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Technical Report

**3rd Generation Partnership Project
Technical Specification Group GERAN
DRAFT Feasibility Study on Single Antenna
Interference Cancellation (SAIC) for GSM Networks
(Release 6)**



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Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

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Introduction

This document studies the feasibility of utilising Single Antenna Interference Cancellation (SAIC) as a means of increasing the downlink spectral efficiency of GSM networks.

SAIC is a generic name for techniques, which attempt to cancel or suppress interference by means of signal processing without the use of multiple antennas. The primary application is the downlink, where terminal space and aesthetics typically preclude the use of multiple antennas.

1 Scope/Objectives

The objective of this document, as defined in the work item [2], is to determine the potential of SAIC in typical network layouts. This includes study of the following aspects:

- a) Determine the feasibility of SAIC for GMSK and 8PSK scenarios under realistic synchronized and non-synchronized network conditions. Using a single Feasibility Study, both GMSK and 8PSK scenarios will be evaluated individually.
- b) Realistic DIR (Dominant-to-rest of Interference Ratio) levels and distributions based on network simulations and measurements.
- c) Robustness against different training sequences.
- d) Determine method to detect/indicate SAIC capability.

Comment: The purpose of the feasibility study is not to suggest radio requirements/performance requirements for SAIC capable mobiles. This part will be included if the feasibility study will be continued in a work item.

2 References

The following documents contain provisions, which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

- [1] UMTS 30.03 version 3.2.0, TR 101 112 v3.2.0 (1998-04), “Universal Mobile Telecommunications System (UMTS); Selection procedures for the choice of radio transmission technologies of the UMTS”
- [2] 3GPP TSG-GERAN TDOC GP-022891, “Work Item Description, Single Antenna Interference Cancellation”, Sophia Antipolis, France, 18-22 November 2002
- [3] 3GPP TSG-GERAN SAIC Workshop TDOC GAHS-030009, “Network level simulation scenarios and assumptions for SAIC”, Atlanta, USA, 8-9 January 2003
- [4] 3GPP TSG-GERAN SAIC Workshop TDOC GAHS-030005, “Scenarios and Modelling Assumptions for SAIC in GERAN”, Atlanta, USA, 8-9 January 2003
- [5] 3GPP TSG-GERAN SAIC Workshop TDOC GAHS-030002, “Single antenna interference cancellation - evaluation principles and scenarios”, Atlanta, USA, 8-9 January 2003
- [6] 3GPP TSG-GERAN SAIC Workshop TDOC GAHS-030020, “Interference Characterization for SAIC Link Level Evaluation”, Seattle, USA, 4-5 March 2003
- [7] 3GPP TSG-GERAN SAIC Workshop TDOC GAHS-030022, “Link Level model for SAIC”, Seattle, USA, 4-5 March 2003

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

3.3 Abbreviations

DIR – Dominant-to-rest interference ratio

DTX – Discontinuous Transmission

FR – Full Rate

HR – Half Rate

SAIC – Single Antenna Interference Cancellation

4 Network scenarios for SAIC evaluation

A multi-step approach to complete SAIC performance evaluation includes System (Network) Level, Link level, and link to system mapping.

System level simulations are performed in order to evaluate the potential benefit of SAIC on network level. The scenarios for these simulations were discussed agreed to as part of SAIC Workshop #1.

The system level scenarios should represent a typical GERAN network at the time frame when operators are deploying SAIC MSs in their network. The goal is to try to make the interference pattern as realistic as possible, whilst trying to keep the overall complexity of the simulation reasonable. As a result of [3], [4], and [5], the following parameters are considered to be the major issues which affect the interference pattern:

- Frequency Hopping scheme
- Reuse (also adjacent channel reuse) and cell radius
- Regularity of the network (different cell sizes, different number of TRXs per cell, hotspots)
- Propagation conditions, including network topology (street corner effects, shadowing from buildings/hills etc.)
- Power Control scheme
- Channel coding, mainly if quality-based PC is used; schemes with less coding requires higher transmission powers
- Penetration of different MSs/bearers in the network
 - SAIC MS penetration: power levels, higher tolerated load/interference for SAIC MSs, but the non-SAIC MS must survive also
 - Packet Switched Connections GPRS and EGPRS => short connections, asymmetry, bursty traffic, multiplexing of several users on the same time slot, often lack of DL PC
 - Legacy non-AMR (mainly EFR) mobiles: higher Tx Powers, less robustness
- Level of synchronization in the network
- Mobility: speed distribution of the mobiles affects the interference pattern

SAIC should give larger gains in tighter reuse networks, as the interference becomes more and more limiting to system performance. Similarly, the higher the load, the more interference to cancel. However, interference scenarios are more complex with a higher load, so the interference cancellation algorithms may be less efficient. Finally, SAIC techniques generally give the largest gains in synchronized networks.

Two tables define the network scenario assumptions. Table 1 defines operator or configuration specific assumptions, table 2 defines common parameters. Both tables were derived from [3], [4], [5], and discussed as part of the SAIC Workshop #1.

Table 1
Configuration Specific Network Scenario Assumptions

Parameter	Value	Unit	Comment
Configuration 1 - Asynchronous			
Frequency	900	MHz	
Bandwidth	7.8	MHz	
Reuse	4/12 (BCCH) 3/9 (TCH)		
Hopping	Baseband		
Voice Codec	AMR 12.2 FR		
Blocking	2	%	
Modulation	<u>Source/Interferer</u> GMSK/GMSK GMSK/8PSK		
Cell Radius	500	m	
Configuration 2 – Sync & Async			
Frequency	1900	MHz	
Bandwidth	1.2	MHz	
Reuse	1/1 (TCH)		
Hopping	Random RF		
Voice Codec	AMR 5.9 FR/HR		
Frequency Load	20, 40 (FR) 10, 20 (HR)	% %	
Modulations	<u>Source/Interferer</u> GMSK/GMSK GMSK/8PSK 8PSK/GMSK 8PSK/8PSK		
Cell Radius	1000	m	
Configuration 3 – Sync & Async (Optional)			
Frequency	900	MHz	
Bandwidth	2.4	MHz	
Reuse	1/1 (TCH)		
Hopping	Random RF		
Voice Codec	AMR 5.9 FR/HR		
Frequency Load	40, 70 (FR) 25, 40 (HR)	% %	
Modulation	<u>Source/Interferer</u> GMSK/GMSK		
Cell Radius	750	m	
Configuration 4 - Asynchronous			
Frequency	900	MHz	
Bandwidth	7.2	MHz	
Reuse	1/3 (TCH)		
Hopping	Random RF		
Voice Codec	AMR 12.2 FR		
Blocking	2	%	
Frequency Load	30	%	
Modulation	<u>Source/Interferer</u> GMSK/GMSK GMSK/8PSK		
Cell Radius	300	m	

Table 2
Common Network Scenario Assumptions

Parameter		Value	Unit	Comment
Sectors (cells) per site		3		
Sector antenna pattern		UMTS 30.03		
Propagation model		UMTS 30.03		Pathloss exponent, MCL Per 30.03
Log-normal fading	standard deviation	6 (900) 8 (1900)	dB dB	
	Correlation distance	110	m	
Adjacent channel interference attenuation		18	dB	Carrier +/- 200 KHz
Handover margin		3	dB	
Mobile speed		TU3 and TU50	km/h	
Mean Call length		90	sec.	
Minimum Call Length		5	sec.	
Voice activity		60%		Includes SID signalling.
DTX		Enabled		
Link adaptation		Disabled		
BTS output power		20	W	
Power control		RxQual/RxLev		
Dynamic Range		14	dB	
Step Size		2	dB	
Noise figure		10	dB	Reference temperature 25c
Inter-site Lognormal Correlation Coefficient		0		
Channel Allocation		Random		
GPRS		FFS		

Table 3
Link Level Parameters for Configuration 2/3

Parameters for Configuration 2/3			
		40%	70%
Dominant interferer i_1	dB	-	-
	TSC	random 0	random 0
Second strongest interferer i_2	dB	6	4
	TSC	random	random
Third strongest interferer i_3	dB	10	8
	TSC	random	random
Residual noise (modelled as white noise)	dB	9	5
Before receiver filter – (AWN sequence) Non-fading I_r	TSC	n/a	n/a
Adjacent channel interferer (after receiver filter) i_{ac_1} (fading)	dB	14	14
	TSC	random	random
Residual adjacent channel (Non-fading) i_{ac_r}	dB	15	14
	TSC	n/a	n/a
Delay		TBD	TBD
Frequency Offset		TBD	TBD

5 Interference Modelling

5.1 Introduction

When assessing the link and system level performance it is important to base the performance investigations on realistic link level models. Especially for SAIC receivers previous studies have demonstrated that the SAIC link level performance for the same interference level will vary significantly for different link level models [GP-030276]. Therefore a lot of work has been ongoing in the SAIC feasibility study to define realistic models and the outcome of this work is recaptured in this section.

Defining realistic link level models is clearly impossible without investigating the interference statistic seen by mobiles when operating in different network scenarios. Thus an important part of the modelling work has been analysis of network traces generated by network simulators for the four different network configurations defined in section 4.

To types of link level models have been derived one for synchronous network configurations and one covering asynchronous networks. The latter is an extension of the model derived for synchronous networks taking effects as delay, power control, DTX etc into account.

5.2 Interference statistics

In GSM/EDGE the performance of the mobiles in interference limited scenarios have traditionally been evaluated for a single interfering signal at a high input level where the sensitivity performance of the mobile will have no or very little influence. This can be described by the conventional CIR (Carrier to Interference Ratio):

$$CIR = \frac{C}{I + N_0}$$

where C is the power of the carrier, I the power of an interfering signal (co- or adjacent channel interference) and N_0 the thermal noise. Although widely used, for evaluation, this ideal one interferer scenario happens very rarely in practice especially when the network is high loaded. When using e.g. AMR a high frequency load can be expected and consequently the mobiles will receive interference from a number of base stations at the same time. This can easily be introduced in the above definition of the CIR:

$$CIR = \frac{C}{\sum_k I_k + N_0}$$

I_k can be both co- and adjacent channel interference (for the adjacent channel interference a realistic ACP (Adjacent Channel Protection) shall be used e.g. ACP=18dB).

For a small number of interfering base stations the performance of a conventional receiver will be identical for the two definitions, but for a SAIC mobile the performance (interference cancellation capability) will depend upon the distribution of the interferer powers. An initial, simple measure of the distribution is the power of the rest of the interferers. The ratio can be described by the DIR (Dominant to rest of Interference Ratio):

$$DIR = \frac{I_{\max}}{\sum_k I_k - I_{\max} + N_0}$$

where I_{\max} is the dominant of the interfering signals (co- or adjacent channel interference). When only a single interferer is active, as in the standard interference test case in 45.005, then the DIR will be identical to the I/N_0 of the received interfering signal. Although the standard interference test case is widely used it has been demonstrated in a number of contributions that this test case does not reflect a realistic scenario for a SAIC mobile [GAHS-030017][GAHS-030018][GAHS-030022].

In [GAHS-030008] a new measure called DIR_2 was introduced in the link level modelling discussion. The DIR_2 measure is defined as:

$$DIR_2 = \frac{I_{\max 2}}{\sum_k I_k - I_{\max} - I_{\max 2} + N_0}$$

and basically it can be used to investigate the validity of using a simple two cochannel interferer model when evaluating the SAIC link level performance. In TSG GERAN #13 the DIR_2 measure was included in a number of studies and the initial conclusion was that more than two cochannel interferers are needed in the SAIC link level model [GP-030159, GP-030276].

In Figure 5-1-Figure 5-3 examples of interferer statistics for network configuration 2 can be seen¹. Clearly the figures demonstrate how the interferer statistic in a network is much more complicated than the single interferer scenario currently tested in 45.005. The DIR and DIR_2 statistics clearly demonstrate the need to define link level models having multiple interferers.

¹ The figures have been taken from [GAHS-030017] but similar figures have been presented in [GAHS-030022] and [GAHS-030018].

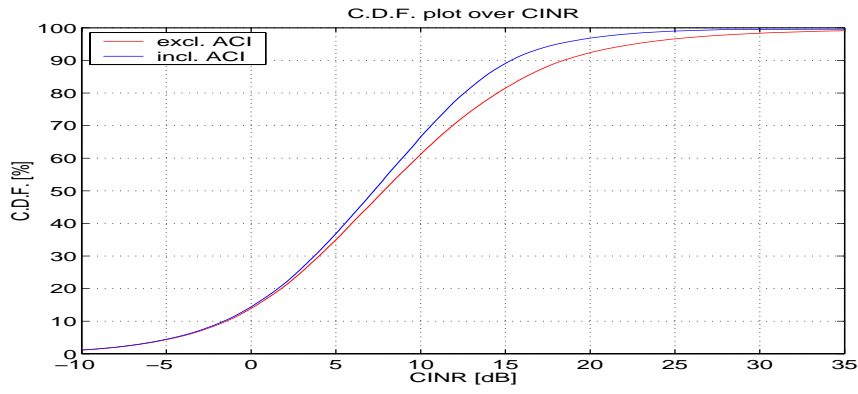


Figure 5-1. The CIR cdfs observed by a MS operating in network configuration 3 [GAHS-030017].

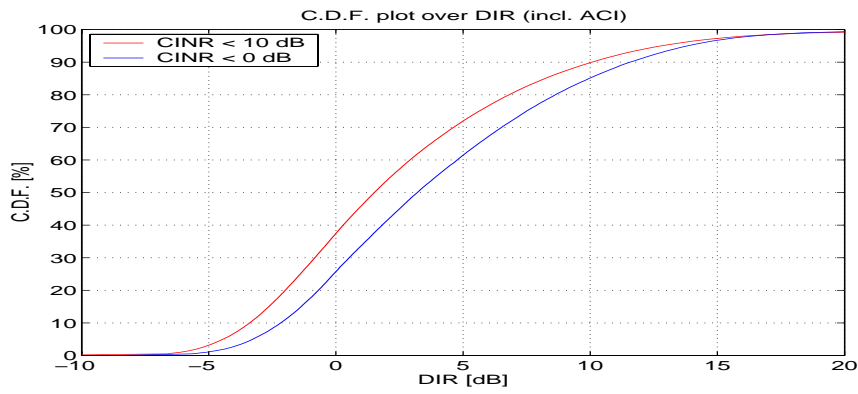


Figure 5-2. The DIR cdfs observed by a MS operating in network configuration 3 [GAHS-030017].

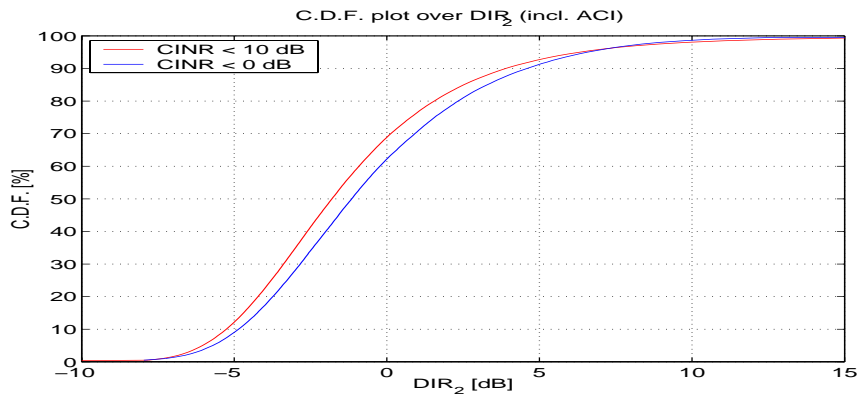


Figure 5-3. The DIR₂ cdfs observed by a MS operating in network configuration 3 [GAHS-030017].

5.3 Synchronous link level models

Early link level investigations for SAIC demonstrated a higher link level gain when using a synchronous compared to asynchronous link level configuration. Consequently it was decided to develop link level models for both types of networks focusing initially on the synchronous mode², which will be described in this section.

5.3.1 Interferer levels

Having identified the need to have multiple interferers in the link level model the necessary number of interferers and their levels have to be estimated. During the SAIC Adhoc #2 a procedure for the estimation was agreed based on investigations made in document [GAHS-030018] and [GAHS-030022]. From network traces the cdf of a number of co- and adjacent channel interferers plus the residual interference were derived. Examples of the cdfs can be seen in Figure 5-4 and Figure 5-5. In the estimation process only bursts having a CIR<10dB have been taken into account because SAIC algorithms are expected to have the largest link level gain for low CIR. The mean power level of each interferer were chosen as the observed median value i.e. for i_2 in configuration 3 (see Figure 5-5) the power level is 4dB below the power level of the main interferer. The final agreed numbers are listed in Table 5-1, where the numbers for the adjacent channel interference is assumed measured after a receive filter having an attenuation of 18dB. Thus in the channel model the power level should be 18dB higher than shown in the table. For configuration 1 the values have been derived in [GP-031203], for configuration 2+3 the values were derived at the SAIC Adhoc #2 and finally for configuration 4 the values have been agreed as the average of the values from [GP-031289] and [GP-031203].

Figure 5-4. cdfs of interferer powers for estimation of link level model for network configuration 2 [GAHS-030024].

Figure 5-5. cdfs of interferer powers for estimation of link level model for network configuration 3 [GAHS-030024].

For the modelling of residual co- and adjacent channel interferers an AWGN source is filtered using the 8PSK modulation filter (linearised GMSK pulse) specified in 45.004 section 3.5. The filtering is done to ensure the correct spectral properties. The residual adjacent channel interference is applied with half the power on each side of the carrier i.e. for configuration 2 two residual adjacent channel interferers being offset $\pm 200\text{kHz}$ from the carrier and having power level 0dB³ should be included.

During the initial investigation of SAIC a number of companies have observed that the performance of most SAIC algorithms is degraded when the interferer has a TSC included compared to use to use the standard GMSK-modulated random sequence defined in 45.005 [GP-020822]. Therefore an important part of the link level modelling is to include TSCs for all except the residual interferers i.e. the interferers generally have a normal burst structure. Apart from the dominant cochannel interferer the TSC is taken from a uniform distribution including all eight TSCs defined in 45.002. In an optimized network it is expected that TSC collision to some extent can be avoided for the main interferer and therefore TSC0 is not included.

² Only burst wise synchronization is assumed.

³ The 18dB adjacent channel protection has been taken into account.

When performing link level analysis the fading is an important part of the modelling and as can be seen in Table 5-1 all except the three residual interferers are subject to fading. Fading is not applied on the residual interferes because these are used to model interference from a number of BTSs each having independent fading. Thus the power variations of the residual interference will be small and are thus neglected in the link level model.

Link Parameter	Configuration 1	Configuration 2 40% Load	Configuration 3 70% Load	Configuration 4
Desired signal, C				
TSC	TSC0	TSC0	TSC0	TSC0
Fading				
Dominant Coch. Interf.				
TSC	Random TSC excluding TSC0	Random TSC excluding TSC0	Random TSC excluding TSC0	Random TSC excluding TSC0
Fading				
2 nd Strongest Coch. Interf.				
Ic1/Ic2	10 dB	6 dB	4 dB	9 dB
TSC	Random TSC	Random TSC	Random TSC	Random TSC
Fading				
3 rd Strongest Coch. Interf.				
Ic1/Ic3	20 dB	10 dB	8 dB	17 dB
TSC	Random TSC	Random TSC	Random TSC	Random TSC
Fading				
Residual Coch. Interf. (filtered AWGN)				
Ic1/Icr				
TSC	-	9 dB	5 dB	20 dB
No Fading	NA	NA	NA	NA
Dominant Adj. Interf.				
Ic1/Ia ⁴	15 dB	14 dB	14 dB	16 dB
TSC	Random TSC	Random TSC	Random TSC	Random TSC
Fading				
Residual Adj. Interf. (filtered AWGN)				
Ic1/Iar ¹	20 dB	15 dB	14 dB	21 dB
TSC	NA	NA	NA	NA

⁴ After the Rx filter assuming an 18dB ACP.

Table 5-1 Interferer levels for network configuration 1-4.

5.3.2 Delay distributions

Even in a synchronized network the mobile station will receive interference from the different BTSs at various delays due to the distance to the interfering sites. Although most SAIC receivers are expected to be robust to delays less than 10 symbols even small delays can affect the correlation properties between different TSCs and therefore the performance of both conventional and SAIC receivers.

Based on network traces, modelling of delay in the synchronous link level models has been investigated by Motorola for the four network configurations. The outcome of these studies is the delay model summarized in this section.

Using a delay resolution of 0.2 symbols, and the observation that delays in the four configurations are limited to the range [-2,+5] symbols, the discrete delay distribution can be approximated as:

1. for delay less than 0, for $k=1$ to 10, the probability $P(k)$ of delay equal to $-0.2k$ is:

$$P(k) = A_1 p_1 (1 - p_1)^k$$

2. for delay greater than 0, for $k=1$ to 25, the probability $P(k)$ of delay equal to $0.2k$ is:

$$P(k) = A_2 p_2 (1 - p_2)^k$$

3. for zero delay:

$$P(0) = A_0$$

The parameters to be used for the different configurations can be seen in Table 5-2.

Configuration	p_1	p_2	A_0	A_1	A_2
Configuration 1 @2% blocking	0.9	0.7	0.5602	0.5	2
Configuration 2@40%	0.37	0.09	0.2157	0.1274	0.8555
Configuration 3@70%	0.7	0.26	0.4005	0.1658	0.7433
Configuration 4@30%	0.95	0.25	0.1106	0.1874	1.1742

Table 5-2 Summary of delay model parameters.

The model demonstrates that the carrier and the interferers often are synchronized when received by the mobile station.

5.3.3 Frequency offset distributions

Frequency offset is inevitable in practical implementations and consequently also needed in the SAIC link level model [GP-032246]. Despite its importance the nature of the frequency offset seems to cause some confusion and has been discussed several times during the SAIC feasibility study.

When a mobile station is connected to a BTS it is synchronized in frequency to this serving BTS. Therefore the mobile station will not detect if the carrier of this BTS is offset compared to a correct carrier frequency. Although synchronized some frequency jitter due to inaccuracy of the frequency estimation procedure will exist in practice. It has been agreed not to include this vendor specific frequency jitter in the model but clearly each vendor has to include their own model when performing simulations.

The frequency offset has to be included for each of the three co-channel and the adjacent channel interferers having a value that includes the fixed offset of the serving BTS⁵. For each of these interferers the frequency offset will be varying on burst-by-burst basis due to frequency hopping and the fact that the interference in the model comes from a number of BTSs all having different offset. The mean value of these offsets is assumed to be 0Hz (plus the fixed frequency offset of the serving BTS⁶) and the standard deviation 33Hz. The frequency offset is modelled as a normal distribution $N(100,33)$.

5.4 Asynchronous link level models

Most of the SAIC link level modelling work done has been concentrated on development of link level models for synchronous network configurations. Although the highest SAIC gain is expected in synchronous networks, the majority of networks will, at least in the near future, still be running in asynchronous mode. Consequently, estimation of the expected SAIC capacity in asynchronous networks is seen as an important part of the SAIC feasibility study.

An exact estimation of the network capacity requires a hybrid link and system level simulator taking all system and link level factors into account. In practice such an approach is not possible and instead a more simple solution splitting the system and link level simulations is used. The principle is to make a table of the link level performance as a function of factors like C/I and DIR. The system simulator will then use these values as the link level performance of the mobiles in the network.

Even though the link level models developed for the feasibility study of SAIC in GERAN are very complicated the agreement so far has been that the performance still can be parameterised by the burst wise C/I and DIR for synchronous networks. For asynchronous networks it would be natural to extend the number of parameters to include information about delay and scaling of the different interferers in order to have an accurate estimate of the capacity. But most system simulators available have been designed for synchronous network operation and updating these for asynchronous operation would be a major task. Therefore the agreement during TSG GERAN #15 was to use the standard system simulators and then restrict the handling of the asynchronism to the link level⁷.

By using this simplified approach an estimation of the capacity in asynchronous networks requires the following, where obviously the modelling is a crucial part when estimating the capacity of asynchronous networks:

- Develop statistical link level model including delay offsets, burst power and structure etc.
- Make link to system level mapping tables using simulations of the statistical link level model.
- Simulate network capacity using developed mapping tables and standard system simulators.

5.4.1 Burst structure

When operating in an asynchronous network the mobile will experience a more complex interferer environment than in a synchronous network due to the time offset and propagation delay between the different BTSs. The agreed way to model this is to use the interferer burst structure shown in Figure 5-6. The middle burst of the interferer is referred to as the main burst. On each side of the main burst, there is an adjacent burst, which is sent in an adjacent timeslot from the same BTS. The interferer is shifted relative to the desired signal and therefore one of the adjacent bursts is shifted into the receive window. Modelling is only necessary for the adjacent burst that is shifted into the receive window.

⁵ A fixed offset of 100Hz will be used to reflect worst case offset at 1800MHz.

⁶ Each BTS can have a frequency offset of 0.05ppm resulting in a worst case of 0.1ppm between the serving and the interfering BTSs (see 45.010).

⁷ This will result in new link to system level mapping tables, which can be parameterised by the burst wise C/I and DIR. The definitions of burst wise C/I and DIR follows the definition in section 0 where the energy of an interferer is calculated as the energy during the receive window, i.e., the interferer energy that the desired burst is exposed to.

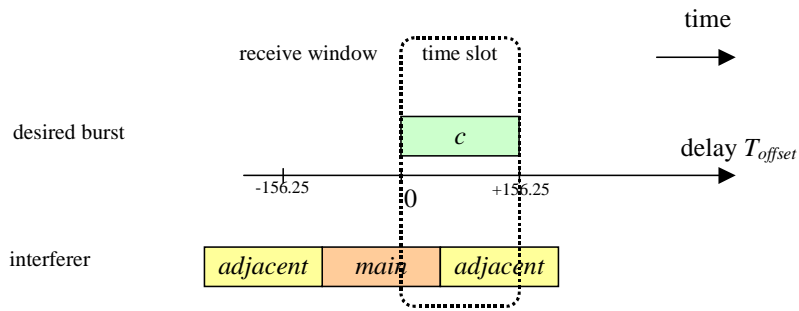


Figure 5-6. Interferer burst structure.

5.4.2 Time-offset modelling

Time-offset modelling is only needed for inter-site interference whereas intra-site interference can be assumed to be time-aligned with the carrier signal. This difference between inter- and intra-site interference can easily be taken into account by using the following equation to describe the time offset⁸ [GP-031524]:

$$T_{\text{offset}} = \begin{cases} 0 \text{ symbols} & \text{in } t_{\text{intra-cell}} \% \text{ of the bursts} \\ U[-t_{\text{max}}; t_{\text{max}}] \text{ symbols} & \text{in } (100 - t_{\text{intra-cell}}) \% \text{ of the bursts} \end{cases}$$

where t_{max} represents full slot length (156.25 symbols), and the uniform distribution is using $\frac{1}{4}$ symbol resolution of the timing offset. In this equation $t_{\text{intra-cell}}$ represents the percentage of time the interference is from the same site. One value of $t_{\text{intra-cell}}$ will be used for each configuration. For configurations 1 and 4, $t_{\text{intra-cell}} = 0$ and for configurations 2 and 3, $t_{\text{intra-cell}} = 20\%$ has been identified as realistic values.

5.4.3 Power control

When designing an asynchronous link level model an important issue is the modelling of the power variation between the different interfering bursts (main and adjacent interferer). Assuming the bursts are located within a frame, i.e. not at a frame boundary, then the bursts will be sent from the same BTS and therefore affected by nearly the same channel (pathloss, shadow and multipath fading). Despite this similarity in fading the received power level of the interfering bursts will in general be different due to power control and DTX operation.

Power control is not used on the main burst but only for the adjacent burst (see Figure 5-6) by multiplying it with a coefficient A. The distribution of A is given in Table 5-3 (A is given in a dB scale). It has an expected value of 1 (in the linear domain) to keep the average power level constant.

Gain	Probability Density Function
$10 \cdot \log_{10}(A)$	$p(A)$
-18	0.0058
-16	0.0222
-14	0.0338

⁸ The notation $U[-x;x]$ is used to represent a uniform distribution in the range $-x$ to x .

-12	0.0503
-10	0.0695
-8	0.0937
-6	0.1335
-4	0.1487
-2	0.1362
0	0.1024
2	0.0763
4	0.0541
6	0.0367
8	0.0242
10	0.0106
12	0.0019

Table 5-3 – Power control gain probability density function.

5.4.4 Phase transition

When different bursts are transmitted from a BTS on a physical channel the relative phase between these bursts are not specified and it cannot be guaranteed that the phase is continues. Besides the duration of timeslots will not always be 156.25 symbols but can also be either 156 or 157 symbols, which by the mobile will be seen as a phase discontinuity (see 45.010 section 5.7). To model these effects it has been decided to have a random generated phase change modelled as a random process uniformly distributed in the range $[0, 2\pi]$. The complex scaling formed jointly by the phase transition and the power control (described in section 0) can be considered as a change of channel conditions and can therefore be a challenge for some SAIC receivers.

5.4.5 Guard period and power ramping

The symbols to be sent during the guard time between the different bursts are not covered by the specifications. Due to the power ramping applied between the bursts it is not expected that the guard symbols will have a major impact on the link layer performance. Therefore it has been agreed to use uniformly distributed random symbols.

According to the specifications the basestations are only required to use power ramping when non-used timeslots are present i.e. the ramping will be used on the non-BCCH frequencies. No specific ramping function has been defined but the ramping should follow the time mask for normal bursts as defined in 45.005. To simplify the asynchronous link level modelling it is agreed to use power ramping on all bursts besides any ramp function can be used as long as it is compliant with the time mask from 45.005.

5.4.6 DTX

When deriving the original synchronous link level model DTX was taken into account in the network simulations and consequently also in the link level model. Because the asynchronous model have been derived from the synchronous model DTX will not be applied to the main burst (see Figure 5-6). For the adjacent burst there are two options:

1. DTX applied
The adjacent burst is present with 60% probability and absent with 40 % probability.
2. DTX not applied
The adjacent burst is always present.

In both cases the complex scaling described in section 0 is applied on the adjacent burst. Option 1 is expected to give slightly to positive performance figures because it does not take into account that when in DTX mode in a real network another interferer will pop up and cause interference. Option 2 on the other hand is expected to be very conservative because it does not use DTX at all. In practice it is expected that the performance will be in between the two extremes used in this feasibility study.

With option 1, the average power level of each discrete interferer shall be increased to compensate for the reduced interferer energy by multiplying the signal by a factor $\sqrt{5/4}$ for configurations 1 and 4 and $\sqrt{25/21}$ for configurations 2 and 3. This is done for both the main and the adjacent burst and regardless of the actual number of bursts that were absent at a particular time instant. For configurations 1 and 4, where $t_{\text{intra-cell}} = 0$, on average half of the desired burst is covered by the main burst (that is present with 100% probability) and half by the adjacent burst (that is present with 60% probability), the energy will on average be $(0.5 \cdot 1 + 0.5 \cdot 0.6) = 4/5$ of the energy without DTX. Multiplying the amplitude of the interferer with $\sqrt{5/4}$ will make the average energy of the interferer the same with option 1 and option 2. For configurations 2 and 3, where $t_{\text{intra-cell}} = 20\%$, on average 60% of the desired burst is covered by the main burst, and the energy will on average be $(0.6 \cdot 1 + 0.4 \cdot 0.6) = 21/25$ of the energy without DTX.

5.5 Summary

In this section the link level modelling used for assessing the SAIC performance gain has been described. The models developed during the SAIC feasibility study include a high number of parameters and are much more complex than conventional interference test cases. Consequently there is a considerable risk that the modelling will be done differently by the companies and this discrepancy can make it difficult to compare results between companies. In case SAIC will be standardized this is clearly an issue that needs to be addressed to ensure companies are using the same baseline for performance evaluation.

Link level models have been derived for synchronous and asynchronous mode network configurations. The interference levels for the two setups are identical but the asynchronous model is modified to take effects like time offset, power control, DTX etc. into account.

Although the goal has been to model the behaviour in real networks as accurate as possible clearly the models are only approximations especially the models for the asynchronous networks. Therefore the link and system level performance estimated in this TR can only be used as guidelines for the performance that will be seen in a real network.

6 SAIC Link Level Characterisation

6.1 Introduction

In this section, the link performance of SAIC receivers is characterised.

In section 6.2, long-term link level performance is summarised and compared to the performance of conventional receivers. Results are presented for the link interference models described in section 5. Detailed simulation results can be found in annex X.

In section 6.3, the principles of link-to-system modelling are described. Simulation results for the link interference models described in section 5 are collected in annex Y.

6.2 Link level performance

In this section, long-term link level performance is summarised and compared to the performance of conventional receivers. Simulation results are presented for the link interference models described in section 5, corresponding to the four network configurations described in section 4. Results from different sources are presented. Detailed simulation results can be found in annex X.

It should be noted that the term “conventional receiver” does not reflect a common reference receiver as no such receiver has been defined. Instead, each source has used a reference receiver of their choice. Consequently, different sources may present different performance for the conventional receiver.

Two performance measures are considered:

- The CIR required to achieve a decoded frame erasure rate of class 1A bits (denoted “FER”) of (less than) 1%
- The CIR required to achieve a raw bit error rate (denoted “raw BER”) of (less than) 10%

6.2.1 Results for exemplary link models

The results for configurations 1 to 4 with unsynchronised interference are summarised in table 6-1. Two options exist for the link interference model for unsynchronised interference, one modelling DTX while the other does not. Results for both options are presented in the table below.

Configur ation	Perf. measure	Receiver	Source						
			Ericsson []	Motorola []	Nokia []	Philips []	Siemens []	...	Average
1 DTX on	CIR @ 1%FER AFS 12.2	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
1 DTX off	CIR @ 1%FER AFS 12.2	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
2 DTX on	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
2 DTX off	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
3 DTX on	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
3 DTX off	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
4 DTX on	CIR @ 1%FER AFS 12.2	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
4 DTX off	CIR @ 1%FER AFS 12.2	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							

Table 6-1. Summary of average performance for configurations 1 to 4 with unsynchronised interference.

The results for configurations 2 and 3 with synchronised interference are summarised in table 6-2.

Configur ation	Perf. measure	Receiver	Source						
			Ericsson []	Motorola []	Nokia []	Philips []	Siemens []	...	Average
2	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							

3	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							
	CIR @ 1%FER AFS 5.9	SAIC							
		Conv.							
		Gain							
	CIR @ 10% raw BER	SAIC							
		Conv.							
		Gain							

Table 6-2. Summary of average performance for configurations 2 to 3 with synchronised interference.

[add discussion about results]

6.2.2 Additional results

[8PSK, sensitivity, etc.]

6.3 Link-to-system interface

The purpose of the link-to-system interface is to allow the system simulator to estimate the performance of each link based on the current interference situation for the link. A common approach is described in [Olofsson]. With this approach, the CIR is mapped to a frame erasure rate in two stages. In stage one, the model takes burst level CIR samples as input and maps them onto the (raw) bit error probability (BEP) for a burst. In stage two, the BEP samples of one speech frame are grouped together (hence, for GSM fullrate speech the group consists of eight BEP samples) and used to estimate the frame error probability (FEP). This is done by calculating the mean and (optionally) the standard deviation (or some other variability measure) of the burst BEP samples of the frame, and mapping these parameters onto the FEP. Finally, the FEP value is used to calculate whether the particular frame was in error.

With SAIC, the receiver performance typically depends on the interference environment in a non-trivial manner. Therefore, the burst CIR alone is not sufficient to determine the burst BEP. Earlier investigations [] have shown that a good way to characterise the interference situation in a particular burst is to use the DIR (for definition, see section 5) in addition to the CIR. A link-to-system interface for a SAIC receiver would then map burst CIR and burst DIR to burst BEP in stage one, and proceed as described above for stage two. The mappings used in the first and second stages are illustrated in figure 6-1 and 6-2, respectively (these figures are for illustration purposes only and do not show actual performance).

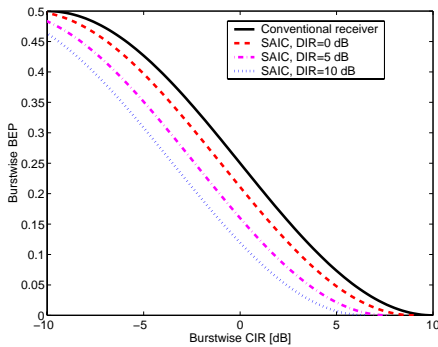


Figure 6-1. Illustration of stage one mapping. The curves show burst-wise BEP versus burst-wise total CIR for SAIC receivers with different DIR. The performance of a conventional receiver has also been included and is assumed to be independent of DIR.

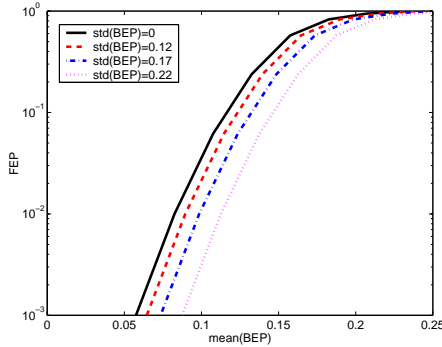


Figure 6-2. Illustration of stage two mapping. The curves show FEP versus mean(BEP) for different std(BEP).

Simulated performance curves from different sources, corresponding to those illustrated in figure 6-1 and figure 6-2, can be found in annex Y. These have been achieved as follows:

- The stage one mapping (burst-wise performance) is achieved by logging the burst-wise DIR, CIR and (raw) BER from each burst in a link level simulation. The bursts are then binned in a two-dimensional “grid”, depending on their DIR and CIR. For each bin, the BEP is calculated by averaging the bit error rates of the individual bursts in that bin. The resulting BEP curves are presented as a function of burst CIR and parameterised with DIR.
- The stage two mapping (frame-wise performance) is achieved from the same type of simulations as the stage one mapping, with the addition that frame errors after channel decoding are also logged. The BEP values described above are grouped in groups of eight (corresponding to the speech frames) and the mean and standard deviation for each frame is calculated. The frames are then binned in a two-dimensional “grid”, depending on their mean(BEP) and std(BEP). For each bin, the FEP is calculated as the average FER of the frames in that bin. The resulting FEP curves are presented as a function of mean(BEP) and parameterised with std(BEP). Note that a simpler, one dimensional mapping may also be considered. In this case, the std(BEP) is not used.

7 SAIC System Level Characterization

7.1 Introduction

In this section, the system level performance of GSM networks with SAIC capable terminals is characterized. System level simulation results are presented for the four network configurations described previously in section 4 of this document. The results presented show the voice system capacity that a network can support when all terminals are SAIC capable. Results are also shown, which describe the system performance as a function of SAIC terminal penetration rate. The following sections describe the methodology employed to develop system capacity estimates along with the results. Section 7.1 describes the link-to-system level mapping required to ‘map’ the SAIC link level characterization described in section 6 into a GSM system level simulator. Section 7.2 describes the framework of the system level simulator including all of the key system assumptions. Section 7.3 presents the system capacity results for both synchronous and asynchronous networks, and as a function of mobile penetration. Finally section 7.4 provides a summary along with the relevant conclusions that can be drawn.

7.2 Link-to-System Mapping

Two stages of mapping are required to properly map the link level results for conventional and SAIC receivers into the system level simulators. For SAIC receivers, the first stage of mapping attempts to define the average of the burst BER as a function of the burst C/I and burst DIR. This is accomplished by running link level simulations and collecting BER statistics on a per burst basis. The mean C/I is set to some nominal value, while the mean interference powers are set per the defined interference profiles. The Rayleigh fading imposed on top of the desired signal and some of the interferers will cause variation in the C/I and DIR. In this way the BER bins corresponding to different values of burst C/I and burst DIR will be filled in. Note that multiple simulation runs at different C/I values may be required to adequately fill in all of the bins. For conventional receivers, there is only a mapping between burst C/I and burst BER, since there is little dependence upon the DIR. In the second stage of this process the frame error probability (FEP) of a speech frame is determined based on the average and standard deviation of BER over the speech frame. [1].

7.3 System Level Simulator

In this section, the framework of the system level simulator used to develop the system capacity results is described. System simulators have been used extensively to estimate the voice and data capacity of GSM and GPRS/EDGE networks. Most of these simulators actually assume a ‘synchronized’ GSM network even though the vast majority of GSM deployments to date are non-synchronized (asynchronous). A synchronized network implies that the transmitted bursts (slots) from all of the BTSs modelled in the simulator completely overlap one another. The reason that the synchronization assumption is invoked is that it becomes computationally prohibitive to introduce sub-slot delays into the simulator framework. In addition, up until the SAIC feasibility study, it has been more or less assumed that there is little loss in the accuracy of system capacity estimates under the synchronized assumption, although this has not been verified in detail. However, the performance of SAIC receivers is known to be dependent upon the delay between the desired signal and the interfering signals. Thus, it is important to understand SAIC performance for both synchronous and asynchronous conditions. To circumvent the problem of developing an asynchronous system simulator, which was estimated to be a very complex and time-consuming task, it was agreed to use synchronous system simulators for both synchronous and asynchronous network evaluations. To account for asynchronous operation, a second link level characterization was performed, whereby the interfering signals had the characteristics of an asynchronous network. Thus, ‘first-stage, link-to-system level’ mappings were developed for both synchronous and asynchronous interferers as described in section 6.

Four network scenarios or configurations have been evaluated to determine the voice capacity gain that SAIC might provide. These four configurations are defined by a unique set of system parameters, and a common set of system parameters defined in Tables 1 and 2 of section 4, respectively. The unique set of system parameters include: designation of synchronous or asynchronous operation, frequency of operation, useable bandwidth, reuse pattern, the type of hopping (baseband or RF), the voice codec, whether the system is blocking limited or soft-limited, the modulation combinations of interest for the desired and interfering signals, and the cell radius. The common set of parameters include such parameters as: number of sectors per site (3), BTS antenna pattern, propagation model, standard deviation of log-normal fading, etc. The following will briefly describe each of the configurations along with

a discussion of some of the common parameters that may need additional explanation beyond that provided in Table 2 of section 4. Note all of the configurations are primarily concerned with the performance of SAIC on the hopping layer. This is where SAIC is expected to give its maximum voice capacity gain, and thus, is the primary emphasis of this study. SAIC will also provide benefits for BCCH carriers – e.g. in terms of link frame erasure rate for SAIC users – but because of the typical sparse reuse pattern (4/12) the capacity gains will not be as high as on the hopping layer.

The metric used for evaluation of performance was frequency load. In the study frequency load was defined to be the percentage of available traffic channels that are used. (e.g. For a sector with 6 hopping carriers, a frequency load of 40% corresponds to having an average of 19.2 traffic channels used out of a total of 48 (6*8)).

Configuration 1 is representative of a typical ‘European’ deployment of GSM at 900 MHz. Asynchronous operation is assumed with a total bandwidth of 7.8 MHz. The BCCH is deployed in a 4/12 reuse pattern and thus, requires 2.4 MHz of bandwidth. The remaining 5.4 MHz of bandwidth is deployed in a 3/9 reuse pattern, which implies three frequencies per sector not counting the BCCH frequencies. Baseband hopping is assumed, which implies that the voice traffic channels hop through the BCCH frequencies. The speech codec is the AMR FR at 12.2 kbps, which is assumed to be equivalent to the EFR. The reuse pattern is sparse enough so that a blocking limit of 2% is specified. The modulation combinations of interest are GMSK/GMSK and GMSK/8PSK, where the first entry is the desired signal and the second entry is the interferer. A 500 meter cell radius is assumed.

Configuration 2 is representative of a GSM deployment of limited spectrum as might be encountered in the United States. Both synchronous and asynchronous networks are of interest. Frequency of operation is 1900 MHz with a total bandwidth of 1.2 MHz deployed in a 1/1 reuse pattern for the hopping layer. This implies six hopping carriers per sector over which random RF hopping is deployed. The tight reuse implies that the capacity will be soft-limited by the interference generated as opposed to a hard blocking limit encountered in sparser reuse. Thus, the fractional load at which the network is operated is the primary performance measure. The AMR 5.9 FR and HR speech codecs are assumed. The modulation combinations of interest are GMSK/GMSK, GMSK/8PSK, 8PSK/GMSK, and 8PSK/8PSK. The cell radius is assumed to be 1000 meters.

Configuration 3 is also representative of a GSM deployment of limited spectrum as might be encountered in the United States, but with greater spectrum availability than that of configuration 2. Synchronous operation is the primary interest while study of asynchronous operation is optional. The frequency of operation is 900 MHz with a total of 2.4 MHz deployed in a 1/1 reuse pattern for the hopping layer. This implies twelve hopping carriers per sector over which random RF hopping is deployed. As with configuration 2, fractional load is the performance measure and the speech codecs are assumed to be AMR 5.9 FR and HR. The modulation combinations of interest are GMSK/GMSK and the cell radius is assumed to be 750 meters.

Configuration 4 is another example of a possible ‘European’ deployment of GSM at 900 MHz. Asynchronous operation is assumed. The frequency of operation is 900 MHz and 7.2 MHz of bandwidth is assumed to be deployed in a 1/3 reuse pattern for the hopping layer. This implies twelve hopping carriers per sector over which random RF hopping is deployed. As with configuration 1, the AMR 12.2 FR speech codec is assumed and a 2% blocking limit is specified. The modulation combinations of interest are GMSK/GMSK and GMSK/8PSK. A cell radius of 300 meters is assumed.

All four network configurations are assumed to have three sectors per cell site, which corresponds to the vehicular environment deployment model given in UMTS 30.03. Each cell is configured with an antenna whose horizontal pattern corresponds to the pattern specified in UMTS 30.03.

The propagation model specified in UMTS 30.03 as the path loss model for vehicular test environment is used for the SAIC Feasibility Study. The received signal is assumed to be affected by log-normal fading, which is assumed to have a standard deviation of 6 dB for 900 MHz deployments and 8 dB for 1900 MHz deployments. Log-normal fading tends to be correlated over short distances and a log-normal correlation distance of 110 meters is assumed. Inter-site log-normal correlation is assumed to be zero.

Voice calls are generated in the system simulator based on Poisson call arrivals and exponential call durations. The call arrival rate is set according to the frequency load that is to be simulated in the network. The mean call duration is assumed to be 90 seconds, with a minimum call duration of 5 seconds. A voice activity factor of 60% (including SID signalling) is assumed and discontinuous transmission (DTX) is assumed to be enabled in the network.

Downlink power control (DPC) is enabled in the system simulator for all four network configurations. A common DPC algorithm for the SAIC Feasibility Study was not specified but it was agreed that the DPC algorithm used should be based on RXQUAL and RXLEV. All system level simulations assume a DPC dynamic range of 14 dB and step size of 2 dB.

7.3.1 Satisfied User Definition

Two definitions for a 'satisfied user' exist and are presented below:

Option 1: The speech quality is measured over the duration of one call. The speech quality is considered satisfactory if the FER is not higher than 2% (the user is said to be satisfied). The network capacity is defined as the network load at which X% of the users are satisfied.

Option 2: The speech quality is measured over periods of 1.92 seconds (i.e., four SACCH periods). The speech quality (of one particular link) is considered satisfactory during the period if the frame erasure rate (FER) is not higher than 2%. The network capacity is defined as the network load at which the speech quality is satisfactory in X% of the measured 1.92 second periods.

One must note that each different option may have a different capacity for an identical system. [] suggests the difference is small, but nonetheless caution must be observed when comparing results when different options were used.

7.4 System Level Simulation Results

The results for the system simulations are presented in Sections 7.4.1 and 7.4.2. Section 7.4.1 presents the results obtained during the feasibility study for 100% SAIC loaded systems vs. a benchmark of a system with 100% conventional users¹. Section 7.4.2 presents the impact of SAIC mobile penetration rate on the system's performance and on the performance of non-SAIC users.

7.4.1 System capacity for 100% SAIC mobile penetration

In the next six sections results for all the configurations under study are presented. Synchronous system performance results may be expected to match closely with what will be seen in actual deployments. However, for asynchronous networks, the system results may only be approximate due to the complex nature of the link-system mapping in asynchronous networks [6]. The general trends shown for the asynchronous network cases should, however, hold when a real network is deployed, but the absolute capacity of those networks may be different.

7.4.1.1 Configuration 1 – unsynchronised network

In this section, results for configuration 1 are shown.

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Siemens			
Ericsson			

Table X.- LOAD when 95% Users were satisfied

[Insert figure]

Figure X. SAIC vs. Conventional Receiver Capacity as

¹ The definition of a conventional terminal and its performance differs between companies. For details on this discussion please refer to Section 6.

a function of system load. (Sample)

7.4.1.2 Configuration 2 – synchronised network

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Motorola ²	34.75	47.25	35.9
Siemens			
Ericsson			

Table X.- LOAD when 95% Users were satisfied

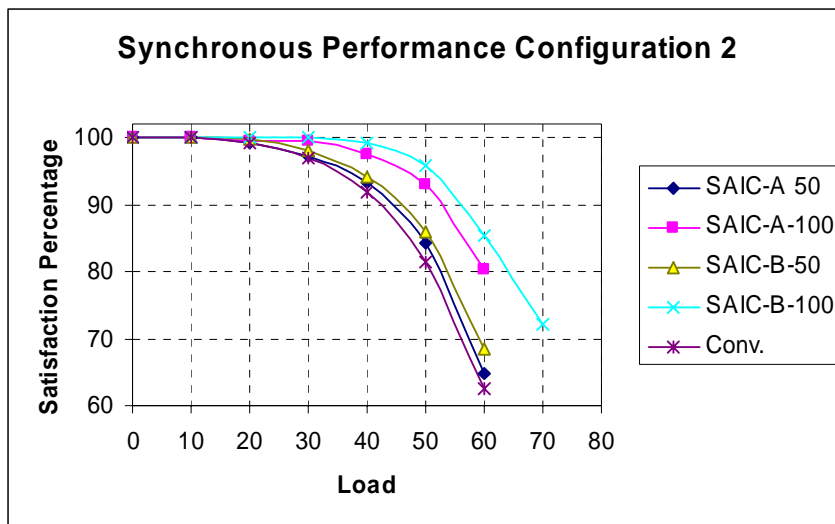


Figure 7.- System Performance for Synchronous – Configuration 2 [7]

7.4.1.3 Configuration 2 – unsynchronised network

² Motorola's performance here is for a receiver architecture denoted SAIC-A in [8]. A different receiver structure SAIC-B provides better SAIC system gains for synchronous networks.

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Motorola	34.00	43.25	27.2
Siemens			
Ericsson			

Table X.- LOAD when 95% Users were satisfied

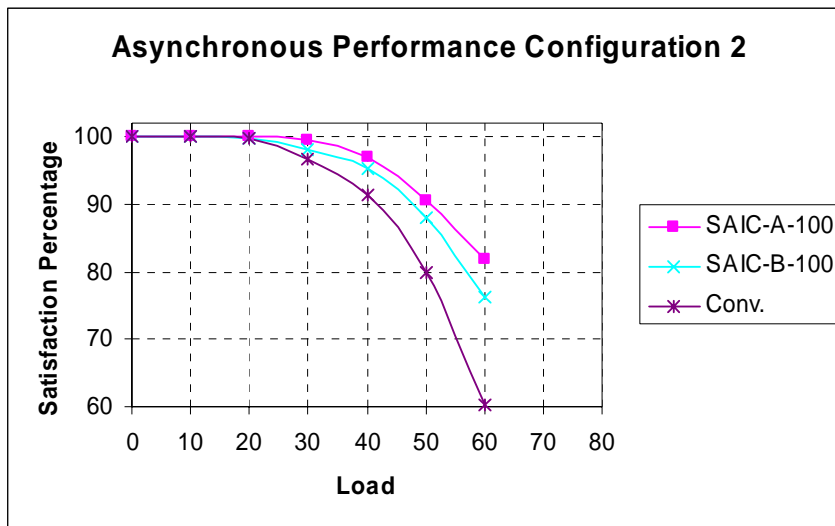


Figure X. Figure 8.- System Performance for Asynchronous -Configuration 2[7]

[Insert results from other sources here]

7.4.1.4 Configuration 3 – synchronised network

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Motorola	33.50	48.75	45.5
Nokia ³	27.6 (Option 1)	41.0 (Option 1)	48.6 (Option 1)
	29.0 (Option 2)	42.0 (Option 2)	44.8 (Option 1)

³ Nokia numbers for AMR 7.4 codec. A direct comparison therefore should not be made with different companies' performance, however the trend of showing gains for SAIC are still present.

Siemens			
Cingular	35.8	51.2	42.8
Ericsson			

Table X.- LOAD when 95% Users were satisfied

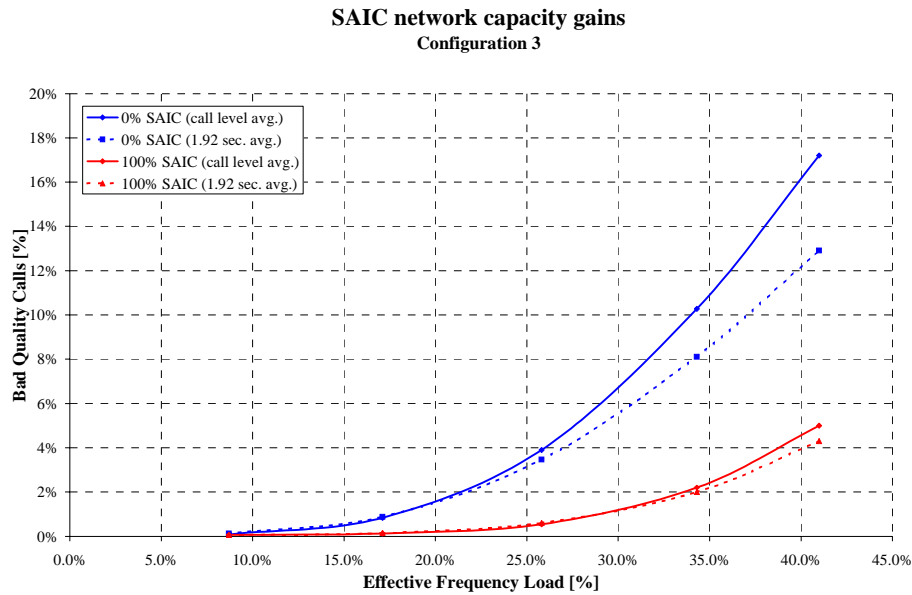


Figure X. Example SAIC capacity gain of two SAIC receivers w.r.t. two conventional receivers for 100% SAIC terminal penetration [GP-032588][GP-032588]

7.4.1.5 Configuration 3 – unsynchronised network

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Motorola	29.75	40.25	35.3
Siemens			
Ericsson			

Table X.- LOAD when 95% Users were satisfied

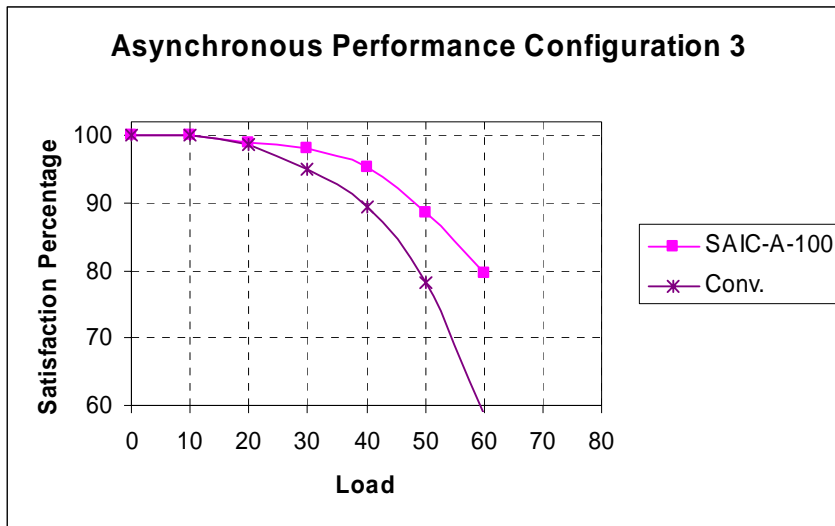


Figure X. SAIC vs. Conventional Receiver Capacity as a function of system load.[7]

7.4.1.6 Configuration 4 – unsynchronised network

	LOAD for which 95% of Satisfied Users is reached.		
Source	100% Conventional	100% SAIC mobiles	Percentage Gain
Motorola	49.50	66.50	34.3
Siemens			
Ericsson			

Table X.- LOAD when 95% Users were satisfied

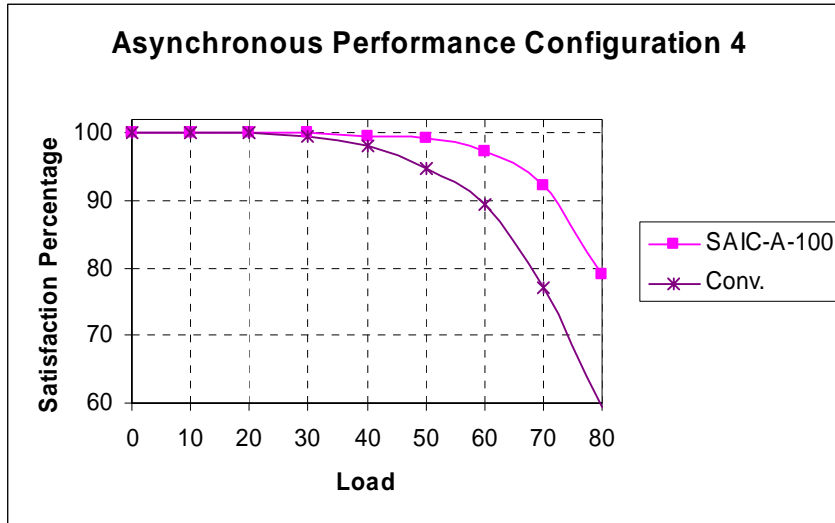


Figure X. SAIC vs. Conventional Receiver Capacity as a function of system load. [7]

7.4.2 Impact of SAIC Mobile Penetration

Figure 7.3.2.1 shows the system capacity as a fractional load for configuration 3 as the SAIC terminal penetration rate goes from 0% to 100%. The results shown in Figure 1 are based on the Philips SAIC and Philips conventional receivers. As the SAIC terminal penetration increases the overall system capacity gradually starts increasing with the peak capacity obtained at 100% penetration. Figure 7.3.2.2 shows the gains in system capacity of a network with various levels of SAIC terminal penetration. The gains shown are with respect to a network with 0% SAIC terminal penetration (i.e. all terminals are conventional receivers). Capacity gain due to SAIC is not linearly related to SAIC terminal penetration. Hence, for low to moderate terminal penetration rates, SAIC is expected to provide its primary benefit in terms of immediate improvement in call quality (and GPRS data rate) of SAIC-enabled terminals, with the secondary benefit of modest system capacity gain. For high terminal penetration rates, SAIC is expected to provide both, improvement in call quality of SAIC-enabled terminals as well as large gain in overall system capacity. Figure 7.3.2.3 shows similar results for two different QoS service values (95% and 98%) and for the two satisfied user definitions specified in section 7.2.1. The effect of increasing QoS is to actually increase the gain realized. The results also indicate that the two satisfied user definitions provide nearly identical results.

In Figure 7.3.2.4 results are compared from Cingular, Motorola and Siemens as presented in GERAN contributions [2] [3] and [4]. This comparison is not totally normalized because the results generated by Motorola and Siemens are based on FER averaged over the entire call duration, while the Cingular results are based on FER averaged over 1.92 seconds. Another difference is that the Cingular results are based on Philips' SAIC algorithm while those of Motorola and Siemens are based on their own respective SAIC algorithms. Nevertheless, such a comparison is useful to validate the non-linear nature of the relationship between SAIC terminal penetration and SAIC capacity gain. In spite of the difference in assumptions, all three sets of results show a similar non-linear relationship between system capacity gain and SAIC terminal penetration. Moreover, the comparison also indicates that SAIC capacity gain estimation is relatively independent of the FER averaging interval, as was also shown by Nokia in contribution [5].

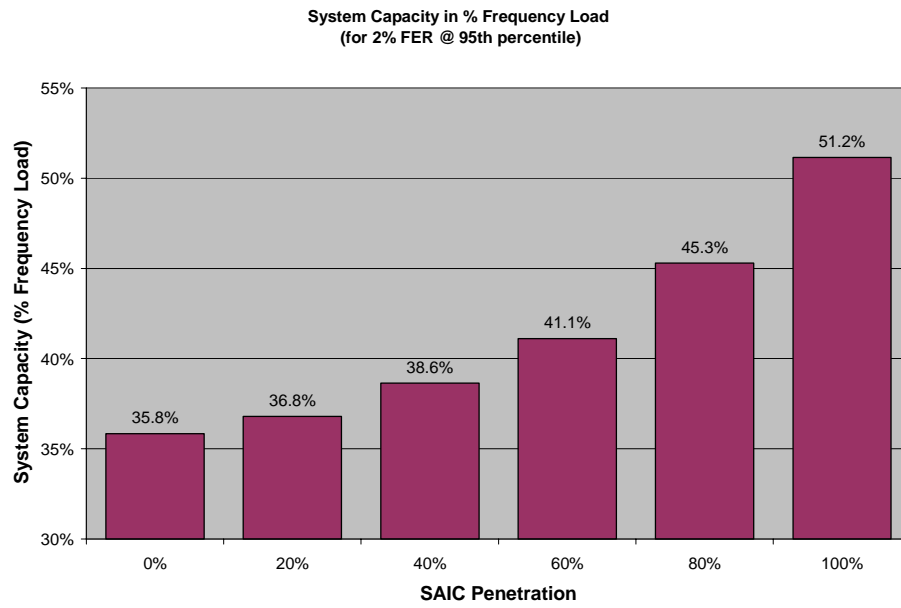


Figure 7.3.2.1: System capacity versus SAIC terminal penetration rate for Configuration 3 [GP-032588]

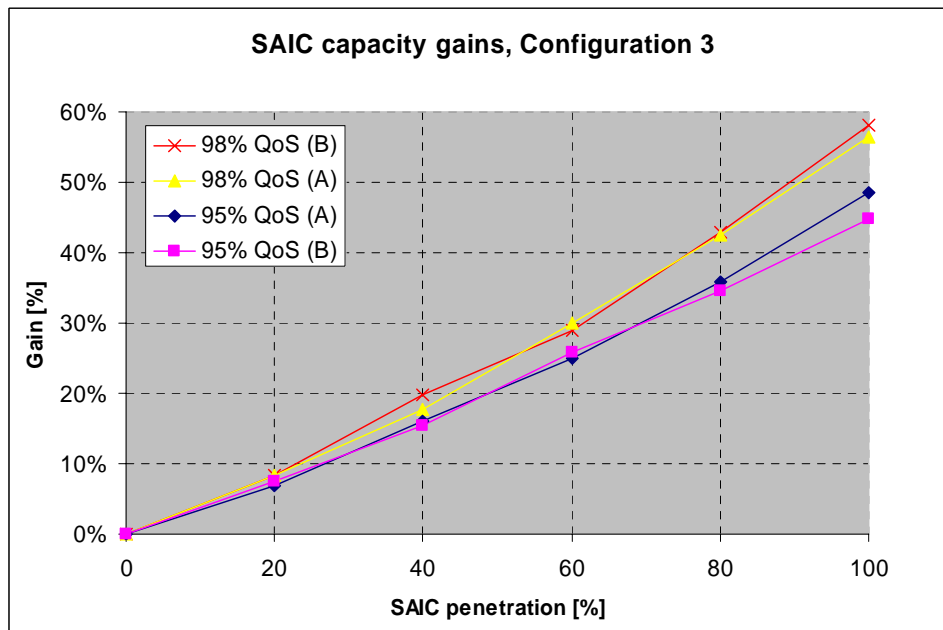


Figure 7.3.2.3. SAIC capacity gain as a function of SAIC penetration. A = call level averaging, B = 1.92 sec. averaging. 95% and 98% satisfied user ratios and 2% FER criteria. GP-032649, source Nokia.

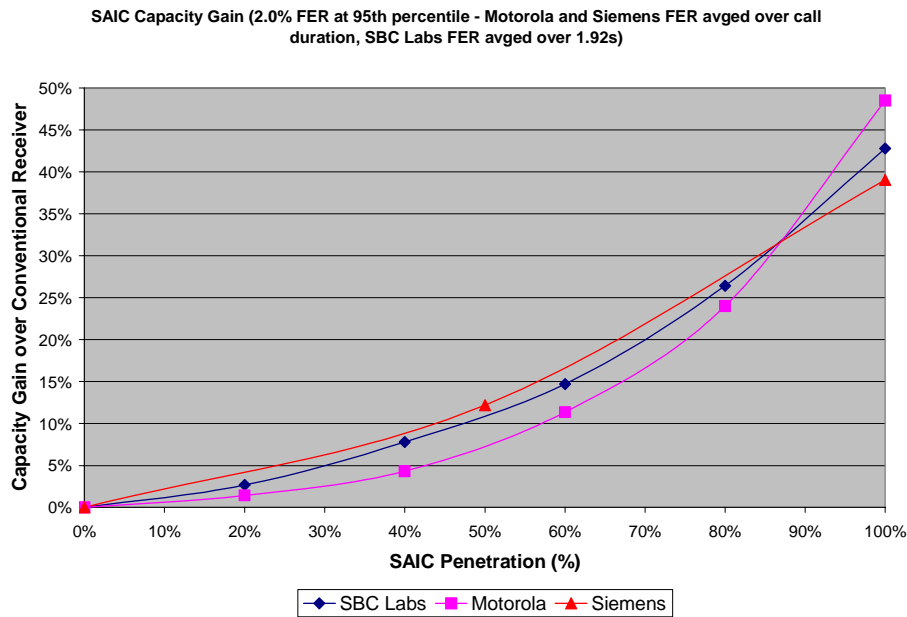


Figure 7.3.2.4: Comparison of results presented at TSG-GERAN [GP-032588]

7.4.3 Additional Results

In this section results from companies that don't fit under the 6 scenarios under study will be included.

7.3.3.1 Effect of antenna patterns on system capacity

During the SAIC feasibility study, the effect of antenna beamwidth on system capacity results was discussed. The default antenna pattern specified in section 4 has a 90-degree beamwidth (at 3 dBi point), which may not be the best choice from a capacity point of view. The antenna pattern may also have an effect on the SAIC gains because it changes the DIR distribution experienced by the MS. To give some insight into this issue, simulations were made with both a 90-degree and a more efficient 65-degree beamwidth. Figure 7.3.3.1.1 shows the results, which indicate that the antenna pattern does affect the SAIC gain, but that the effect is not that large. With a wider beamwidth the gains are actually 5-10% greater than the narrower beamwidth. The reason for this is that although the narrow beamwidth supports higher absolute performance, there is actually less interference in the system to cancel and thus, the SAIC gain is not as large.

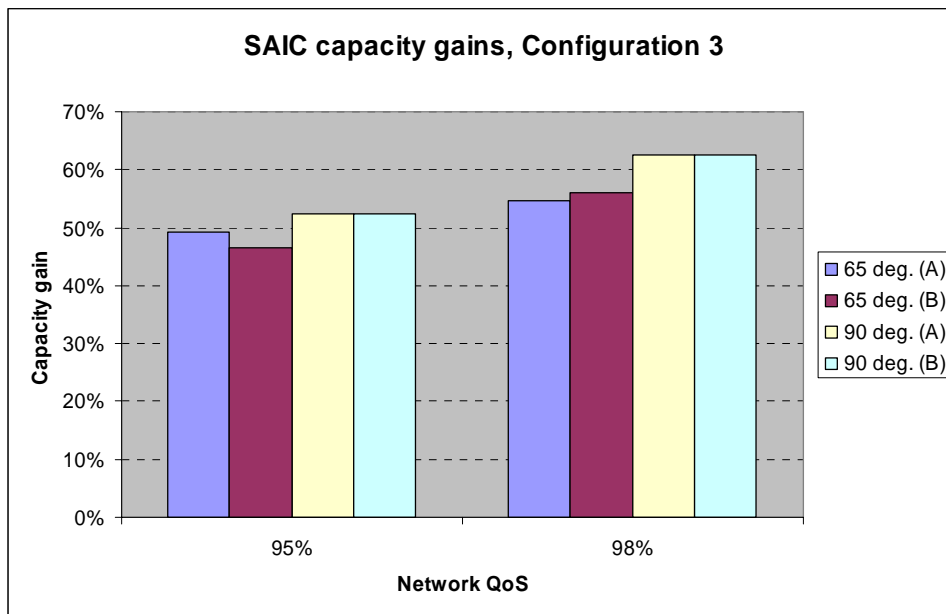


Figure 7.3.3.1.1. SAIC capacity gain with two different antenna patterns. A = call level averaging, B = 1.92 sec. averaging. 95% and 98% satisfied user ratios and 2% FER criteria. GP-032649, source Nokia.

7.5 Summary and Conclusions

We have seen gains when SAIC is deployed for all the configurations under study. This holds true for synchronous and asynchronous networks....

References

- [1] H. Olofsson, et al, 'Improved Interface Between Link Level and System Level Simulations Applied to GSM', IEEE Vehicular Technology Conference, 1997.
- [2] GP-032588, 'SAIC System Capacity Results', Source Cingular.
- [3] GP-032107, 'Effect of SAIC Terminal Penetration on System Performance', Source Motorola.
- [4] GP-032023, 'System Performance Results for SAIC' Source Siemens.
- [5] GAHS-030040, 'SAIC network capacity with different antenna patterns and performance criteria' Source Nokia.
- [6] GAHS-030036, Ericsson, 'Working assumptions for capacity estimation for SAIC in unsynchronized networks', Chicago, USA 28-30 2003
- [7] GAHS-030029, Motorola, 'SAIC System Simulation Results', Chicago, USA 28-30 2003
- [8] GAHS-030030, Motorola, 'SAIC link level results', Chicago, USA 28-30 2003.

8 SAIC Field Trials

In order to determine the viability of SAIC technology for GSM networks, Cingular Wireless conducted two separate field trials using a prototype SAIC mobile offered by Philips Semiconductors [1] [2]. The first trial was conducted in an operational, asynchronous (non-synchronized) GSM network. Network parameters were varied to determine performance as function of the Frequency Load (FL). A maximum gain of 2.7 dB in the C/I distribution at the 10% point was obtained at the maximum load. The second trial was conducted in a synchronized network, the status of which was pre-operational at the time of testing. Synchronized networks are expected to provide higher SAIC gains since the amount of overlap between the desired signal and the interference can be controlled. The results of this latter trial support the above conclusion, where a C/I gain of 4.5 dB was observed. The following sections provide additional information for each of the respective trials.

8.1 Asynchronous Network Field Trial

Cingular's Savannah market was chosen as the test market for the first asynchronous network trial of SAIC technology. The field trial took place in June 2002. Savannah is representative of a relatively mature GSM network, which employs Frequency Hopping (FH) on the voice traffic channels in a very tight 1/1 reuse, with the FL per sector ranging from 10-25%. The results of the trial indicated a gain in the downlink C/I distribution at the 10% points of 2.7 dB for the most heavily loaded test condition, Figure 8.1.1. This gain was measured by alternately toggling SAIC on and off every RXQUAL reporting period (0.48 s). Gain was also observed in terms of a reduction in the BER and FER as recorded by the mobile. For example, for the most heavily loaded condition, the probability of the BER being less than 3% increased from 75% to 82%, while the average FER decreased from 4.4% to 2.5%.

Additional testing was performed where the duty cycle of SAIC on to off was changed to see the effect SAIC might have on Downlink Power Control (DPC). The results of this latter testing at a SAIC on-to-off duty cycle of 15:1 indicated a decrease in the average BTS transmit power of 1.8 dB and a 1.3 dB decrease in the average received signal level at the mobile. In addition, the mobile reported RXQUAL was almost identical for both duty cycles indicating that performance was not compromised for the high SAIC on duty cycle condition.

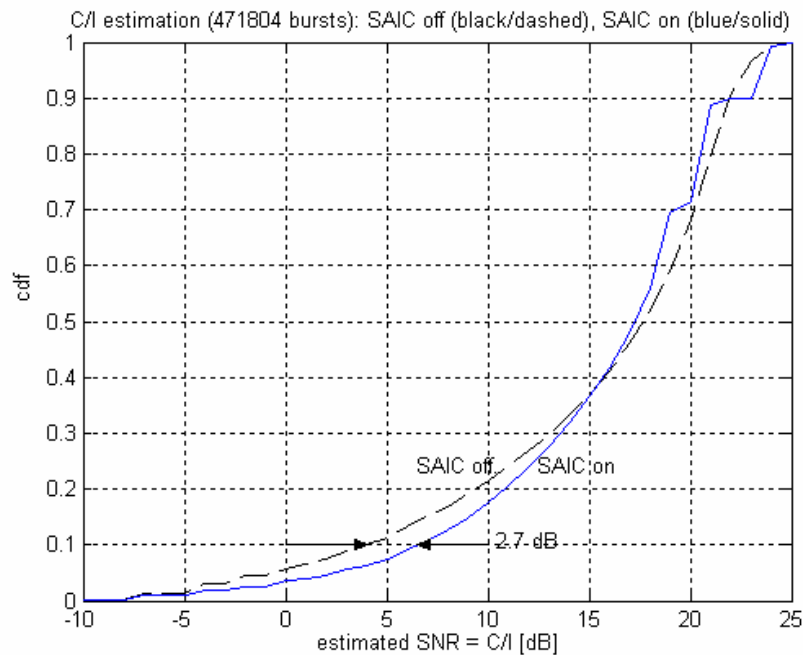


Figure 8.1.1. C/I distributions for asynchronous field trial.

8.2 Synchronous Network Field Trial

To determine performance in a synchronized network the same SAIC Philips' prototype was tested in Cingular's Delaware market in November 2002. This trial was particularly useful as the Delaware network was pre-operational at the time of SAIC testing, and as such offered the unique capability to test SAIC under both synchronized and non-synchronized conditions. Tests were conducted for synchronized random FH with three and five interferers, and for non-synchronized random FH for one and three interferers..

The results of the synchronized random FH tests with five interferers indicate a gain in the C/I distribution of approximately 4.5 and 5.0 dB at the 10 and 20% points, respectively, as shown in Figure 8.2.1. The results of the same test for three interferers indicate a gain in the C/I distribution in the range of 2-3 dB. This decrease is expected since the network load was not as high as the five-interferer condition, and thus, there was not as much interference for SAIC to cancel.

For the non-synchronized tests, the amount of gain observed varied with the delay between the desired signal and the interfering signals. This was expected since as the delay increases a 'second' interferer begins to overlap the slot of interest and thus, causes degradation in performance. For a single interferer, the gain in C/I distribution at the 10% points ranged from 0 dB when the delay was equal to about 80 symbols (near worst case) to 5.3 dB when the delay was less than 19 symbols. For the three-interferer tests the same trends were observed. The lowest gain of 1.6 dB was observed when all three interferers had delays of greater than 20 symbols, while a gain of 4.0 dB was observed when only one of the three had a delay greater than 20 symbols.

The conclusion from these trials is that SAIC will provide gains in both non-synchronized and synchronized networks, but that maximum gains will be achieved with a synchronized network, where the amount of overlap between desired signal and interference can be controlled.

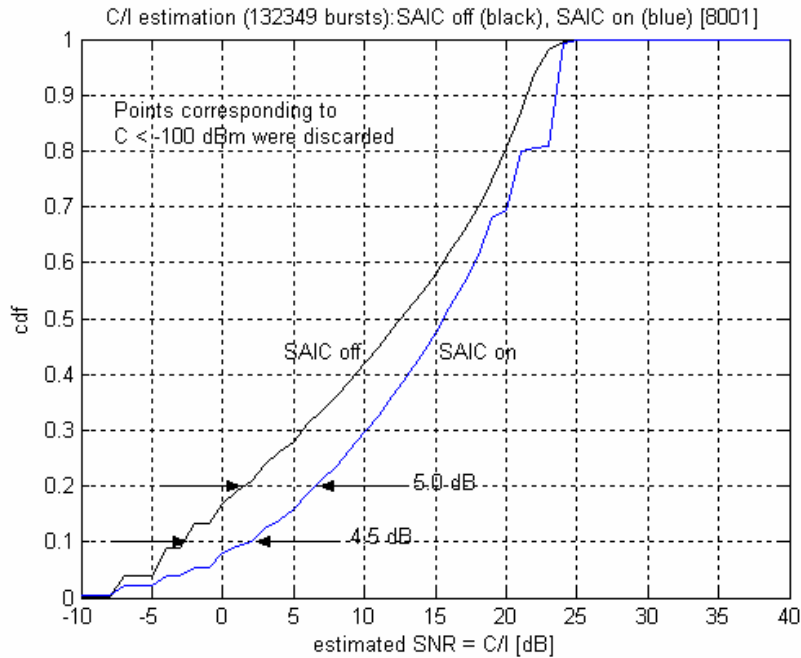


Figure 8.2.1. C/I distributions for synchronous field trial.

References

- [1] GP-022557, "Laboratory & Field Testing of Mono Interference Cancellation (MIC) for GSM Networks", Source: Philips Semiconductors, Cingular Wireless.
- [2] GP-03xxxx, "SAIC Field Trials for Asynchronous and Synchronous GSM Networks", Source: Cingular Wireless.

9 Test Considerations

9.1 Introduction

While it is not within the scope of the SAIC Feasibility Study to define detailed performance requirements for inclusion into e.g. 3GPP TS 45.005, nor detailed test scenarios for 3GPP TS 51.010 to verify conformance to those requirements,

it is recognised that the Feasibility Study Technical Report should comment on the requirements and practicality of the test apparatus required to assess SAIC receivers.

This section therefore briefly discusses the SAIC testing problem, which clearly is far from trivial. In the event SAIC is accepted by GERAN as a feasible technology, more comprehensive studies will be needed both in TSG GERAN WG1 and WG3. In performing this work it is respectfully suggested that WG1 and WG3 take particular care to ensure that:

- the requirements which are adopted reflect and warrant those receiver performance improvements identified as feasible during the Feasibility Study phase, and in doing so, ensure the realisation of the original goals of the Feasibility Study,
- improvements in specific areas of receiver performance are not achieved at the expense of poorer performance in other areas, or by creating the risk of non-robust receiver operation under normal GSM/GPRS/EGPRS system conditions, and
- any effort to simplify the assessment criteria used by the Feasibility Study (in order, for example, to simplify test apparatus or procedures) should be done without risking adherence to item a) above.

9.2 Discussion

Conformance to the 3GPP TS 45.005 and 3GPP TS 51.010 specifications requires that a combination of narrowband and modulated signal sources be made available as part of the test apparatus. Fundamentally, however, the most commonly required test configuration can be summarised by the structure shown in Figure 9-9.

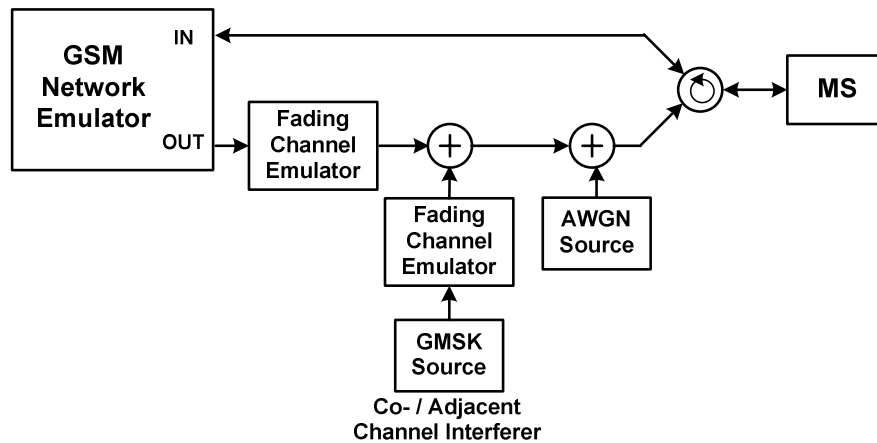


Figure 9-9 – Summary – current MS test configuration⁴.

At the same time, however, in order to capture real-world network scenarios the synchronous and asynchronous link-level models identified by the SAIC Feasibility Study capture more complex interference scenarios, including:

- simultaneous generation of multiple, independently-faded, co- and adjacent channel interferers,
- burst-formatted interfering signals with randomly varying training sequences,
- randomly-selected interferer delays & frequency offsets, and
- interferer inter-burst phase changes, DTX (optional) and power control.

These scenarios were determined to be very important when investigating achievable link and system level performance gains for SAIC mobiles, and it is recommended that they are used as the starting point in determining test procedures and requirements for SAIC-enhanced terminals. If TSG GERAN determines that direct implementation of these

⁴ No AWGN test signal are currently specified in 51.010 although available in most test equipment.

scenarios is an essential part of SAIC terminal assessment, one possible approach to synthesising such signals in real-time appears in Figure 9-10⁵, where a general-purpose streaming signal source is used to generate multiple interfering signals which are agile in terms of embedded training sequence, delay and frequency offset etc.

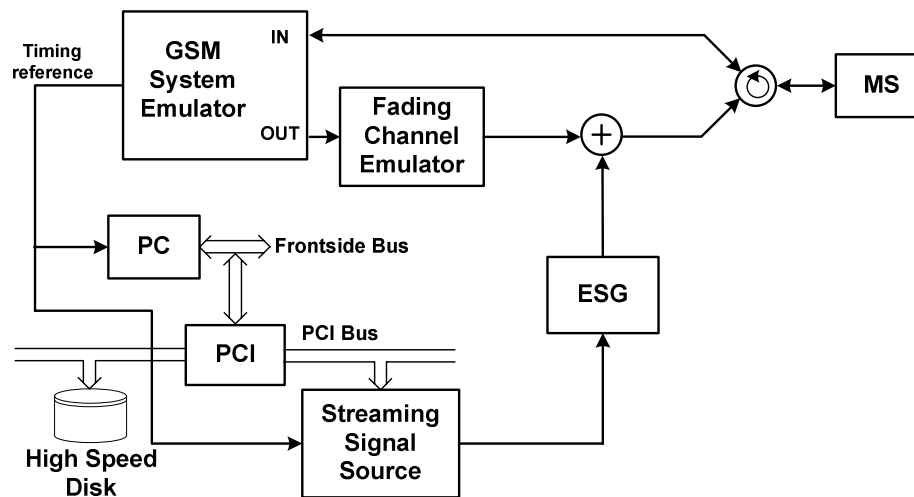


Figure 9-10 – Alternative potential configuration for complex test signal scenario generation.

It is also recognised, however, that support for such an approach could represent a considerable technical and economic challenge and may well be too complex to realise in practice. Accordingly, it may be necessary to consider which elements of the GERAN interference models are necessary to verify conformance, and how the models could potentially be simplified.

In considering potential simplifications, the following considerations and options should be considered.

Requirement for Simultaneous Co- and Adjacent Channel Interference – Although the current CIR and DIR definitions do not discriminate between interferer types (i.e. co- or adjacent channel), it may be possible to reduce the required number of simultaneous discrete interferers by restricting performance assessment to be *either* on the basis of co-channel *or* adjacent channel performance. Alternatively if a combined test is seen as necessary, a single co- or adjacent channel interferer could be combined with residual interferers to model more complex scenarios.

Structured Interfering Signals – A departure from the currently-specified continuous, randomly-generated interfering signal definition can be principally divided into a) selection of an interfering burst type, and modification of the interfering signal power burst envelope, and b) modification of the interfering symbol content. It is obviously commonplace to generate interfering signal bursts compliant with the envelope definition of 3GPP TS 45.005, and the normal burst could be a natural choice when synthesising transmitted waveforms for test purposes.

Similarly, generation of an interfering signal with a pseudo-randomly generated training sequence and pseudo-randomly generated data payload is not fundamentally difficult⁶. Indeed, training sequence's (TSC's) could be selected on a per-burst basis, or – if this was not feasible – selection of constant TSC's per interferer could also be considered. However, either change would most likely require upgrading of test apparatus, depending on the capability of the signal generators currently available to each tester, and could also make calibration of e.g. interferer power marginally more difficult. One possible simplification would be to require only that a specified bit sequence (i.e. tail bits, data payload, and training sequence) be periodically applied to the interfering signal, and that the interfering signal remain a continuously-modulated waveform.⁷

⁵ All of the outline equipment configurations proposed in this section should be regarded as 'potential' configurations; i.e. the identification of a preferred configuration is for further study.

⁶ Such a test signal is currently not available in 3GPP TS 51.010.

⁷ Note that the nominal 156.25 symbol normal burst duration may create further difficulties with this approach.

Number of Interfering Signals – The GERAN models currently define a total of 3 co-channel interferers, plus a residual co-channel interferer. Synthesis of the residual co-channel interference term could, with the addition of an appropriate filter, be achieved relatively straightforwardly using the apparatus of Figure 9-9. Using the discretely-configured apparatus of Figure 9-9 as a guide, however, a requirement to synthesise 3 co-channel interfering signals could be challenging, since it would imply a requirement for multiple discrete fading channel emulators. An obvious alternative is to reduce the number of co-channel interferers to 2 or even a single interferer. Restricting testing to be performed only with a single interferer would, however, represent a significant departure from the GERAN models, and therefore testing under dual interferer conditions could represent a practical compromise.⁸ For test apparatus where the desired signal fading is handled by the system emulator, this would require the provisioning of only a single dual-channel fading emulator. A possible system configuration appears in Figure 9-11. Importantly, however, the relative power of the interfering signals would need to be established by further work, as would the equivalence (in terms of guaranteeing performance) of this configuration compared to the link scenarios generated in the GERAN Feasibility Study.

Interferer Frequency Offset – The GERAN models currently specify a normally distributed interferer frequency offset, with a new offset generated for each interfering signal burst. Again, provided the network emulator (Figure 9-9) and interfering signal generator have a shared triggering signal, and the interfering signal generator is appropriately programmable, this is not a difficult proposition. However, this requirement again complicates laboratory calibration and traceability, and older apparatus may not possess such a capability. As an alternative, constant interferer frequency offsets could be applied to each interfering signal source (using values specified in the Work Item phase). Indeed, based on future simulation results, such a requirement could be found to have little bearing on receiver performance and might be eliminated as redundant.

Interferer Delay Generation – Again, specification of a pseudo-randomly generated interferer delay (according to the GERAN interferer models) could present practical difficulties to legacy signal generators, or add complexity to the overall timing control of the test apparatus. However, in a similar fashion to the frequency offset problem, a constant delay or set of delays could be specified for each interferer. In more detail, the synchronous case could make use of a constant delay which could include zero relative delay for interferers, or alternatively a simplified delay distribution could be used. Again this would depend on test vendor capability and further simulation work. Potential simplifications for asynchronous operation would also be for further study, since such scenarios are recognised as important in establishing robust receiver operation.

Power Control and DTX – The power control distribution requirement and (optional) DTX aspect of the asynchronous interferer scenario could also be potentially difficult (although not impossible) for contemporary test apparatus to implement. Nevertheless, a subsequent Work Item phase could determine that assessment of robust performance in asynchronous network scenarios is important, and it is therefore worthwhile to consider how the current asynchronous GERAN model could be approximated. One potential approach would be to simply convert the GERAN-specified power control distribution into a simple binary distribution, and to essentially ‘gate’ each interfering signal (i.e. on or off). This approach has the advantage of a relatively simple calibration procedure.

⁸ Of course, single-interferer tests could be defined in addition to multi-interferer tests.

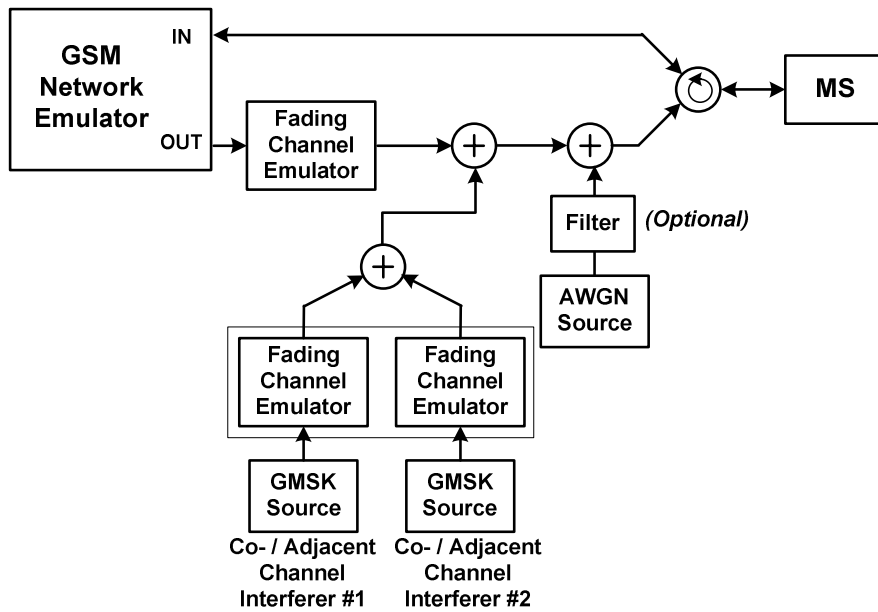


Figure 9-11 – Potential reduced-order co-channel interference configuration.

9.3 Summary

It is beyond the scope of the SAIC Feasibility Study to specify exactly which test scenarios are addressed during a performance specification phase. A variety of options exist for constructing test waveforms that may be either precisely or approximately consistent with the GERAN Feasibility Study. The exact nature of the conformance of these approaches to the original Feasibility Study models is for further study. This section has identified some potential approaches to achieving this; the views of test equipment vendors will be needed in the performance and test specification phase of SAIC.

Comment: Assuming here that we have a positive conclusion of the SAIC feasibility.

10 SAIC signalling aspects

11 Aspects for further study

12 Conclusions

12.1 Specification impacts

12.1.1 Core specifications

Section No	Title	Analysis	TS and section number

12.1.2 Testing specifications

Section No	Title	Analysis	TS and section number

Annex A

Annex B

Annex C

Annex X

In this section, link performance results are presented. A summary of the results can be found in section 6.

X.1 Configuration 1 – unsynchronised network

X.1.1 With DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 1 with DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 1 with DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 1 with DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.1.2 Without DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 1 without DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 1 without DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 1 without DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.2 Configuration 2 – synchronised network

Figure X and figure Y show raw BER and FER, respectively, for configuration 2, synchronised case.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 2, synchronised case. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 2, synchronised case. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.3 Configuration 2 – unsynchronised network

X.3.1 With DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 2, unsynchronised case with DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 2, unsynchronised case with DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 2, unsynchronised case with DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.3.2 Without DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 2, unsynchronised case without DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 2, unsynchronised case without DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 2, unsynchronised case without DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.4 Configuration 3 – synchronised network

Figure X and figure Y show raw BER and FER, respectively, for configuration 3, synchronised case.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 3, synchronised case. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 3, synchronised case. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.5 Configuration 3 – unsynchronised network

X.5.1 With DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 3, unsynchronised case with DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 3, unsynchronised case with DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 3, unsynchronised case with DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.5.2 Without DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 3, unsynchronised case without DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 3, unsynchronised case without DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 3, unsynchronised case without DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.6 Configuration 4 – unsynchronised network

X.6.1 With DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 4 with DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 4 with DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 4 with DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

X.6.2 Without DTX

Figure X and figure Y show raw BER and FER, respectively, for configuration 4 without DTX.

[Insert figure]

[Insert figure]

Figure X. Average performance for configuration 4 without DTX. The curves show raw bit error rate versus average total CIR. Source: X

Figure Y. Average performance for configuration 4 without DTX. The curves show class 1A frame erasure rate versus average total CIR for TCH/AFS X. Source: X

[Insert results from other sources here]

Annex Y

In this section, link performance results used in the link-to-system interface are presented. The results are further described in section 6.

Y.1 Stage one mapping

The stage one mapping maps the burst-wise CIR and DIR to a burst-wise BEP. It is achieved by logging the burst-wise DIR, CIR and (raw) BER from each burst in a link level simulation. The bursts are then binned in a two-dimensional “grid”, depending on their DIR and CIR. For each bin, the BEP is calculated by averaging the bit error rates of the individual bursts in that bin. The resulting BEP curves are presented as a function of burst CIR and parameterised with DIR.

The performance of a conventional receiver has also been included and is assumed to be independent of DIR. It should be noted that the term “conventional receiver” does not reflect a common reference receiver as no such receiver has been defined. Instead, each source has used a reference receiver of their choice. Consequently, different sources may present different performance for the conventional receiver.

Y.1.1 Configuration 1 – unsynchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 1.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR at different DIR for SAIC receivers for configuration 1. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.1.2 Configuration 2 – synchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 2, synchronised case.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR at different DIR for SAIC receivers for configuration 2, synchronised case. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.1.3 Configuration 2 – unsynchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 2, unsynchronised case.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR

at different DIR for SAIC receivers for configuration 2, unsynchronised case. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.1.4 Configuration 3 – synchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 3, synchronised case.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR at different DIR for SAIC receivers for configuration 3, synchronised case. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.1.5 Configuration 3 – unsynchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 3, unsynchronised case.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR at different DIR for SAIC receivers for configuration 3, unsynchronised case. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.1.6 Configuration 4 – unsynchronised network

The figures below show burst-wise BEP versus burst-wise total CIR and DIR is shown for configuration 4.

[Insert figure]

Figure X. Burst-wise BEP versus burst-wise total CIR at different DIR for SAIC receivers for configuration 4. The performance of a conventional receiver has also been included and is assumed to be independent of DIR. Source: X

[Insert results from other sources here]

Y.2 Stage two mapping

The stage two mapping maps the burst-wise BEP values of a frame to the frame error probability (FEP). It is achieved from the same type of simulations as the stage one mapping, with the addition that frame errors after channel decoding are also logged. The BEP values described above are grouped in groups of eight (corresponding to the speech frames) and the mean and standard deviation for each frame is calculated. The frames are then binned in a two-dimensional “grid”, depending on their mean(BEP) and std(BEP). For each bin, the FEP is calculated as the average FER of the frames in that bin. The resulting FEP curves are presented as a function of mean(BEP) and parameterised with std(BEP). Note that a simpler, one dimensional mapping may also be considered. In this case, the std(BEP) is not used.

[perhaps it is not necessary to show for all configurations since the curves are expected to be very similar?]

[Insert figure]

Figure X. FEP versus mean(BEP) for different std(BEP) for TCH/AFS Y. Source: X

Figure Y. FEP versus mean(BEP) for different std(BEP) for TCH/AFS Z. Source: X

[Insert results from other sources here]

Annex ZZ: Change history

Change history							
Date	TSG #	TSG Doc.	CR	Rev	Subject/Comment	Old	New