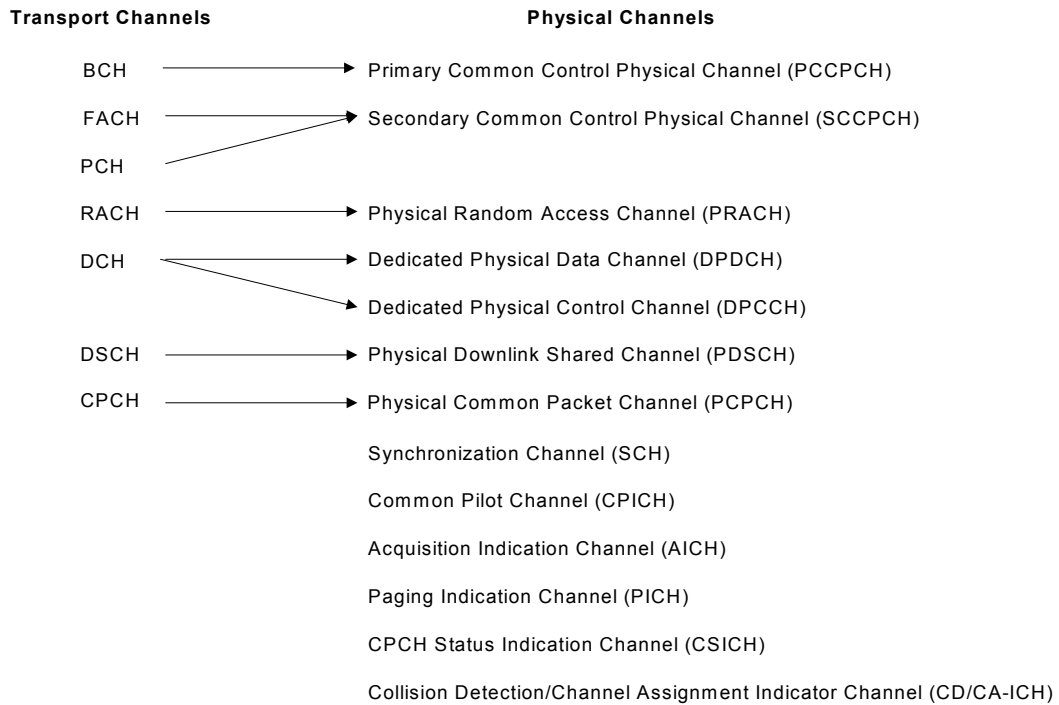


Figure 5-3 - Mapping of the transport channels to the physical channels. [3GP01g]

5.2 Channel Coding and Modulation

5.2.4 Error Control Coding

WCDMA uses two error correction coding methods: convolutional coding and turbo coding. The different types of traffic channels described in the previous section utilize them as shown in Table 5.1. Eventually, some channels may use no forward error correction at all.

Type of Traffic Channel	Coding method	Coding rate
BCH	Convolutional coding	1/2
PCH		
RACH		
CPCH, DCH, DSCH, FACH	Turbo coding	1/3, 1/2
		1/3
	No coding	

Table 5-1 – Error correction coding methods used in WCDMA. [3GP01h, 3GP01i, KOR01]

The modulation process in WCDMA is performed in two stages: spreading and scrambling. Spreading encodes the modulating data using orthogonal codes, increasing its bandwidth. Scrambling uses pseudo-noise sequences to alter the order the data was applied to the modulator. Scrambling does not affect the signal bandwidth, but makes signals from different sources separable from each other. The relation between these processes is illustrated in Figure 5-4.

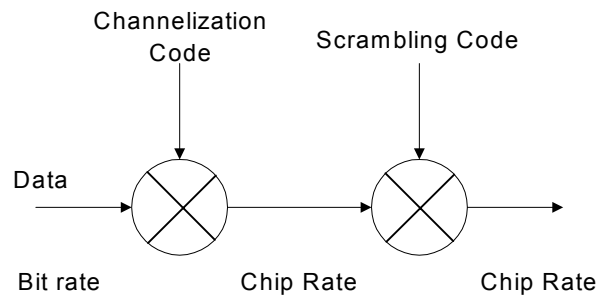


Figure 5-4 - Spreading and Scrambling schemes used in WCDMA. [Hol00]

Table 5-2 summarizes the functionality of the channelization and scrambling codes.

Parameter	Channelization Code	Scrambling Code
Usage	Uplink: Separation of physical data (DPDCH) and control channels (DPCCH) from same terminal. Downlink: Separation of downlink connections to different users within one cell.	Uplink: Separation of terminals Downlink: Separation of sectors
Length	Uplink: 4-256 chips (1.0~66.7 μ s) Downlink: 4-512 chips (1.0~133.3 μ s)	Uplink (1) 10 ms=38400 chips or (2) 66.7 μ s=256 chips Downlink: 10ms=38400 chips
Number of codes	Number of codes under one scrambling code= spreading factor	Uplink: 16,777,216 Downlink: 512
Code family	Orthogonal Variable Spreading Factor	Long 10 ms code: Gold code Short code: Extended S (2) code family
Spreading	Increases transmission bandwidth	Does not affect transmission bandwidth

Table 5-2 - Functionality of the WCDMA channelization and spreading codes. [Ho100]

5.2.5 Uplink Coding, Spreading and Modulation

5.2.5.1 Channel Coding and Multiplexing

WCDMA supports multiple channels simultaneously, allowing the service channels to be multiplexed dynamically in order to produce a continuous data stream. All symbols transmitted over the DPDCH have equal power level. Rate matching is used to achieve the required rate equalization among the active channels at any given time. The steps of the coding and multiplexing operation in the uplink are:

- Add CRC to each transport block
- Transport block concatenation and code block segmentation
- Channel coding radio frame equalisation
- Rate matching

- Insertion of discontinuous transmission (DTX) indication bits
- Interleaving
- Radio frame segmentation
- Multiplexing of transport channels
- Physical channel segmentation
- Mapping to physical channels

Error detection is provided on transport blocks through a **Cyclic Redundancy Check (CRC)**. The length of the CRC is 24, 16, 12, 8 or 0 bits. The indication of the length to be used for each traffic channel comes from higher protocol layers.

Convolutional coding and turbo coding have been defined. Convolutional codes with constraint length 9 and coding rates $1/3$ and $1/2$ are used. The scheme of Turbo coder is a **Parallel Concatenated Convolutional Code (PCCC)** with two 8-state constituent encoders and one Turbo code internal interleaver. The coding rate of the Turbo coder is $1/3$ [3GP01i].

Rate matching is used to equalize the data rate of simultaneous traffic channels. It consists of repeating or puncturing the transport channel bits to increase or lower the channel data rate. Higher layers assign a rate-matching attribute for each transport channel. This attribute is semi-static and can only be changed through higher layer signaling [3GP01i].

The number of bits on a transport channel can vary between different transmission time intervals. In the downlink the transmission is interrupted if the number of bits is lower than maximum. When the number of bits between different transmission time intervals in uplink is changed, bits are repeated or punctured to ensure that the total bit rate after traffic channel multiplexing is identical to the total channel bit rate of the allocated dedicated physical channels. Figure 5-5 shows the coding and multiplexing chain.

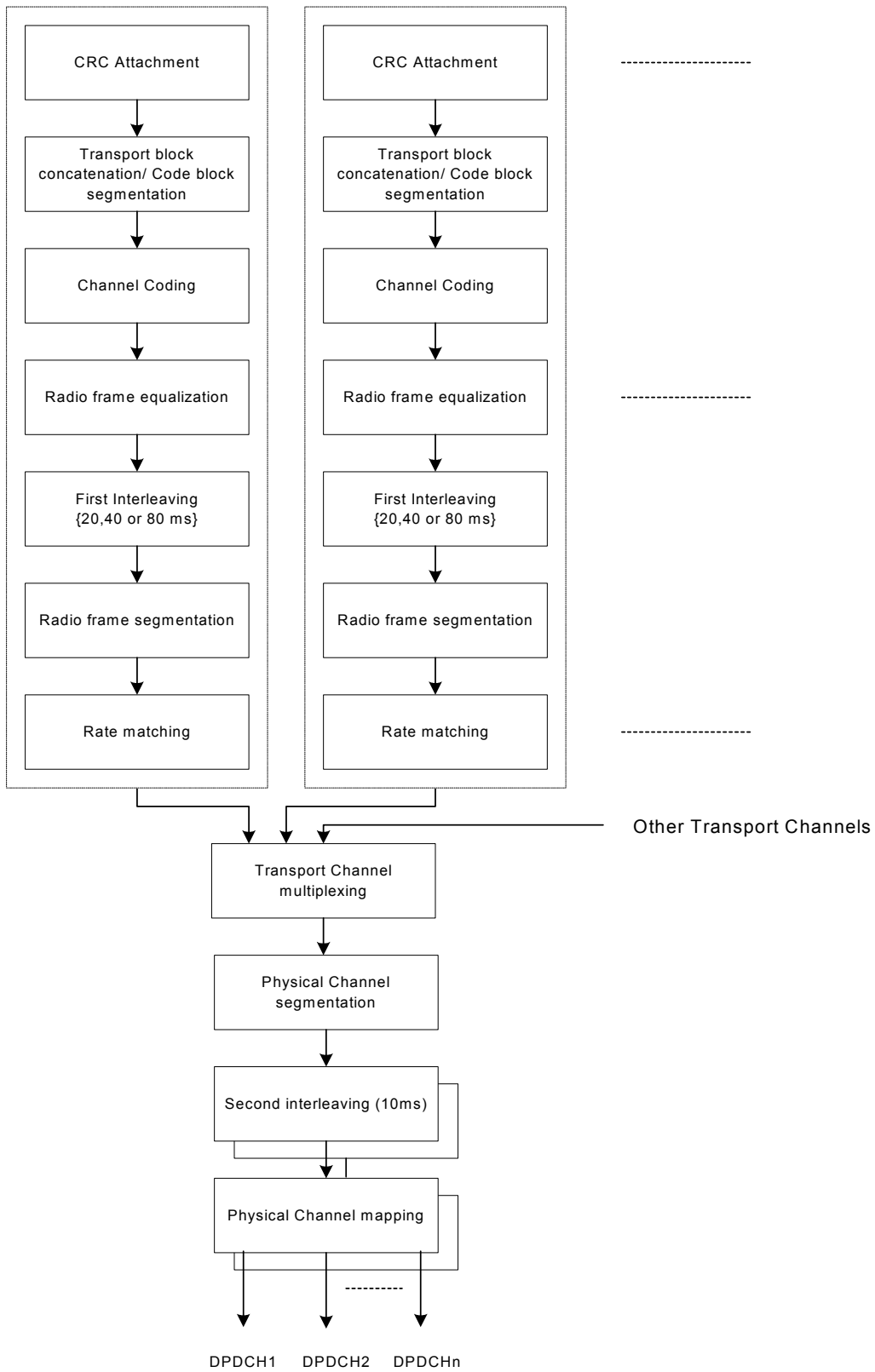


Figure 5-5 – WCDMA Uplink Coding and Multiplexing chain. [3GP01h]

5.2.5.2 Spreading (Channelization Codes)

Transmissions originating from a single source are separated by different channelization codes. This occurs in the downlink, for connections within one sector, and in the uplink, for the dedicated physical channels from one terminal.

WCDMA utilizes the **Orthogonal Variable Spreading Factors (OVSF)** technique, which allows the spreading factor to change without link disruption, while maintaining orthogonality between different spreading codes of different lengths. The spreading chip rate is 3.84 Mcps.

The algorithm for the generation of the code tree is based on the following structure. The leftmost value in each channelization code word corresponds to the chip transmitted first in time [3GP01i].

$$C_{ch,1,0} = 1$$

$$\begin{bmatrix} C_{ch,2,0} \\ C_{ch,2,1} \end{bmatrix} = \begin{bmatrix} C_{ch,1,0} & C_{ch,1,0} \\ C_{ch,1,0} & -C_{ch,1,0} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$\begin{bmatrix} C_{ch,2^{(n+1)},0} \\ C_{ch,2^{(n+1)},1} \\ C_{ch,2^{(n+1)},2} \\ C_{ch,2^{(n+1)},3} \\ \vdots \\ C_{ch,2^{(n+1)},2^{(n+1)}-2} \\ C_{ch,2^{(n+1)},2^{(n+1)}-1} \end{bmatrix} = \begin{bmatrix} C_{ch,2^n,0} & C_{ch,2^n,0} \\ C_{ch,2^n,0} & -C_{ch,2^n,0} \\ C_{ch,2^n,1} & C_{ch,2^n,1} \\ C_{ch,2^n,1} & -C_{ch,2^n,1} \\ \vdots & \vdots \\ C_{ch,2^n,2^{n-1}} & C_{ch,2^n,2^{n-1}} \\ C_{ch,2^n,2^{n-1}} & -C_{ch,2^n,2^{n-1}} \end{bmatrix}$$

Figure 5-6 – WCDMA Orthogonal Variable Spreading factor (OVSF) code structure. [3GP01i]

The code tree generated by the above structure has the form illustrated in Figure 5-7, where the spreading factors 1 thru 8 are shown.

In order to guarantee orthogonality, a spreading factor can only be assigned to a physical channel if no other channel using the same code tree is using a code on an underlying branch, i.e., using a higher spreading factor. A smaller spreading factor on the path to the root is not allowed either.

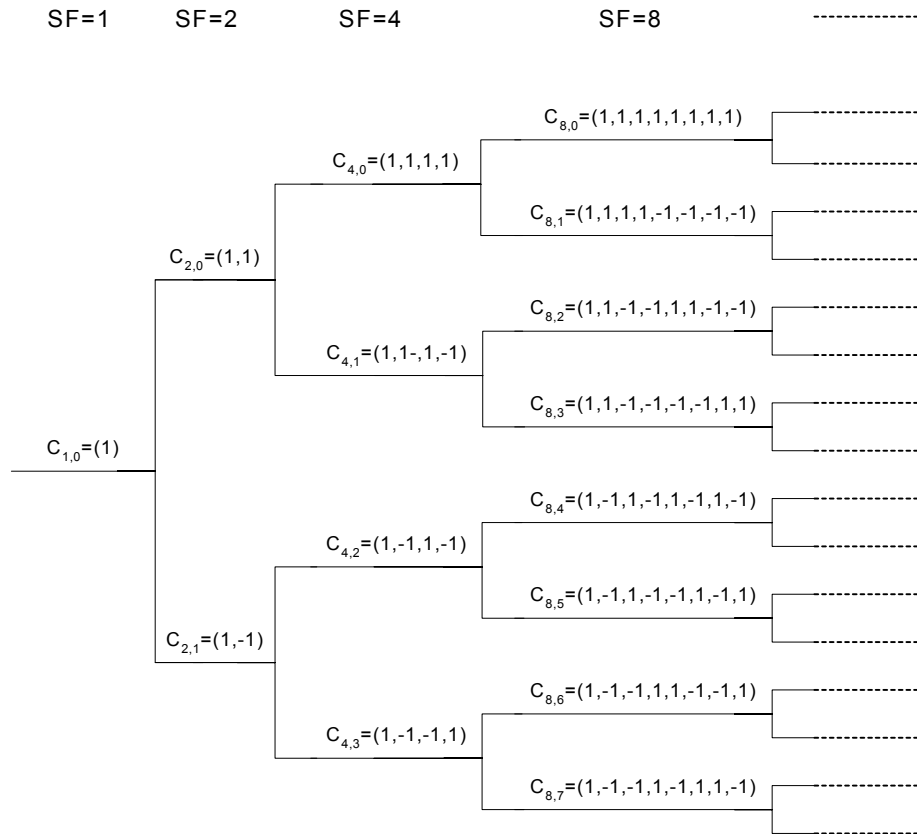


Figure 5-7 – Root of the code tree structure used in WCDMA [3GP01i]

5.2.5.2.1 Code Allocation for DPCCH/DPDCH

The spreading codes for the DPCCH and DPDCH are assigned as follows:

- The DPCCH is always spread by code $c_c = C_{ch,256,0}$
- When only one DPDCH is transmitted, it is spread by code $c_{d,1} = C_{ch,SF,k}$, where SF is the spreading factor and $k = SF / 4$

- When more than one DPDCH is transmitted, they all have spreading factor equal to 4. DPDCH_n is spread by the code $c_{d,n} = C_{ch,4,k}$, where $k=1$ if $n \in \{3,4\}$ and $k=2$ if $n \in \{5,6\}$

In order to minimize the audible interference effect caused by discontinuous transmission (DTX), the DPDCH and DPCCH are I-Q code-multiplexed, also known as dual channel QPSK modulation. The code multiplexing assures that, in the absence of data in the DPDCH, the channel is still active with the DPCCH, which is continuously transmitted, as shown in Figure 5-8.

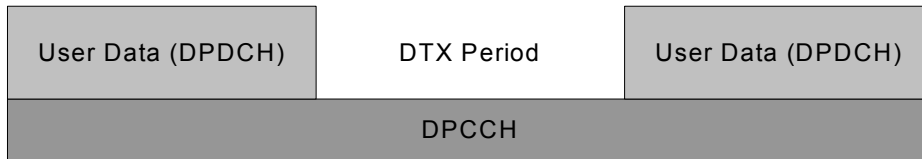


Figure 5-8 – Uplink I-Q multiplexing of Dedicated Physical Data Channel (DPDCH) and Dedicated Physical Control Channel (DPCCH). [Hol00]

A block diagram of the multiplexer is presented in Figure 5-9. The power levels of the DPDCH and DPCCH are usually distinct, becoming increasingly different as the traffic data rates increase, resulting in a BPSK-type transmission. In order to avoid such reduction in efficiency, a complex-valued scrambling is applied to the I-Q signal after the spreading.

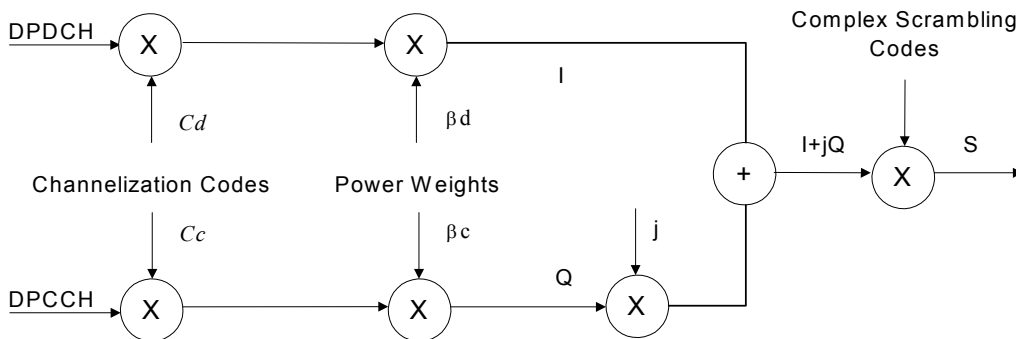


Figure 5-9 – Uplink I-Q code multiplexing block diagram. [3GP01i, KOR01]

Since a WCDMA mobile terminal can transmit multiple physical channels at different power levels simultaneously, the peak-to-average ratio (crest factor) of the signal may increase substantially. The reduction in the amplifier efficiency caused by such effect is recovered by the use of power weights for each channel, making the amplifier efficiency constant irrespective of the power difference between the DPDCH and the DPCCH. Table 5-3 shows the values for β_c and β_d , which are quantized into 4-bit words. At any given time at least one of the variables has the amplitude 1.0.

Signalling values for β_c and β_d	Quantized amplitude ratios β_c and β_d
15	1.0
14	14/15
13	13/15
12	12/15
11	11/15
10	10/15
9	9/15
8	8/15
7	7/15
6	6/15
5	5/15
4	4/15
3	3/15
2	2/15
1	1/15
0	Switch off

Table 5-3 – Quantization of the β_c and β_d variables applied to the uplink I-Q code multiplexer. [3GP01i]

5.2.5.3 Uplink Scrambling

Complex scrambling is used to separate the transmissions from distinct mobile terminals, with two scrambling methods being defined: short and long codes. The short codes are used when multi-user detectors (MUD) or interference cancellation receivers are available in the uplink. Long codes are applied when RAKE receivers are used.

There are a total of 2^{24} short codes and 2^{24} long codes available for uplink use, facilitating the code planning, i.e., making it virtually unnecessary. The short codes have a length of 256 chips, whereas the long codes are truncated at 38400 chips (10 ms frame duration).

The short codes are derived from the family of periodically extended S (2) codes. The implementation of the scrambling sequence generator is shown in Figure 5-10.

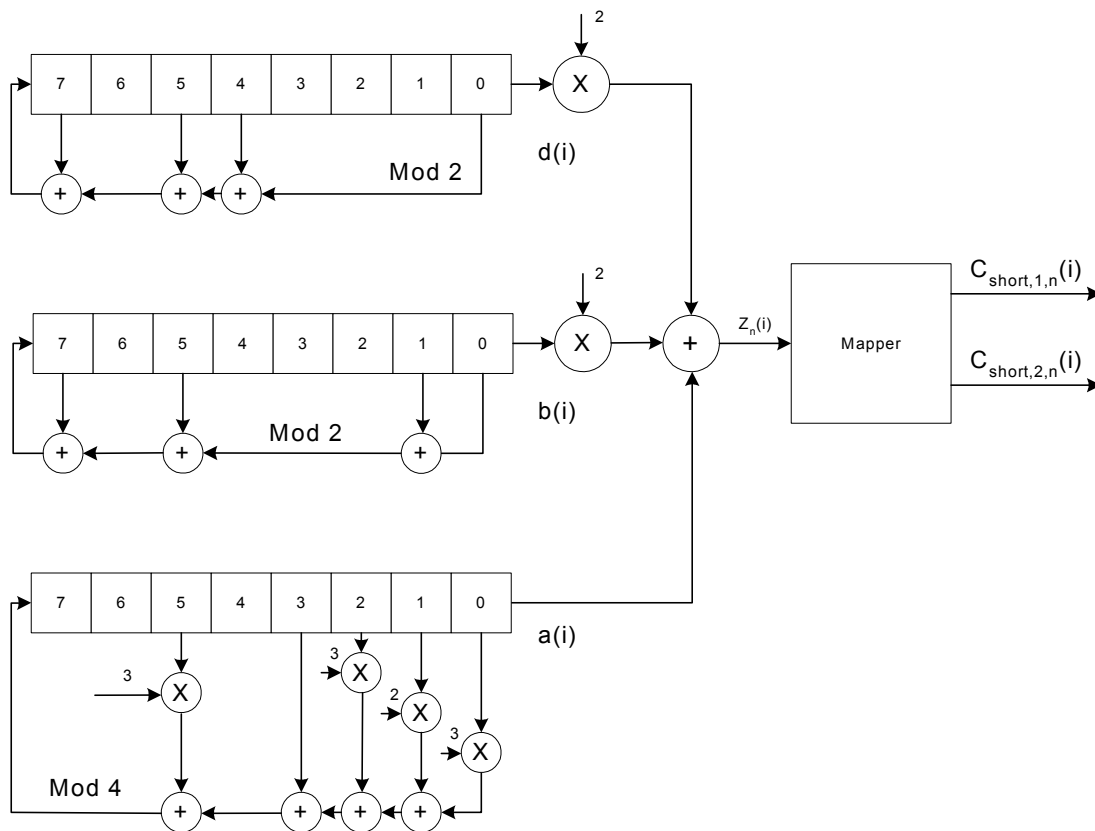


Figure 5-10 - Uplink short scrambling sequence generator. [3GP01i]

The long codes are derived from the Gold sequences, using the primitive polynomial $X^{25}+X^3+1$ over GF (2) for the x sequence and $X^{25}+X^3+X^2+X+1$ for the y sequence. The sequence generator for the uplink scrambler is shown in Figure 5-11.

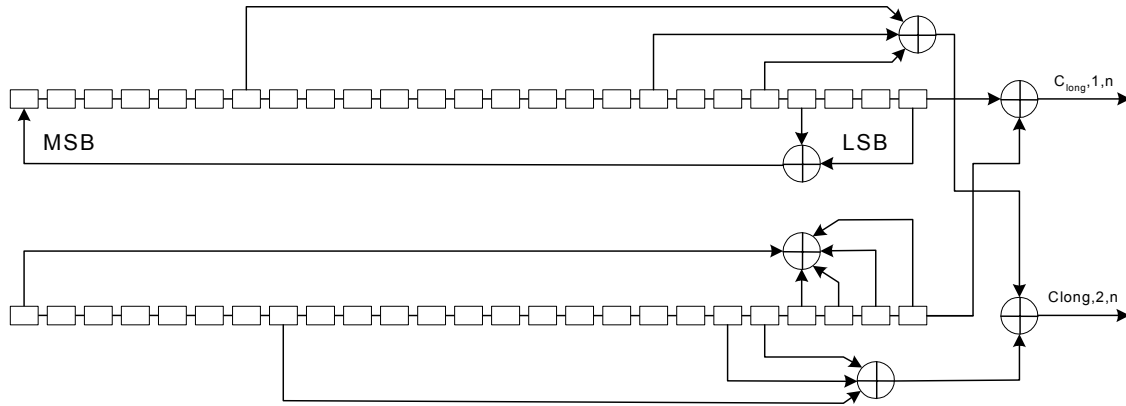


Figure 5-11 -25-bit long code uplink sequence generator. [3GP01i]

5.2.5.4 Uplink Dedicated Channel Structure

The uplink DPDCH utilizes a frame slot structure composed of 15 slots per 10ms radio frame, with slot duration of 2560 chips (666.67 μ s). The DPDCH data rate may vary on a frame-by-frame basis, with the rate being informed on the DPCCH.

The maximum data rate on a single channel is 960 kbps without channel coding, with a spreading factor of 4. Channel coding reduces the effective rate to 480 kbps. If higher data rates are required, parallel code channels can be deployed - up to six, raising the maximum data rate to 5760 kbps without coding and 2.3 Mbps with coding.

The DPDCH channel structure is illustrated in Figure 5-12. Table 5-4 summarizes the data rates with and without coding for the different spreading factors supported. The rates with coding assume a $\frac{1}{2}$ -rate coding and do not include tail bits or Cyclic Redundancy Check (CRC) bits.

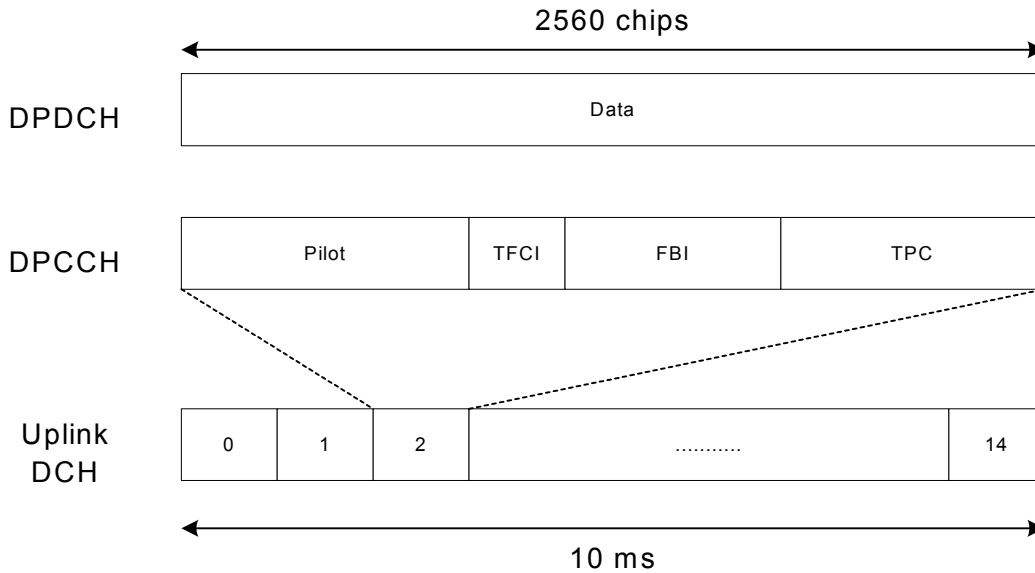


Figure 5-12 Uplink dedicated channel structure. [ET97, HOL00]

DPDCH spreading factor	DPDCH channel bit rate (kbps)	Maximum user data rate with R=1/2 coding (kbps)
256	15	7.5
128	30	15
64	60	30
32	120	60
16	240	120
8	480	240
4	960	480
4, with 6 parallel channels	5760	2300

Table 5-4 – WCDMA Uplink Dedicated Physical Data Channel (DPDCH) data rates with and without coding. [Hol00]

5.2.5.5 Modulation

The complex-valued uplink signal produced by the diagram shown in Figure 5-8 is fed to the modulator illustrated in Figure 5-12. Square-Root Raised Cosine pulse shaping with roll-off factor equal to 0.22 is employed.

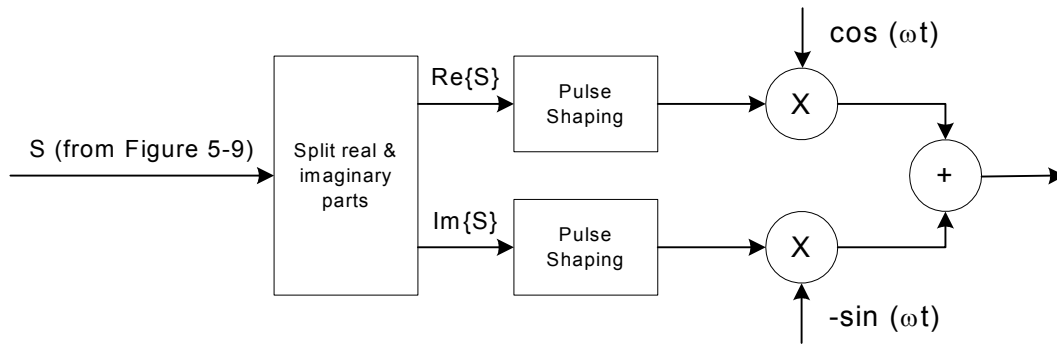


Figure 5-13 – WCDMA Uplink Modulator. [3GP01i]

5.2.6 Downlink Coding and Modulation

5.2.6.1 Channel Coding and Multiplexing

The downlink coding and multiplexing chain is very similar to the uplink one, consisting of the same steps, as illustrated in Figure 5-14. The main difference is in the order in which the rate matching and the interleaving functions are performed.

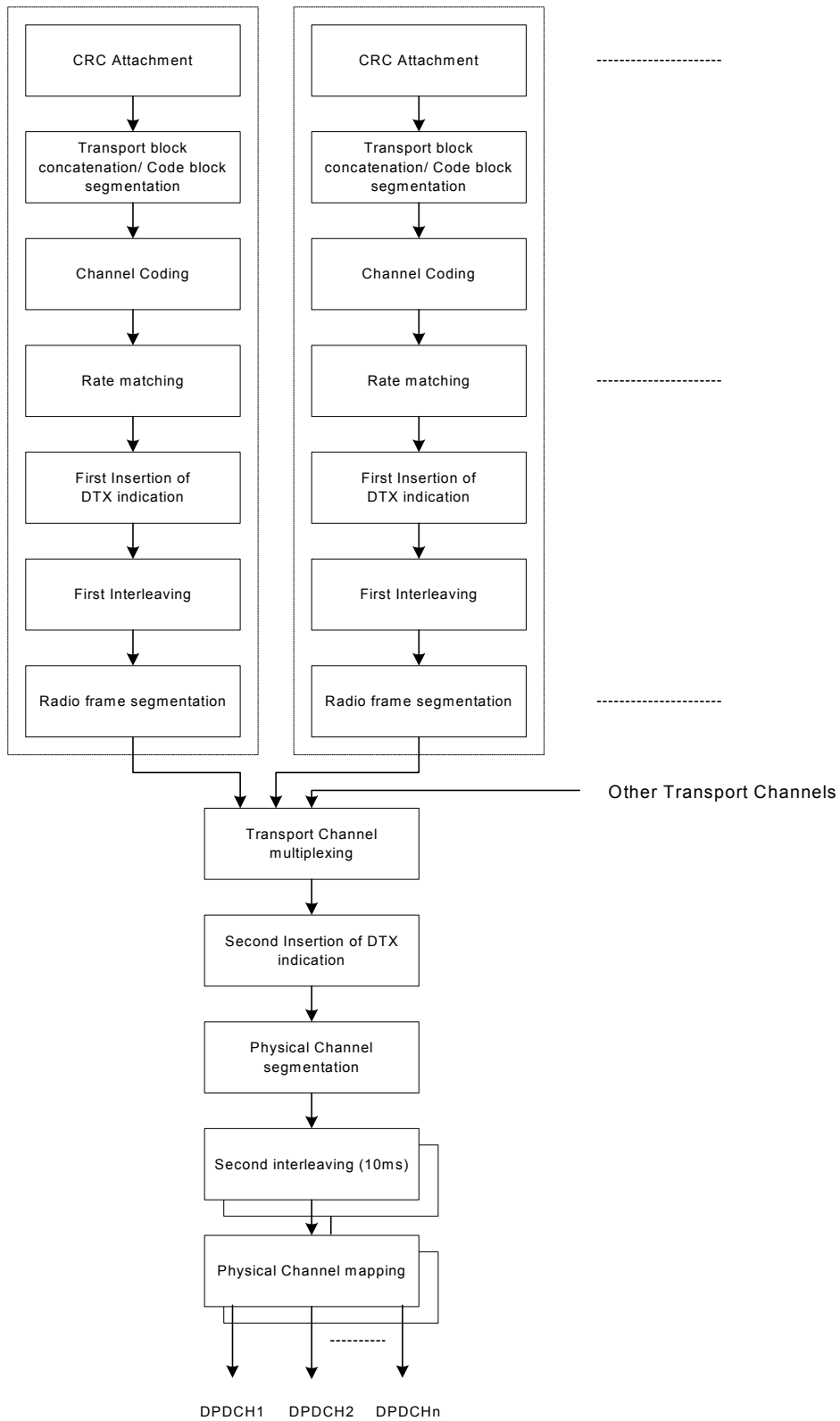


Figure 5-14 - Downlink Coding and Multiplexing chain. [3GP01h]

5.2.6.2 Spreading (Channelization Codes)

The downlink channelization codes are the same as used in the downlink. Each cell site sector utilizes one code tree (one scrambling code) and all links established in the sector share the assigned code tree. Common channels and dedicated channels share the same code tree with the exception of the SCH, which is not under a scrambling code [Hol00].

Unlike in the uplink, the downlink spreading factor does not vary on a frame-by-frame basis. Data rate variation is accomplished either by rate matching or by discontinuous transmission. When parallel code channels are used for a single user all codes have the same spreading factor and are under the same code tree [Hol00]. Figure 5-15 shows the block diagram of the downlink multiplexer, while Figure 5-16 illustrates how different channels are combined.

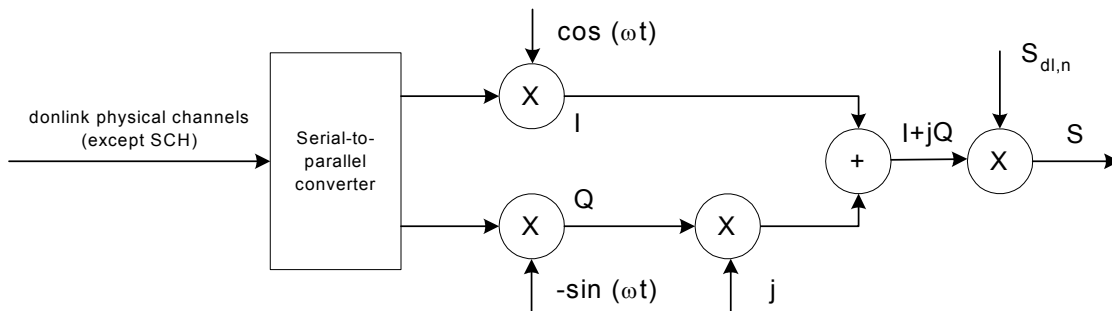


Figure 5-15 – Downlink I-Q code multiplexer. [3GP01i]

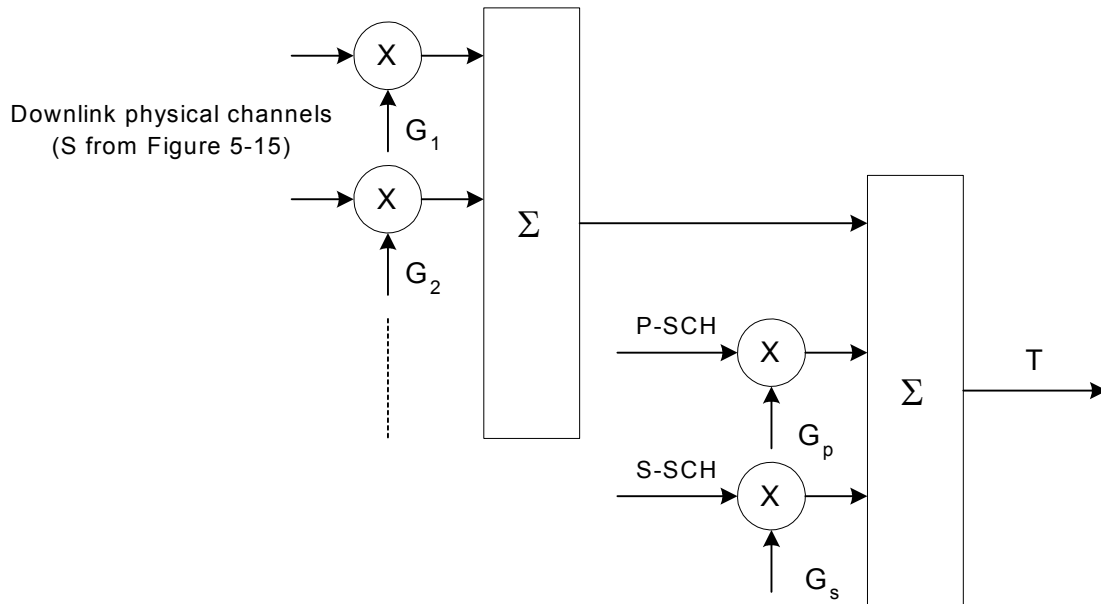


Figure 5-16 -Combining of the downlink physical channels. [3GP01i]

5.2.6.3 Downlink Scrambling

The downlink scrambling codes are derived from the same family of long codes used in the uplink - Gold codes. The short codes are not used in the downlink. A total of $2^{18}-1 = 262,143$ scrambling codes can be generated, but not all of them are used. A primary and a secondary group have been defined. The set of primary scrambling codes is limited to 512 sequences, in order to facilitate the cell search procedure. There is, therefore, the need for code planning during the network design phase. The secondary group contains 15 sequences.

Figure 5-17 shows the block diagram of the downlink scrambling code generator.

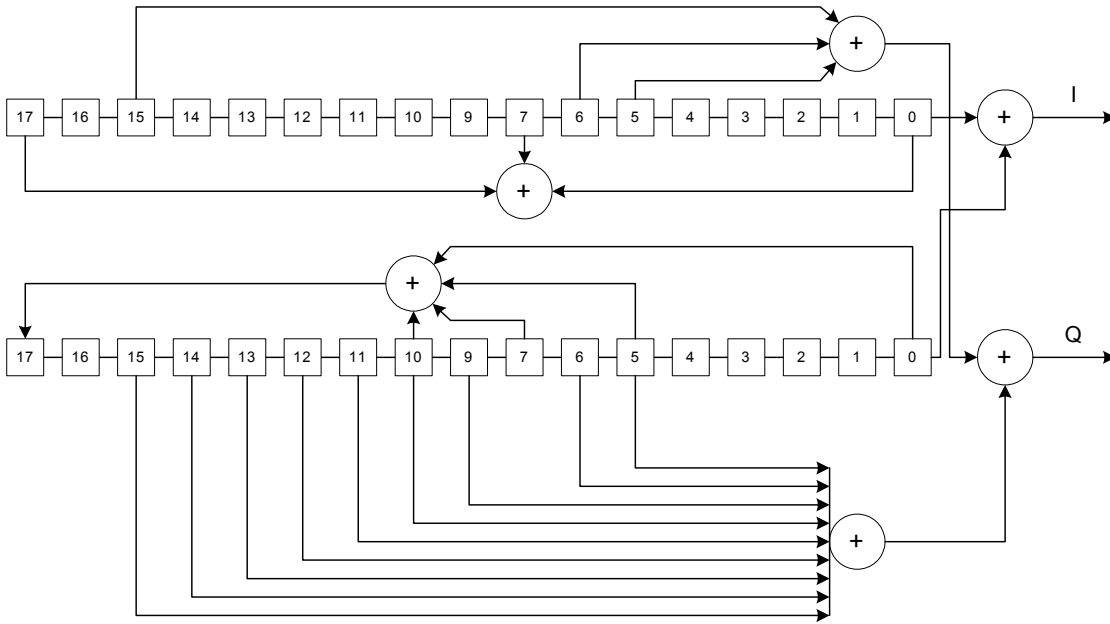


Figure 5-17 - Downlink scrambling code generator. [3GP01i]

5.2.6.4 Downlink Dedicated Channel Structure

The downlink DPDCH also has a frame slot structure composed of 15 slots per 10ms radio frame, with the slot duration totaling 2560 chips (666.67 μ s). The spreading factors range from 4 to 512. Restrictions in the time adjustment step of 256 chips during soft handoff limit the use of the spreading factor 512. Such spreading factor is generally used when there is low downlink activity and in these cases soft handoffs are rarely required. Figure 5-18 shows the slot and frame structures for the downlink DPCH and Table 5-5 lists the maximum data rates for the various supported spreading factors with and without coding.

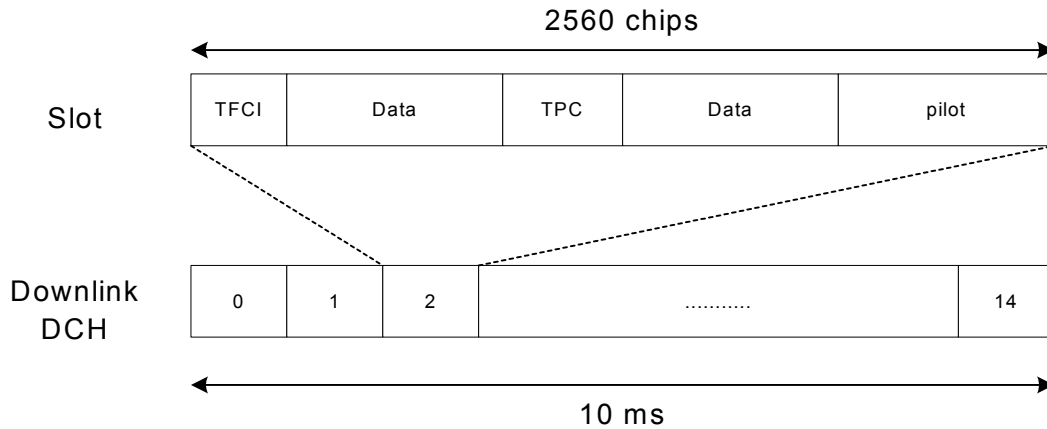


Figure 5-18 - Downlink dedicated channel structure. [ET97, HOL00]

Spreading Factor	Channel Symbol Rate (kbps)	Channel Bit Rate (kbps)	DPDCH channel bit rate range (kbps)	Maximum user data rate with ½ rate coding (kbps)
512	7.5	15	3~6	1~3
256	15	30	12~24	6~12
128	30	60	42~51	20~24
64	60	120	90	45
32	120	240	210	105
16	240	480	432	215
8	480	960	912	456
4	960	1920	1872	936
4, with 3 parallel codes	2880	5760	5616	2,300

Table 5-5 – WCDMA Downlink Dedicated Physical Data Channel (DPDCH) data rates with and without coding. [Hol00]

5.2.6.5 Downlink Modulation

The downlink utilizes conventional QPSK modulation with time-multiplexed control and data streams. The effect of DTX is not present in the downlink, since the common

channels are continuously transmitted. Figure 5-19 illustrates the block diagram for the downlink modulator. Square-Root Raised Cosine pulse shaping with roll-off factor equal to 0.22 is employed.

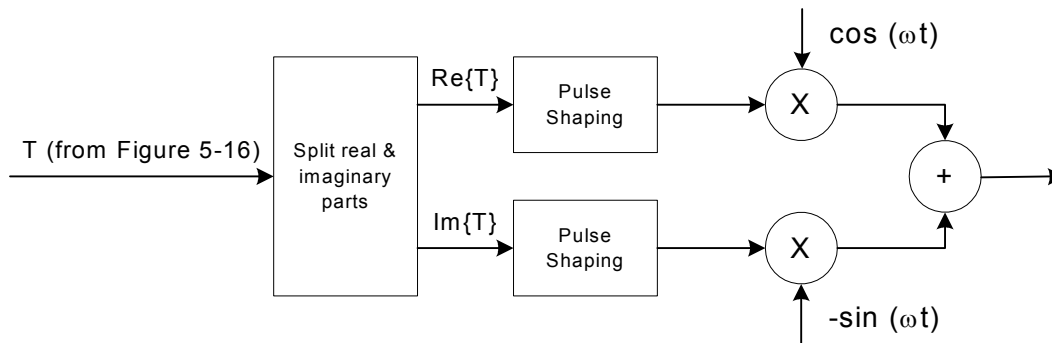


Figure 5-19 - Downlink Quadrature Phase shift Keying (QPSK) modulator. [3GP01i]

5.3 WCDMA Power Control Mechanisms

Power control is a fundamental part of CDMA-based systems, particularly in the uplink. The fundamental reason for the uplink power control is to prevent any overpowered mobile stations from blocking access to the whole cell by unnecessarily raising the noise level.

WCDMA employs power control in both the downlink and uplinks. The solution for both links is based on a dual-loop technique. The outer loop utilizes an open-loop to provide a coarse initial power setting at the beginning of the connection. The inner-loop is a fast closed-loop control acting at a rate of 1.5 kHz, i.e., 1,500 corrections per second.

In the uplink the base station performs the estimates of the received Signal-to-Interference Ratio (SIR) and compares it to a target value. If the received SIR is higher than the target it commands the mobile station to power down; if it is lower it commands the mobile station to power up.

The downlink uses power control to improve link performance as the mobile moves away from the serving cell, suffering increased other-cell interference. Also, it provides additional power margin for low-speed mobiles affected by Rayleigh fading. At low speeds the interleaving and error correcting codes do not work effectively, because the duration of the fading nulls may cause more bits to be in error than those mechanisms can correct. In these cases the fast downlink power control helps compensate for the diminished signal-to-noise due to fading.

Figure 5-20 exemplifies the power control reaction to a fading channel and Figure 5-21 shows the resulting received power for the same link.

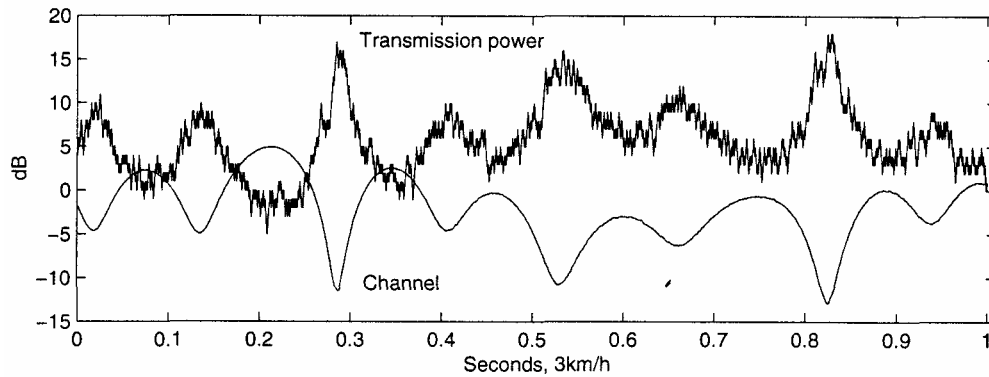


Figure 5-20 - Reaction of the WCDMA closed-loop fast power control to the fading channel. [Hol00]

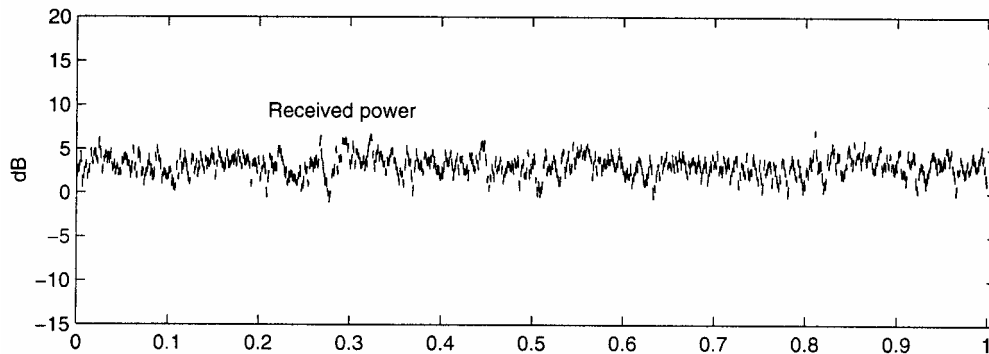


Figure 5-21 - Effect of the WCDMA closed-loop fast power control on the received power. [Hol00]

When compared to a link with slow power control, fast power control reduces the necessary E_b/N_0 for the same quality requirement. Table 5-6 shows the gain obtained with power control for three propagation environments.

	Eb/No (dB) - Slow Power Control (dB)	Eb/No (dB) - Fast Power Control – 1.5 kHz	Gain from fast power control (dB)
ITU Pedestrian A 3 Km/h	11.3	5.5	5.8
ITU Vehucular A 3 Km/h	8.5	6.7	1.8
ITU Vehucular A 50 Km/h	6.8	7.3	-0.5

Table 5-6 – Required E_b/N_0 values for WCDMA with slow power control and fast power control for different propagation environments. [Hol00]

5.4 Simulations on WCDMA Link Performance

5.4.1 Background to the Simulation Results

WCDMA link level performance has been extensively researched and simulated. The numerous test conditions arising from the complexity of the technology have produced a vast array of simulation results. This work focuses on those for the test scenarios defined by the standardization committees, namely the European Telecommunications Standard Institute (ETSI). These test scenarios were defined with the intention of allowing for the performance comparison between the various competing proposals submitted as candidates to the 3G selection process.

The simulation results presented herein were obtained by the group of contributors responsible for the original WCDMA Concept Evaluation Proposal submitted to the ITU. This group of contributors is known within the IMT-2000 framework as Group Alfa, being composed of several university and industrial partners, among them Ericsson, Nokia, Siemens, France Telecom, Fujitsu, NEC and Panasonic.

5.4.2 Simulation Environments and Services

The services and environments simulated are summarized in Table 5-7. They cover the wide range of applications envisioned for third generation networks, as well as the different environments where the services are expected to be available.

Test Service	Parameter	Indoor	Outdoor to Indoor and Pedestrian	Vehicular - 120 Km/h	Vehicular - 500 Km/h
Low delay data bearer – Speech	Bit rate	8 kbps	8 kbps	8 kbps	8 kbps
	BER	$\leq 10E-3$	$\leq 10E-3$	$\leq 10E-3$	$\leq 10E-3$
	Delay	20 ms	20 ms	20 ms	20 ms
	Channel Activity	50%	50%	50%	50%
Circuit-switched, low delay – LDD Data	Bit rate	144-384-2048 kbps	64 - 144 - 384 kbps	32 - 144 - 384 kbps	32 - 144 - 384 kbps
	BER	$\leq 10E-6$	$\leq 10E-6$	$\leq 10E-6$	$\leq 10E-6$
	Delay	50 ms	50 ms	50 ms	50 ms
	Channel Activity	100%	100%	100%	100%
Circuit-switched, long delay, constrained – LCD Data	Bit rate	144-384-2048 kbps	64 - 144 - 384 kbps	32 - 144 - 384 kbps	32 - 144 - 384 kbps
	BER	$\leq 10E-6$	$\leq 10E-6$	$\leq 10E-6$	$\leq 10E-6$
	Delay	300 ms	300 ms	300 ms	300 ms
	Channel Activity	100%	100%	100%	100%
Connection-less packet – UDD Data	Bit rate	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1
	BER	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1
	Delay	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1
	Channel Activity	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1	See 5.4.2.1

Table 5-7 - Test services and environments [ET98]

5.4.2.1 The Circuit Switched and Packet Switched Modes

One of the requirements for third generation technologies is the support of packet data transmission. The conventional operational mode supported by first and second generation technologies is named Circuit Switched. In this mode, once a connection is established between both ends, the circuit is dedicated to those users and no other users are allowed to share the resources, even if there is no utilization of the channel. A voice connection is generally active for less than 50 % of time. Usually one user is talking while the other is listening and the pause between sentences represents idle time in the channel. Such usage pattern results in sub-utilization of the channel.

The Packet Switched mode (connection-less) allows multiple users to share the same resource by benefiting from the idle times described in the previous paragraph. This mode is ideal for digital transmission, since data can be arranged in packets of equal size, allowing the system to accommodate multiple users in a single circuit by transmitting packets from one user during the idle time of other users.

The nature of packet data traffic requires a different modeling approach, departing from the conventional circuit-switched traffic models in use for voice telephony. A packet data call (or connection) is named a *session* and within its duration there are data *bursts*. Each burst is composed of a certain number of data *packets*, which, in turn, have their own duration. Both the duration of these events and the interval between their occurrences are used as parameters in the modeling of packet data traffic.

In circuit-switched telephony the Erlang distribution has been used to model traffic. Studies and measurements of data traffic, including the Internet traffic, have shown that the Erlang model is not suitable for modeling these applications, for they present a distinctive *self-similar behavior*, better characterized by long-tailed distributions such as the Pareto distribution. The rationale behind this different behavior is justified by the nature of data transmission. Most of the traffic during a data session is composed of short data bursts. Occasionally long and very long bursts will occur, but the duration of these

bursts prevent other users for using it. This new traffic pattern required different simulation scenarios for technologies supporting high data rate applications in packet switched modes. A comprehensive analysis on self-similarity can be found in [Par00].

The Pareto distribution, whose probability density function (pdf) and probability distribution function (PDF) are shown below, has been used to model the self-similar behavior of data traffic.

$$\text{pdf:} \quad p(x) = \alpha k^\alpha x^{-\alpha-1} \quad 0 < k \leq x$$

$$\text{PDF:} \quad F(x) = P[X \leq x] = 1 - \left(\frac{k}{x}\right)^\alpha$$

Where:

K : Is the smallest possible value of the random variable. Represents the minimum packet size.

α : Variable that defines the “weight” of the distribution’s tail; the smaller its value, the heavier the tail of the distribution.

The packet switched simulation modes defined for the link level performance of WCDMA are based on the Pareto distribution for the length of the data packet. The inter-arrival time of packets follows the Poisson distribution (the same distribution used to model voice traffic). Table 5-8 shows the test scenarios and related parameters for connection-less packet data.

Packet-based service types	Average number of bursts within a session	Average reading time between packet calls [s]	Average amount of packets within a burst	Average interarrival time between packets [s]	Parameters for the packet size distribution - Pareto
WWW surfing UDD 8 kbit/s	5	412	25	0.5	K=81.5 Alfa=1.1
WWW surfing UDD 32 kbit/s	5	412	25	0.125	K=81.5 Alfa=1.1
WWW surfing UDD64 Kbit/s	5	412	25	0.0625	K=81.5 Alfa=1.1
WWW surfing UDD 144 Kbit/s	5	412	25	0.0277	K=81.5 Alfa=1.1
WWW surfing UDD 384 Kbit/s	5	412	25	0.0104	K=81.5 Alfa=1.1
WWW surfing UDD 2048 Kbit/s	5	412	25	0.0195	K=81.5 Alfa=1.1

Table 5-8 - Test scenarios and simulation parameters for connection-less packet data simulations. [ET98]

5.4.3 Downlink Performance

The WCDMA downlink has been simulated for test cases and environments listed in Tables 5-6 and 5-7. The results for the following models are presented:

- Vehicular Channels A & B
- Outdoor to Indoor and Pedestrian Channels A & B
- Indoor Channels A & B.

A detailed description of these models is presented in [ET98]. The following sections summarize the results.

5.4.3.1 Speech, Indoor Office A, 3 Km/h

The simulation parameters are:

Figure	5-22	5-22	5-22	5-23	5-23	5-23
Parameter	Value					
Service	Speech	Speech	Speech	Speech	Speech	Speech
Link-level bit rate	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps
Channel type	Indoor A	Indoor A	Indoor A	Indoor A	Indoor A	Indoor A
Mobile Speed	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h
Antenna Diversity	No	No	No	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096	4.096	4.096
DPDCH						
Code Allocation	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128
Information/CRC/Tail bits	80/8/8	80/8/8	80/4/4	80/8/8	80/8/8	80/4/4
Convolutional Code Rate	1/3	1/3	1/3	1/3	1/3	1/3
Rate matching	9/10	9/10	33/40	9/10	9/10	33/40
Interleaver	10 ms	10 ms	20 ms	10 ms	20 ms	20 ms
DPCCH						
Code Allocation	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256
Power control [Hz]	800	800	800	800	800	800
Power Control step [dB]	1	1	1	1	1	1
Slots per frame	8	8	8	8	8	8
Pilot/PC/FCH bits per slot	12/4/4	16/4/0	16/4/0	12/4/4	12/4/4	16/4/0
DPDCH-DPCCH power [dB]	-3	-3	-3	-3	-3	-3

Table 5-9 – Simulation parameters for Indoor Office A, 3 Km/h [ET97]

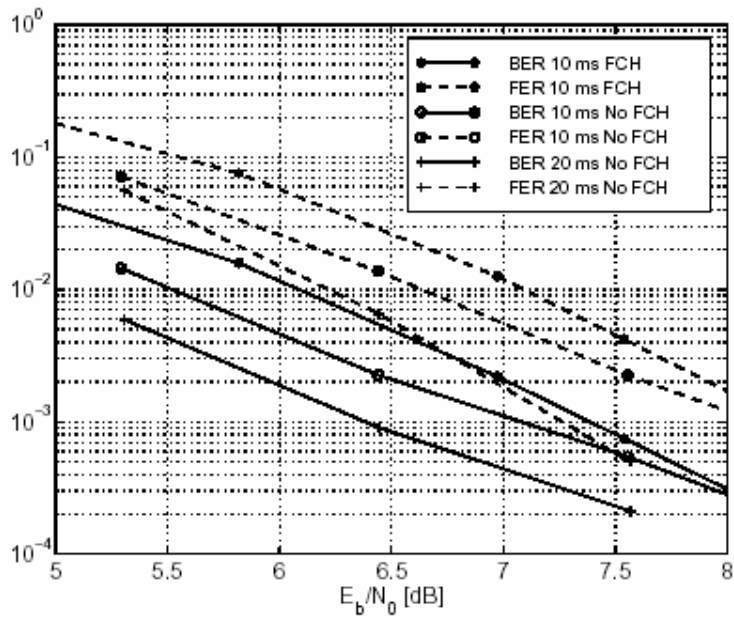


Figure 5-22 – Bit Error Rate (BER) & Frame Error Rate (FER) versus E_b/N_0 for Speech, Indoor Office A, without antenna diversity, Bit Rate= 8kbps, 3Km/h. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

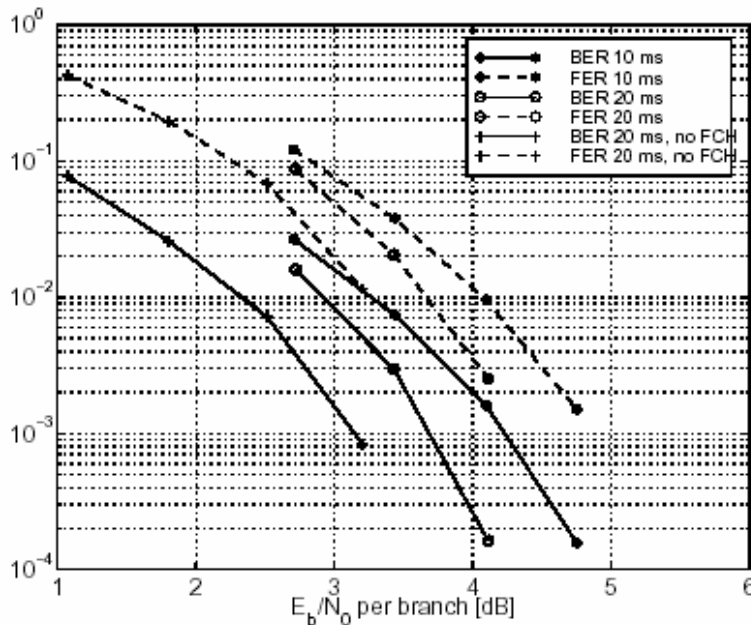


Figure 5-23 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Indoor Office A, with antenna diversity, Bit Rate= 8kbps, 3Km/h. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

5.4.3.2 Speech, Outdoor to Indoor and Pedestrian A, 3 Km/h

The simulation parameters are:

Figure	5-24	5-24	5-24	5-25	5-25	5-25
Parameter	Value					
Service	Speech	Speech	Speech	Speech	Speech	Speech
Link-level bit rate	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps
Channel type	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A
Mobile Speed	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h
Antenna Diversity	No	No	No	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096	4.096	4.096
DPDCH						
Code Allocation	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128
Information/CRC/Tail bits	80/8/8	80/8/8	80/4/4	80/8/8	80/8/8	80/4/4
Convolutional Code Rate	1/3	1/3	1/3	1/3	1/3	1/3
Rate matching	9/10	9/10	33/40	9/10	9/10	33/40
Interleaver	10 ms	10 ms	20 ms	10 ms	20 ms	20 ms
DPCCH						
Code Allocation	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256
Power control [Hz]	800	800	800	800	800	800
Power Control step [dB]	1	1	1	1	1	1
Slots per frame	8	8	8	8	8	8
Pilot/PC/FCH bits per slot	12/4/4	16/4/0	16/4/0	12/4/4	12/4/4	16/4/0
DPDCH-DPCCH power [dB]	-3	-3	-3	-3	-3	-3

Table 5-10 – Simulation parameters for Outdoor to Indoor and Pedestrian A, 3 Km/h [ET97]

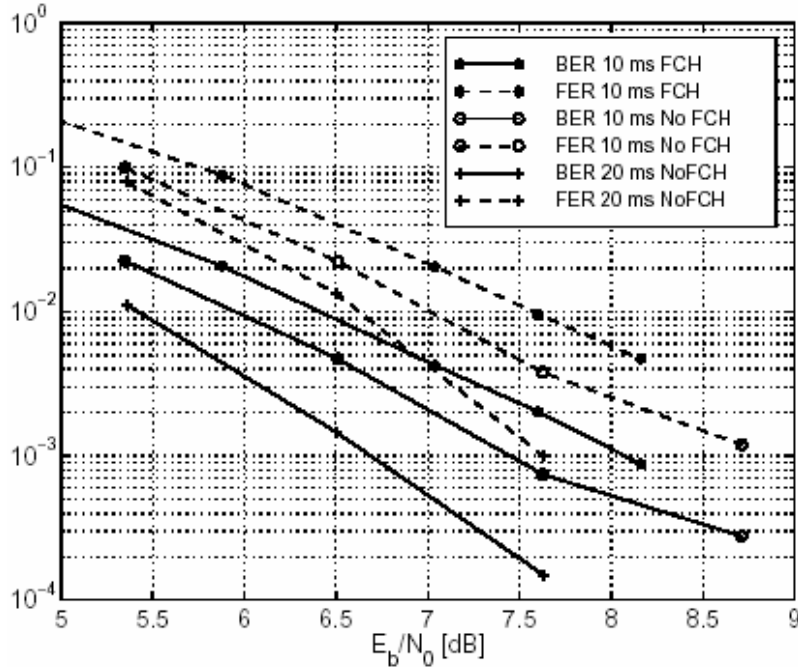


Figure 5-24 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Outdoor to Indoor and Pedestrian A, without antenna diversity, Bit Rate= 8kbps, 3Km/h. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=1 dB. slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

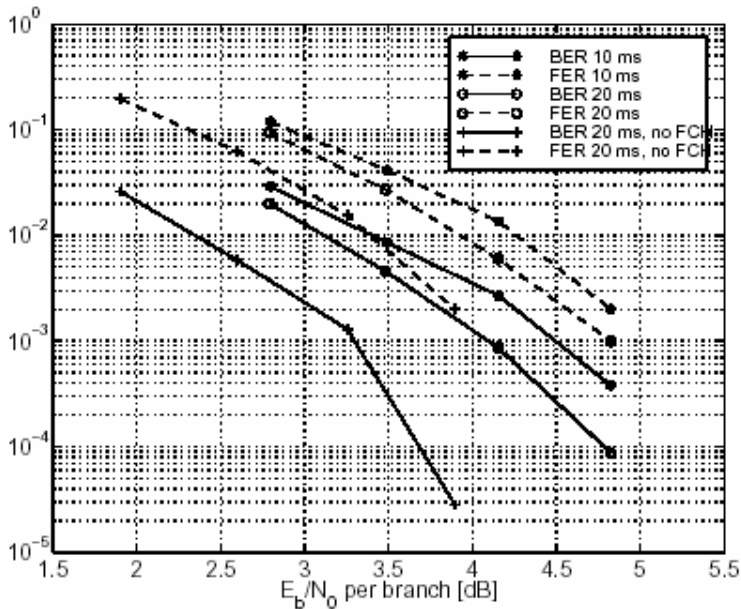


Figure 5-25 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Outdoor to Indoor and Pedestrian A, with antenna diversity, Bit Rate= 8kbps, 3Km/h. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

5.4.3.3 Speech, Vehicular A, 120 Km/h

The simulation parameters are:

Figure	5-26	5-26	5-26	5-27	5-27	5-27	5-27
Parameter	Value						
Service	Speech	Speech	Speech	Speech	Speech	Speech	Speech
Link-level bit rate	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps	8 kbps
Channel type	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A	Out. To Ind. A
Mobile Speed	120 Km/h	120 Km/h	120 Km/h	120 Km/h	120 Km/h	120 Km/h	120 Km/h
Antenna Diversity	No	No	No	No	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096	4.096	4.096	4.096
DPDCH							
Code Allocation	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128	1xSF128
Information/CRC/Tail bits	80/8/8	80/8/8	80/4/4	80/4/4	80/8/8	80/8/8	80/4/4
Convolutional Code Rate	1/3	1/3	1/3	1/3	1/3	1/3	1/3
Rate matching	9/10	9/10	33/40	33/40	9/10	9/10	33/40
Interleaver	10 ms	10 ms	20 ms	20 ms	10 ms	20 ms	20 ms
DPCCH							
Code Allocation	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256
Power control [Hz]	1600	1600	1600	1600	1600	1600	1600
Power Control step [dB]	0.25	0.5	0.25	0.25	0.5	0.5	0.25
Slots per frame	16	16	16	16	16	16	16
Pilot/PC/FCH bits per slot	7/1/2	8/2/0	7/1/2	8/2/0	6/2/2	6/2/2	8/2/0
DPDCH-DPCCH power [dB]	-3	-3	-3	-3	-3	-3	-3

Table 5-11 - Simulation parameters for Vehicular A, 120 Km/h [ET97]

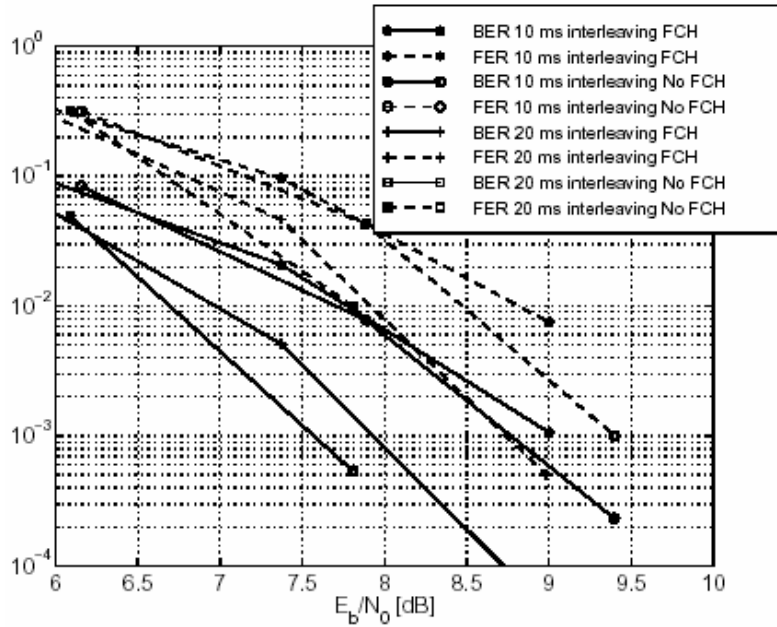


Figure 5-26 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular A 120 Km/h, without antenna diversity, Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 & 0.5 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

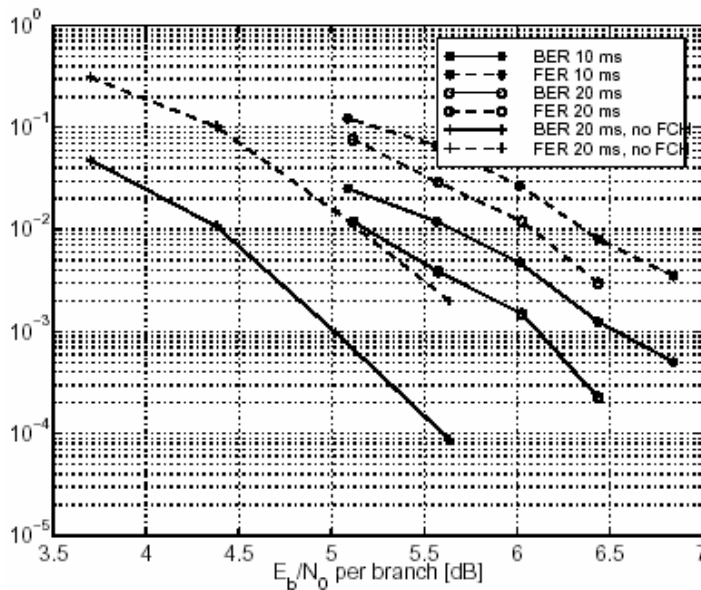


Figure 5-27 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular A 120 Km/h, with antenna diversity. Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 & 0.5 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

5.4.3.4 Speech, Vehicular B, 120 Km/h

The simulation parameters are:

Figure	5-28	5-29
Parameter	Value	
Service	Speech	Speech
Link-level bit rate	8 kbps	8 kbps
Channel type	Vehicular B	Vehicular B
Mobile Speed	120 Km/h	120 Km/h
Antenna Diversity	No	Yes
Chip Rate [Mcps]	4.096	4.096
DPDCH		
Code Allocation	1 x SF 128	1 x SF 128
Information/CRC/Tail bits	80/4/4	80/4/4
Convolutional Code Rate	1/3	1/3
Rate matching	33/40	33/40
Interleaver	20 ms	20 ms
DPCCH		
Code Allocation	1 x SF 256	1 x SF 256
Power control [Hz]	1600	1600
Power Control step [dB]	0.25	0.25
Slots per frame	16	16
Pilot/PC/FCH bits per slot	8/2/0	8/2/0
DPDCH-DPCCH power [dB]	-3	-3

Table 5-12 - Simulation parameters for Vehicular B, 120 Km/h [ET97]

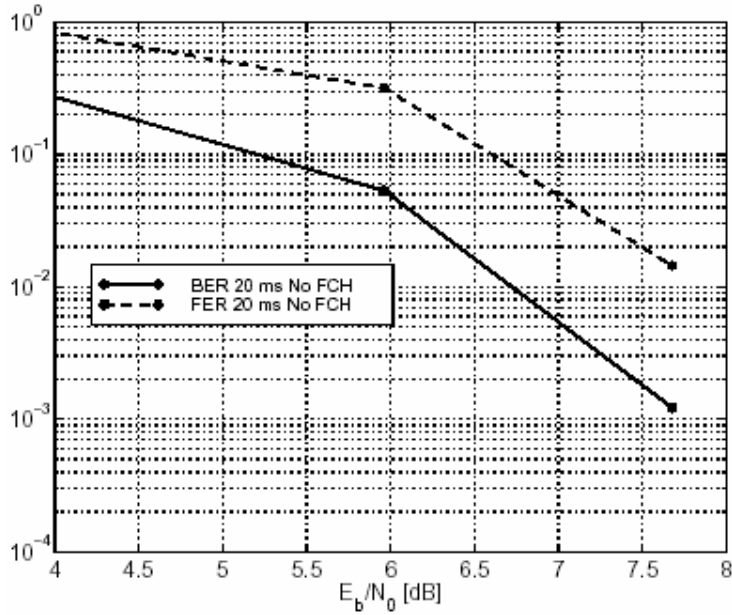


Figure 5-28 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular B 120 Km/h, without antenna diversity. Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=33/40, Interleaver= 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

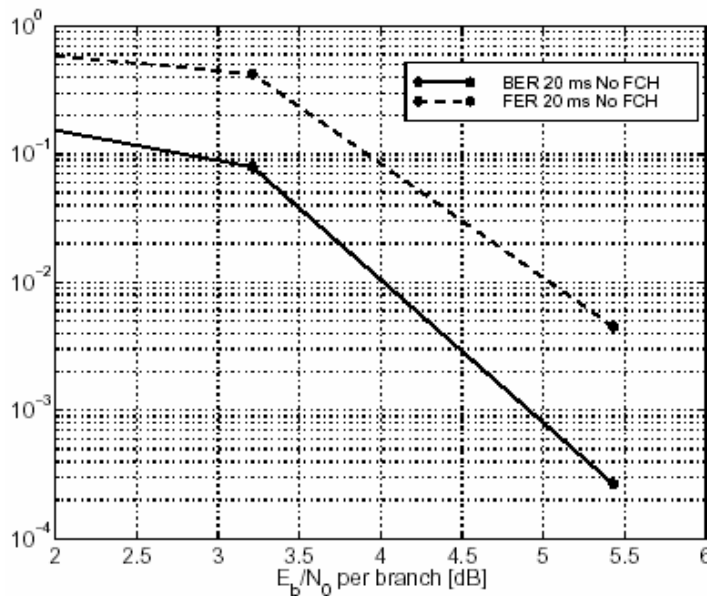


Figure 5-29 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular B 120 Km/h, with antenna diversity. Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching= 33/40, Interleaver= 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

5.4.3.5 Speech, Vehicular B, 250 Km/h

The simulation parameters are:

Figure	5-30	5-30	5-31	5-31
Parameter	Value			
Service	Speech	Speech	Speech	Speech
Link-level bit rate	8 kbps	8 kbps	8 kbps	8 kbps
Channel type	Vehicular B	Vehicular B	Vehicular B	Vehicular B
Mobile Speed	250 Km/h	250 Km/h	250 Km/h	250 Km/h
Antenna Diversity	No	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096
DPDCH				
Code Allocation	1xSF128	1xSF128	1xSF128	1xSF128
Information/CRC/Tail bits	80/8/8	80/4/4	80/4/4	80/4/4
Convolutional Code Rate	1/3	1/3	1/3	1/3
Rate matching	33/40	9/10	33/40	33/40
Interleaver	20 ms	10 ms	20 ms	20 ms
DPCCH				
Code Allocation	1xSF256	1xSF256	1xSF256	1xSF256
Power control [Hz]	3200	3200	3200	3200
Power Control step [dB]	0.25	0.25	0.25	0.25
Slots per frame	32	32	32	32
Pilot/PC/FCH bits per slot	4/1/0	3/1/1	3/1/1	4/1/0
DPDCH-DPCCH power [dB]	-3	-3	-3	-3

Table 5-13 - Simulation parameters for Vehicular B, 250 Km/h [ET97]

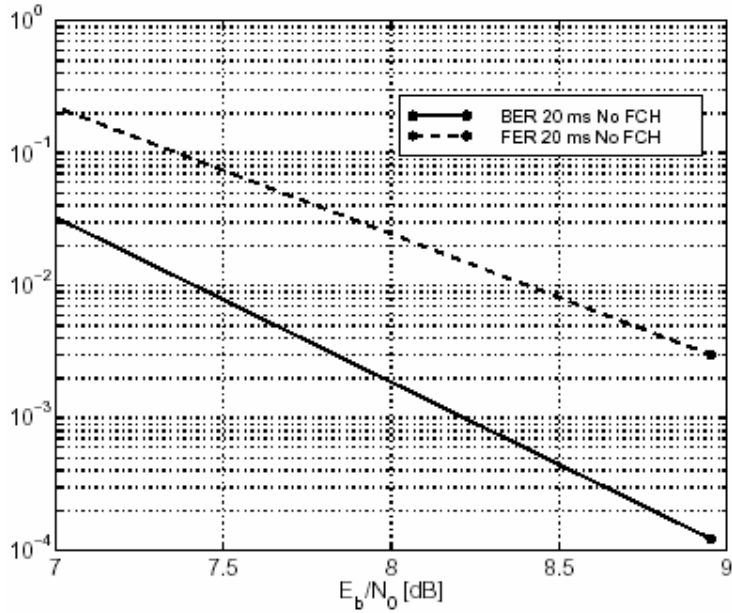


Figure 5-30 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular B 250 Km/h, without antenna diversity. Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 dB. 32 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

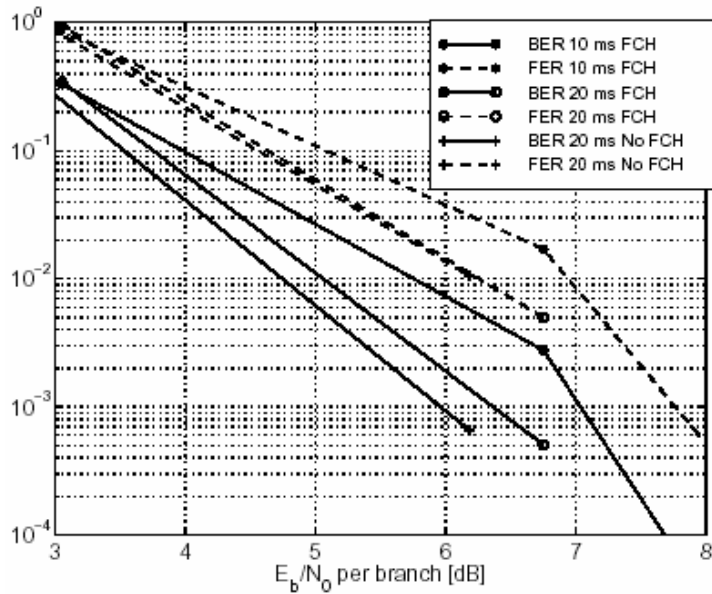


Figure 5-31 - Bit Error Rate (BER) & Frame Error Rate (FER) for Speech, Vehicular B 250 Km/h, with antenna diversity. Bit Rate= 8kbps. DPDCH: Spreading Factor=128, Convolutional Code Rate=1/3, Rate Matching=9/10 & 33/40, Interleaver=10 & 20 ms. DPCCH: Spreading Factor=256, Power Control Step=0.25 & 0.5 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 3dB. [ET97]

5.4.3.6 Circuit Switched, Long Constrained Data Delay – LCD, Multiple Channel Types

The simulation parameters are:

Figure	5-32	5-32	5-32	5-33	5-33
Service	LCD 144	LCD 144	LCD 144	LCD 144	LCD 144
Link-level bit rate	144 kbps	144 kbps	384 kbps	384 kbps	2048 kbps
Channel type	Out. To Ind. A	Indoor A	Vehicular A	Indoor A	Indoor A
Mobile Speed	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h
Antenna Diversity	Yes	Yes	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096	4.096
DPDCH					
Code Allocation	1xSF8	1xSF4	1xSF4	1xSF4	5xSF4
Information/CRC/Tail bits	1440/8	3840/3x8	3840/3x8	3840/3x8	1440/8
Reed-Solomon Code Rate	180/225	192/240	192/240	192/240	192/240
Convolutional Code Rate	1/3	1/2	1/2	1/2	1/2
Rate matching	339/320	603/640	603/640	603/640	201/220
Inner Interleaver [bits]	128x480	256x480	128x960	256x480	300x256
Outer Interleaver [bytes]	225x12	80x90	240x30	80x90	240x160
DPCCH					
Code Allocation	1xSF256	1xSF256	1xSF256	1xSF256	1xSF256
Power control [Hz]	800	800	1600	800	800
Power Control step [dB]	1	1	1	1	1
Slots per frame	8	8	16	8	8
Pilot/PC/FCH bits per slot	12/4/4	12/4/4	6/2/2	12/4/4	12/4/4
DPDCH-DPCCH power [dB]	-10	-10	-10	-10	-10

Table 5-14 - Simulation parameters for LCD [ET97]

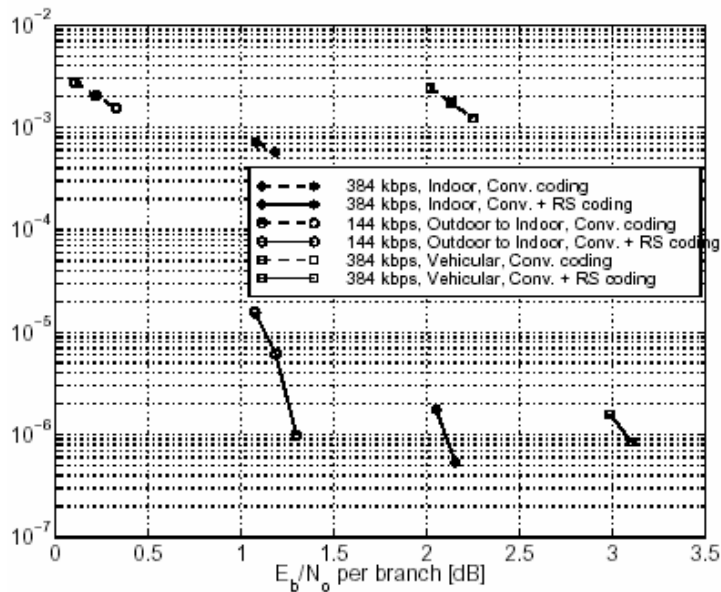


Figure 5-32 - Bit Error Rate (BER) versus E_b/N_0 for LCD 144 and LCD 384 with antenna diversity. Bit Rate= 144kbps & 384 kbps. DPDCH: Spreading Factor=8, 4 & 5x4, Convolutional Code Rate=1/3 & 1/2, Rate Matching=339/320 & 603/640. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 & 16 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

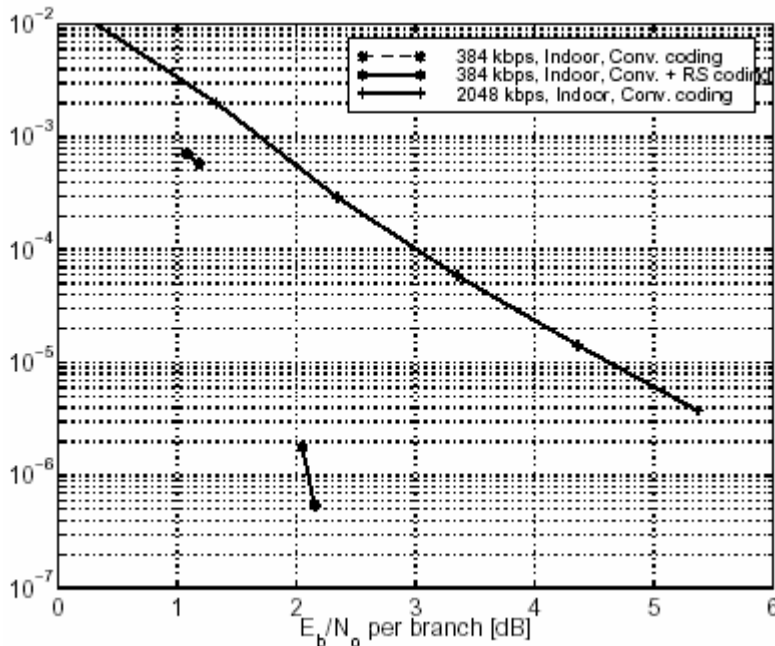


Figure 5-33 - Bit Error Rate (BER) versus E_b/N_0 for LCD 2048 with antenna diversity. Bit Rate= 384kbps & 2048 kbps. DPDCH: Spreading Factor=4 & 5x4, Convolutional Code Rate=1/2, Rate Matching=201/200 & 603/640. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

5.4.3.7 Unconstrained Data Delay - UDD 144, Vehicular A

The simulation parameters are:

Figure	5-34	5-35
Parameter	Value	
Service	UDD 144	UDD 144
Link-level bit rate	240 kbps	240 kbps
Channel type	Vehicular A	Vehicular A
Mobile Speed	120 Km/h	120 Km/h
Antenna Diversity	No	Yes
Chip Rate [Mcps]	4.096	4.096
DPDCH		
Code Allocation	1 x SF 8	1 x SF 8
Information/CRC/Tail bits	300/12/8	300/12/8
Convolutional Code Rate	1/2	1/2
Rate matching	None	None
Interleaver	20 ms	20 ms
DPCCH		
Code Allocation	1 x SF 256	1 x SF 256
Power control [Hz]	1600	1600
Power Control step [dB]	1	1
Slots per frame	16	16
Pilot/PC/FCH bits per slot	6/2/2	6/2/2
DPDCH-DPCCH power [dB]	-8	-10

Table 5-15 - Simulation parameters for Vehicular A, UDD 144, 120 Km/h [ET97]

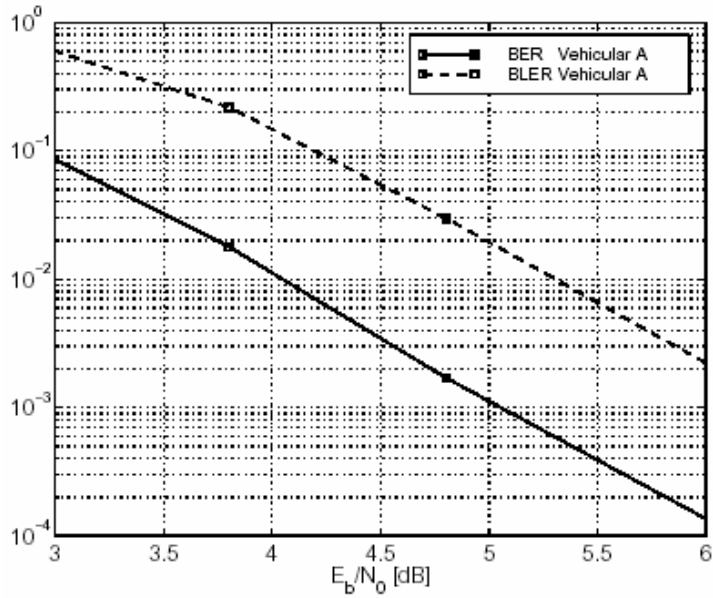


Figure 5-34 - Bit Error Rate (BER) & Block Error Rate (BLER) versus E_b/N_0 for UDD 144, without antenna diversity. Bit Rate= 240 kbps. DPDCH: Spreading Factor=8, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 8 dB. [ET97]

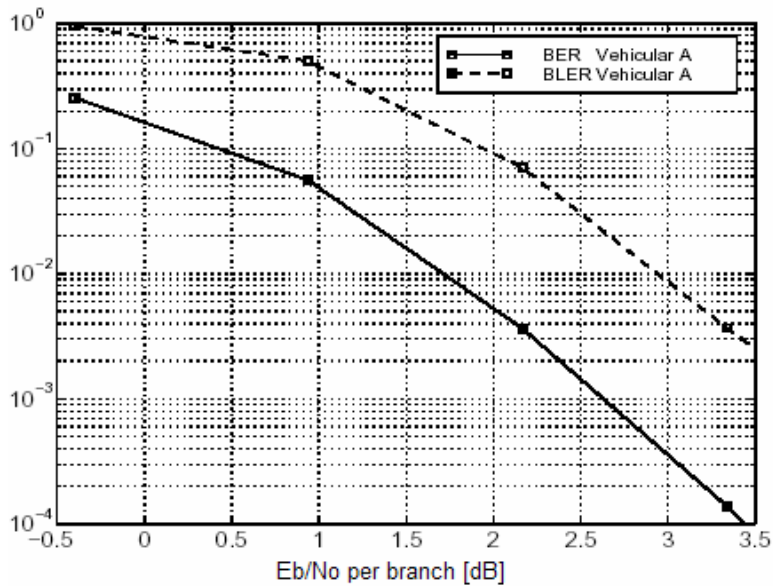


Figure 5-35 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 144, with antenna diversity. Bit Rate= 240 kbps. DPDCH: Spreading Factor=8, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

5.4.3.8 Unconstrained Data Delay - UDD 384, Outdoor to Indoor

The simulation parameters are:

Figure	5-36	5-38
Parameter	Value	
Service	UDD 384	UDD 384
Link-level bit rate	240 kbps	240 kbps
Channel type	Out. To Ind. A	Out. To Ind. A
Mobile Speed	3 Km/h	3 Km/h
Antenna Diversity	No	Yes
Chip Rate [Mcps]	4.096	4.096
DPDCH		
Code Allocation	1 x SF 8	1 x SF 8
Information/CRC/Tail bits	300/12/8	300/12/8
Convolutional Code Rate	1/2	1/2
Rate matching	None	None
Interleaver	10 ms	10 ms
DPCCH		
Code Allocation	1 x SF 256	1 x SF 256
Power control [Hz]	800	800
Power Control step [dB]	0.5	0.5
Slots per frame	8	8
Pilot/PC/FCH bits per slot	14/2/4	14/2/4
DPDCH-DPCCH power [dB]	-10	-10

Table 5-16 - Simulation parameters for Outdoor to Indoor A, UDD 384, 3 Km/h [ET97]

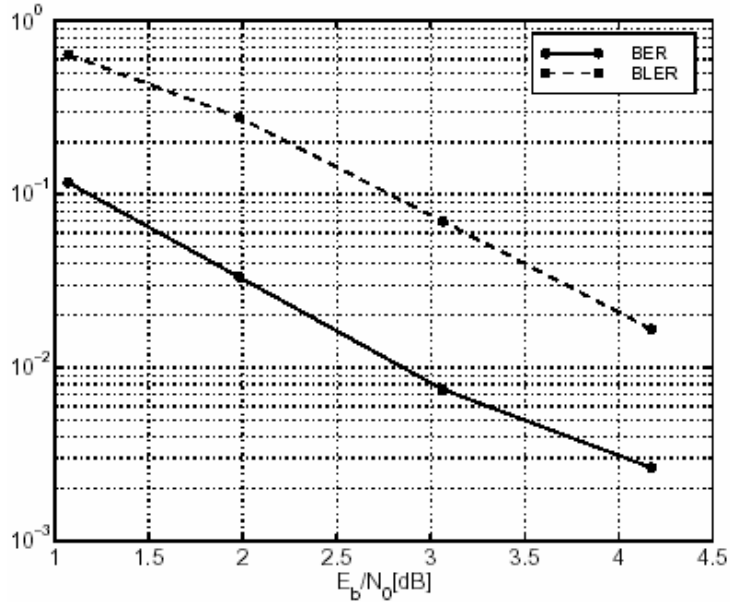


Figure 5-36 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 384, without antenna diversity. Bit Rate= 240 kbps. DPDCH: Spreading Factor=8, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

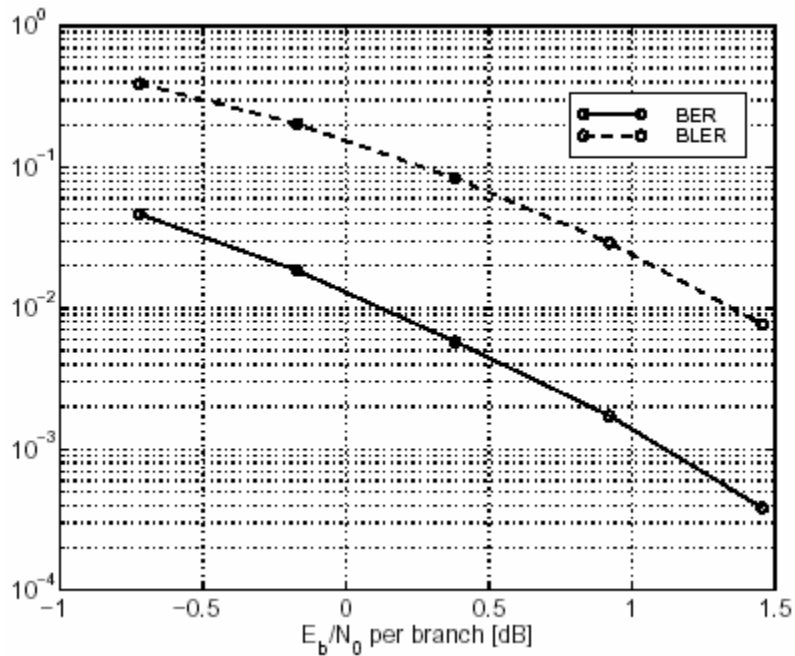


Figure 5-37 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 384, with antenna diversity. Bit Rate= 240 kbps. DPDCH: Spreading Factor=8, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 16 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

5.4.3.9 Unconstrained Data Delay - UDD 2048, Multiple Channel Types

The simulation parameters are:

Figure	5-38	5-38	5-39	5-39	5-40	5-40
Parameter	Value					
Service	UDD2048	UDD2048	UDD2048	UDD2048	UDD2048	UDD2048
Link-level bit rate	480 kbps	480 kbps	480 kbps	480 kbps	2.4 Mbps	2.4 Mbps
Channel type	Indoor A	Out. to Ind. A	Indoor A	Out. to Ind. A	Indoor A	Out. to Ind. A
Mobile Speed	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h	3 Km/h
Antenna Diversity	No	No	Yes	Yes	Yes	Yes
Chip Rate [Mcps]	4.096	4.096	4.096	4.096	4.096	4.096
DPDCH						
Code Allocation	1 x SF4	1 x SF4	1 x SF4	1 x SF 4	5 x SF4	5 x SF4
Information/CRC/Tail bits	300/12/8	300/12/8	300/12/8	300/12/8	300/12/8	300/12/8
Convolutional Code Rate	1/2	1/2	1/2	1/2	1/2	1/2
Rate matching	None	None	None	None	None	None
Interleaver	10 ms	10 ms	10 ms	10 ms	10 ms	10 ms
DPCCH						
Code Allocation	1 x SF256	1 x SF256	1 x SF256	1 x SF256	1 x SF256	1 x SF256
Power control [Hz]	800	800	800	800	800	800
Power Control step [dB]	1	1	1	1	1	1
Slots per frame	8	8	8	8	8	8
Pilot/PC/FCH bits per slot	12/4/4	12/4/4	12/4/4	12/4/4	12/4/4	12/4/4
DPDCH-DPCCH power [dB]	-10	-10	-10	-10	-12	-12

Table 5-17 - Simulation parameters for UDD 2048, Indoor A and Outdoor to Indoor A, 3 Km/h [ET97]

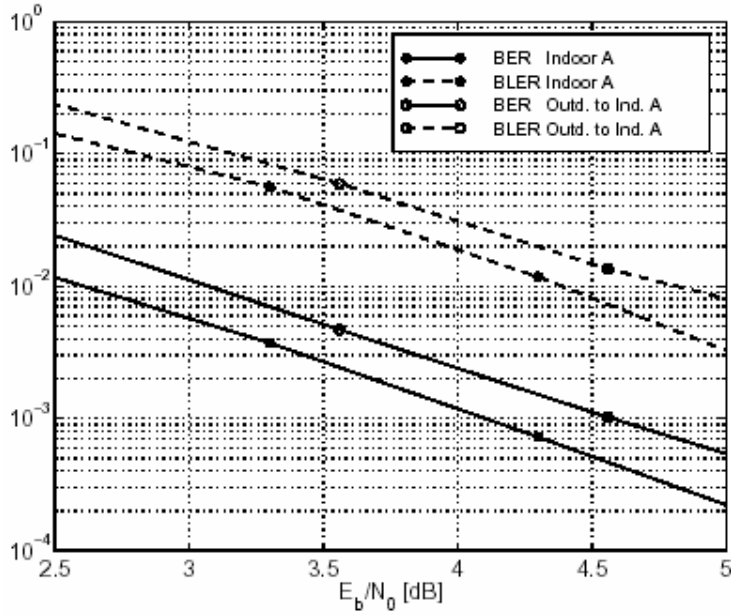


Figure 5-38 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 2048, without antenna diversity. Bit Rate= 480 kbps. DPDCH: Spreading Factor=4, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

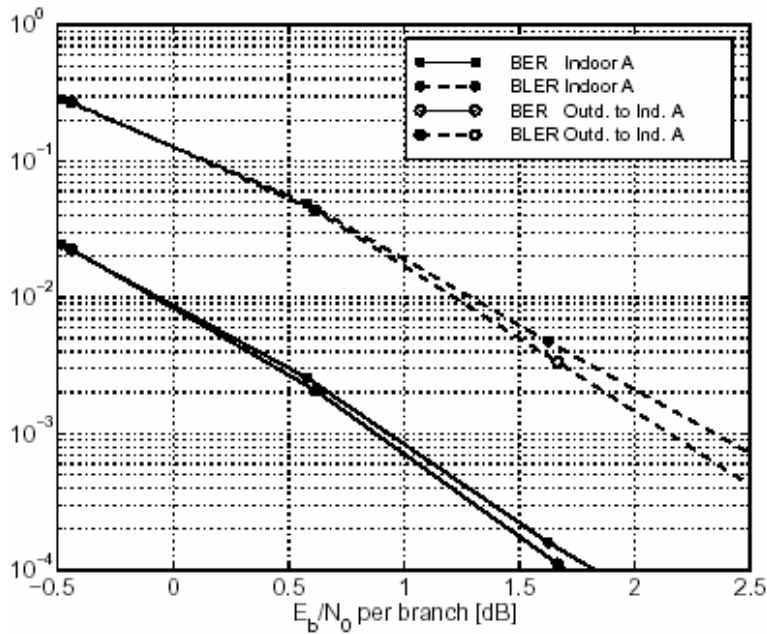


Figure 5-39 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 2048, with antenna diversity. Bit Rate= 480 kbps. DPDCH: Spreading Factor=4, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 10 dB. [ET97]

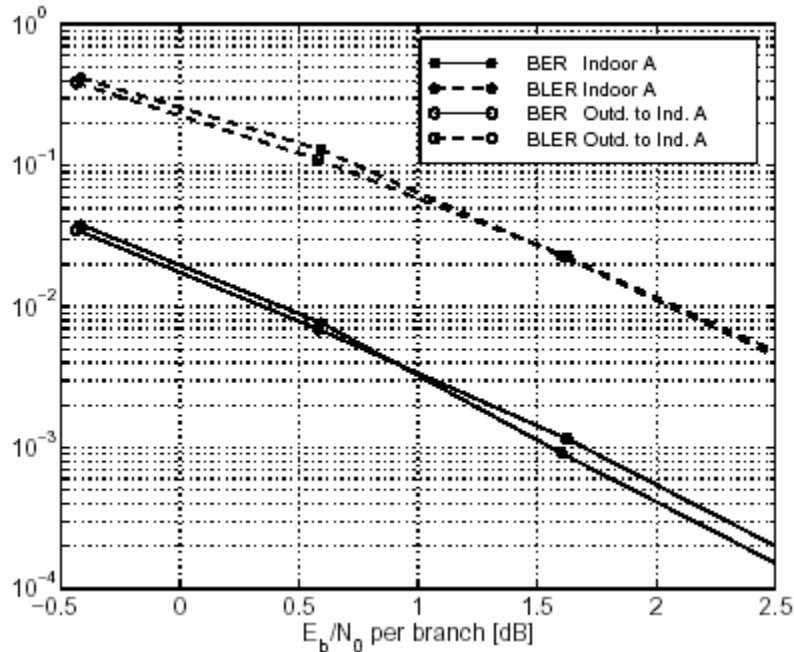


Figure 5-40 - Bit Error Rate (BER) & Block Error Rate (BLER) for UDD 2048, with antenna diversity. Bit Rate= 2048 kbps. DPDCH: Spreading Factor=5x4, Convolutional Code Rate= 1/2, Rate Matching=None. DPCCH: Spreading Factor=256, Power Control Step=1 dB. 8 slots per frame. Power difference between DPDCH and DPCCH= 12 dB. [ET97]

5.4.4 Downlink Performance in the Presence of Interference

WCDMA simulation results for interference limited environments have not been extensively published. The complexity of the simulators, the number of variables required for an accurate simulation and the simulation times involved limit the feasibility of such simulations. Partial simulations aiming at analyzing particular variables have been performed [Hol00, Oja00]. The following paragraphs briefly discuss the effect of the non orthogonality on the downlink performance.

The orthogonality of the WCDMA spreading codes should guarantee an interference-free condition in the downlink. However, in a multipath channel the orthogonality is partially lost, degrading the downlink performance. The effect of the reduced orthogonality is the rise of the interference as the number of active users increase.

Figure 5-41 exemplifies the impact of interference in the required transmission power of a WCDMA traffic channel. I_c represents the transmission power of the traffic channel and I_{or} represents the total transmission power of the cell. N_o represents the interference from other cells plus the thermal noise. The ratio $G = I_{or}/N_o$ is named *geometry factor*.

The closer the mobile is from the base station the grater the value of G .

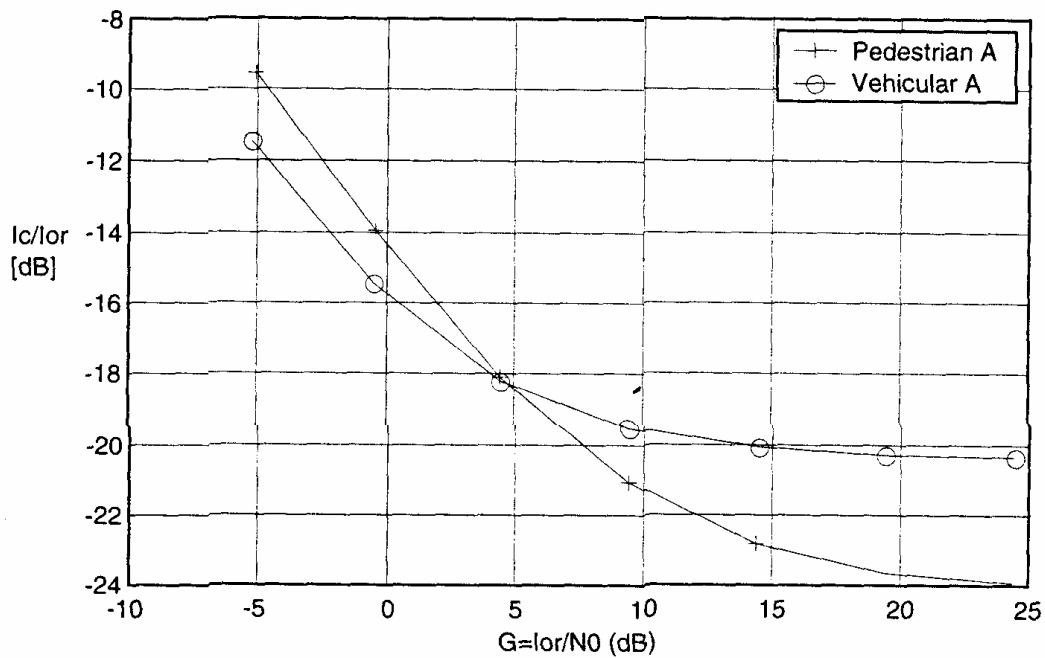


Figure 5-41 - Effect of interference in the required transmission power of a WCDMA traffic channel. I_c represents the transmission power of the traffic channel and I_{or} represents the total transmission power of the cell. N_o represents the interference from other cells plus the thermal noise. Simulation for Speech, Data rate= 8Kbps, interleaving=10 ms with 1% Frame Error Rate (FER). No soft handover. Speed for Pedestrian A= 3 Km/h and for Vehicular A=120 Km/h. [Hol00]

As G increases, indicating lower interference levels, less power is required for the traffic channel. Close to the base station (high values of G), low speed mobiles experience better performance, because of the diminished multipath interference caused by the low orthogonality degradation. Conversely, at the cell edge the high speed mobiles have superior performance, benefiting from the multipath diversity gain.

5.5 Discussion

The link performance curves shown in Figure 5-22 to 5-40 result from simulations done at 4.096 Mcps. This chip rate has been lowered to 3.84 Mcps in the final WCDMA recommendation, requiring the utilization of a correction factor of 0.28 dB to compensate for this difference when consulting these charts. The reduction in the processing gain due to the narrower spreading factor increases the E_b/N_o required to achieve the same BER, BLER or FER.

The use of transmit diversity in the downlink provides for a significant improvement in performance –approximately 2.5 dB at high speeds (120 Km/h) and 3 dB at low speeds (3 Km/h), having been specified as a mandatory supported feature in all WCDMA terminal receivers [HOL00]. Such technique is also referred to as space-time block coding-based transmit diversity (STTD). Two⁵ transmit antennas are used at the base station, with the coded bits being split into two output streams. Different channelization codes are used per antenna for spreading, maintaining orthogonality between the antennas and eliminating self-interference. In addition, at slow speeds this technique reduces the power variance of the downlink fast power control

⁵ Four and eight-antenna setups are also possible. The gain is proportional to the number of antennas.

Chapter 6 - Conclusions

The evolution of existing second-generation (2G) wireless technologies has been discussed, pointing out the possible evolutionary paths each one has taken. The transitional technologies, known as 2.5G, are closely related to the third-generation solutions, for they link existing networks to their future 3G versions.

The third generation of wireless mobile networks is characterized by the support of multimedia and increased data functionality, with emphasis in packet-switched services. The transitional technologies arising from GSM (Global System for Mobile Communications), namely GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for the GSM Evolution), have emerged as efficient solutions to the evolution of GSM and Time Division Multiple Access (TDMA) IS-136 towards 3G. The increased data rates supported by EDGE have encouraged its use as an eventual third-generation solution.

The GPRS channel coding has been described and link performance in different propagation environments has been presented. Both noise-limited and interference-limited link performance results have been presented. GPRS uplink throughput has been presented. The use of link adaptation brings improved throughput performance to GPRS, making it suitable for its intended application, packet-switched services.

Similarly, the EDGE modulation and coding schemes have been described. EDGE link performance in different propagation environments has been presented. The results of noise-limited and interference-limited performance simulations have been presented, along with downlink throughput performance results. The combination of link adaptation (LA) and incremental redundancy (IR) yield substantial performance improvements to EDGE, especially in low quality links.

The general WCDMA channel structure, with its transport and physical channels has been described. The principles of spreading (channelization), scrambling and modulation have been presented. The downlink performance for the expected usage scenarios has been presented, showing the benefits of downlink transmit diversity in the link performance.

The technologies aforementioned are not intended to compete among themselves, but rather serve as solutions to different steps of the transition from the second to the third generation of wireless mobile networks. GPRS is the first step, followed by EDGE. WCDMA is a complete 3G solution, offering full support to packet data and multimedia. The comparison of their link performance is only sensible from the data capacity perspective if they are seen as evolutionary steps

As an example of the performance capability of these technologies, for a carrier-to-interference ratio (C/I) of 25 dB, a GPRS wireless user moving at a speed of 50 Km/h will be able to maintain a data connection at 50 kbps if using four GSM time slots. The same user would be able to maintain a 440 kbps connection if using EDGE with eight time slots. If WCDMA is used the data rate can be elevated to 2.3 Mbps, for a 5 MHz bandwidth.

The different modulations in each technology result in distinct network design requirements. For instance a 10^{-3} Block Error Rate (BLER) requires 20 dB of C/I for a GPRS link at 50 Km/h using Coding Scheme 2 (CS-2). The same BLER would require 24 dB of C/I if the link used EDGE's Modulation and Coding Scheme 6 (MCS-6). The EDGE link would allow a maximum data rate of 29 kbps per time slot, against 13 kbps of the GPRS link. The improved data rate comes at the expense of power. In WCDMA data rate comes at the expense of bandwidth

The complexity of these technologies and the many possible operation conditions makes it difficult to perform simulations for all possible situations. The results available so far intend to cover the basic expected operation conditions, as well as provide guidance in

the design of the wireless networks using them. Further investigations, particularly in WCDMA, are required to provide a better understanding of its performance.

Appendix A - Abbreviations and Acronyms

2.5G	Transitional Technology between 2G and 3G
2G	Second Generation of Wireless Technologies
3G	Third Generation of Wireless Technologies
3GPP	3 rd Generation Partnership Project

A

AFC	Automatic Frequency Control/Automatic Frequency Correction
AP-AICH	Preamble Acquisition Indicator Channel
AWGN	Additive White Gaussian Noise
BCCH	Broadcast Channel
BCS	Block Check Sequence
BER	Bit Error Rate
BLER	Block Error Rate
BOD	Bandwidth on Demand
BPSK	Binary Phase Shift Keying

C

C/(I+N)	Carrier-to-Interference plus Noise Ratio
C/I	Carrier-to-Interference Ratio
CD/CA-ICH	Collision-Detection/Channel Assignment Indicator Channel
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CPCH	Uplink Common Packet Channel
CPICH	Common Pilot Channel
CRC	Cyclic Redundancy Check
CS	Coding Scheme
CSICH	CPCH Status Indicator

D

DCH	Dedicated Channel
DPCCH	Dedicated Physical Control Channel
DPCH	Downlink Dedicated Physical Channel
DPDCH	Dedicated Physical Data Channel
DSCH	Downlink Shared Channel
DTX	Discontinuous Transmission

E

E	Extension bit
Eb/No	Bit Energy-to-Noise Density Ratio
ECSD	Enhanced Circuit Switched Data
EDGE	Enhanced Data Rates for GSM Evolution

EGPRS	Enhanced General Packet Radio Services
ETSI	European Telecommunications Standard Institute
EVM	Error Vector Magnitude
F	
FACH	Forward Access Channel
FBI	Final Block Indicator
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FH	Frequency Hopping
G	
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
H	
HCS	Header Check Sequence
HSCSD	High Speed Circuit Switched Data
HT100	Hilly Terrain @ 100 Km/h - Propagation Environment
I	
IP	Internet Protocol
IR	Incremental Redundancy
IS-136	EIA Interim Standard 136 - United States Digital Cellular with Digital Control Channels
IS-95	EIA Interim Standard 95 - United States Code Division Multiple Access
ITU	International Telecommunications Union
L	
LA	Link Adaptation
LCD	Long Delay Constrained Data
LDD	Low Delay Data
LQC	Link Quality Control
M	
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MUD	Multi-user Detection
O	
OVSF	Orthogonal Variable Spreading Factor
P	
P1, P2, P3	Puncturing Schemes used in EDGE

PC	Power Control
PCCC	Parallel Concatenated Convolutional Code
PCCPCH	Primary Common Control Physical Channel
PCH	Paging Channel
PCPCH	Physical Common Packet Channel
PDC	Pacific Digital Cellular
PDCH	Packet Data Channel
PDSCH	Physical Downlink Shared Channel
PICH	Page Indication Channel
PRACH	Physical Random Control Channel
PSK	Phase Shift Keying
Q	
QPSK	Quadrature Phase Shift Keying
R	
RA250	Rural @ 2500 Km/h - Propagation Environment
RACH	Random Access Channel
RLC	Radio Link Control
RMS	Root-Mean-Square
S	
SCH	Synchronization Channel
SF	Spreading Factor
S-PCCPCH	Secondary Common Control Physical Channel
T	
TB	Tail Bit
TCFI	Transport Format Combination Indicator
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TFI	Transport Format Indicator
TU3	Typical Urban@ 3 Km/h - Propagation Environment
TU50	Typical Urban@ 50 Km/h - Propagation Environment
U	
UDD	Unconstrained Delay Data
UMTS	Universal Mobile Telecommunications System
USF	Uplink State Flag
UWC	Universal Wireless Consortium
W	
WARC	World Administrative Radio Conference
WCDMA	Wideband Code Division Multiple Access
WWW	World Wide Web

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