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Digital cellular telecommunications system (Phase 2+); Feasibility study on Single Antenna Interference Cancellation (SAIC) for GSM networks (3GPP TR 45.903 version 13.0.0 Release 13)

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Contents

Foreword

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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.

Clause 1 of this document defines the scope and objectives of this feasibility study. Clause 4 defines the network scenarios that have been defined to evaluate SAIC performance in GSM networks. These scenarios are representative of typical GSM deployments worldwide today. Clause 5 presents the interference statistics associated with the network scenarios defined in Clause 4. These interference statistics are developed via system simulations, and are defined in terms of the distributions of the parameters which are critical to understanding SAIC performance. These critical parameters include;

- The Carrier to Interference plus noise Ratio (CIR)
- The Dominant to rest of Interferer Ratio (DIR)
- The other interferer ratios, which define the relative power of the dominant co-channel interferer to each of the other considered interferers
- The delay between the desired signal and each of the interferers.

It is important to understand the network statistics of these key parameters since most SAIC algorithms can only cancel one interferer, and their effectiveness in doing this is affected by the 'remaining' interference, and delays between the desired signal and the interferers.

In Clause 6, candidate SAIC algorithms are evaluated at the link level based on the interference statistics defined in Clause 5. Both 'long-term average' and per burst results are generated. The long-term average results represent the classical way of looking at link performance via link simulations, defining the Bit Error Rate (BER) and Frame Error Rate (FER) averaged over the entire simulation run as a function of the CIR. This is the type of performance that is typically specified in the GSM standards. However, to develop a system capacity estimate, it is necessary to define the link performance on a per burst basis. To this end, Clause 6 also defines the average BER over the burst as a function of the burst CIR and burst DIR. This burst performance is used to develop a link-to-system level mapping. This mapping is used in Clause 7 to develop voice capacity and data throughput estimates for both conventional and SAIC receivers. The voice capacity gain and data throughput gain for SAIC is then deduced from these estimates.

Clause 8 describes the field trials that have been conducted using an SAIC prototype Mobile Station (MS). Clause 9 addresses testing considerations for SAIC capable MSs, while Clause 10 defines a couple of signalling options for identifying an MS as being SAIC capable. Finally, Clause 11 provides the relevant conclusions that can be drawn from this feasibility study, the most important of which is the conclusion that SAIC is a viable and feasible technology, which will support significant voice capacity gains for both synchronous and asynchronous networks when applied to GMSK modulation. In addition, modest increases in GPRS data throughput are also supported for the types of data traffic considered. Clause 11 also identifies those clauses of the core and testing specifications that will be impacted by the inclusion of an SAIC capability.

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 interference statistics including CIR (Carrier to Interference plus noise Ratio) and DIR (Dominant-to-rest of Interference Ratio) levels and distributions based on network simulations and measurements, where possible.

c) Robustness against different training sequences.

d) Determine method to detect/indicate SAIC capability.

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.
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[1] ETSI 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.

Additional references are noted in the individual clauses of this document

3 Abbreviations

ACI	Adjacent Channel Interference
AMR	Adaptive Multi Rate
BEP	Bit Error Probability
BER	Bit Error Rate

BLER	Block Error Rate
BTS	Base Transceiver Station
CDF	Cumulative Distribution Function
C/I	Carrier-to-Interference Power Ratio
cdfs	cumulative distribution functions
CINR	Carrier to Interference-plus-Noise Ratio
DIR	Dominant-to-rest Interference Ratio
DPC	Downlink Power Control
DTX	Discontinuous Transmission
EFL	Effective Frequency Load
FEP	Frame Error Probability
FER	Frame Error Rate
FL	Frequency Load
FR	Full Rate
FTP	File Transfer Protocol
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
HR	Half Rate
IE	Information Element
MMS	Multimedia Messaging Service
MS	Mobile Station
PDF	Probability Distribution Function
PSK	Phase-Shift Keying
QoS	Quality of Service
SAIC	Single Antenna Interference Cancellation
TSC	Training Sequence

4 Network scenarios for SAIC evaluation

A multi-step approach was taken to evaluate SAIC performance in realistic network scenarios. This approach consisted of first determining relevant interference statistics based on the network scenarios described in this clause. These interference statistics were then used to determine the link level performance at the GSM burst level. From this link level characterization, link-to-system mapping tables were developed, which were then used in system level simulations to determine the voice and data capacity gains provided by SAIC capable MSs. The network scenarios used in these simulations were discussed and agreed to as part of SAIC Workshop #1.

It was agreed that the network scenarios, also referred to as configurations in this document, should represent typical GERAN networks at the time frame when operators would be deploying SAIC capable MSs. The goal was to try to make the interference statistics as realistic as possible, while trying to keep the overall complexity of the simulations reasonable. As a result of [3], [4], and [5], the following parameters are considered to be the major issues which affect the interference statistics:

- 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.)
- Downlink Power Control (DPC) scheme
- Channel coding, mainly if quality-based DPC 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 not be negatively impacted

- Packet-switched connections to support GPRS and EGPRS, which are characterized by short connection times, asymmetry, bursty traffic, multiplexing of several users on the same time slot, and often lack of DPC
- Legacy non-AMR (mainly EFR) mobiles: higher transmit powers, less robustness
- Level of synchronization in the network
- Mobility: speed distribution of the mobiles affects the interference pattern

Going into the study, it was believed that SAIC would support 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. These initial observations were found to be true, for the most part as is shown in clause 7, which provides a characterization of the system level performance of SAIC.

Two tables define the network scenario assumptions. Table 4-1 defines operator or configuration specific assumptions, while table 4-2 defines parameters common to all of the configurations. Both tables were derived from [3], [4], [5], and discussed as part of the SAIC Workshop #1. The four configurations defined in Table 4-1, and the common parameters defined in Table 4.2 are described in detail in clause 7.

Table 4-1
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	Source/Interferer		
	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	Source/Interferer		
	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	Source/Interferer		
	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	Source/Interferer		
	GMSK/GMSK		
	GMSK/8PSK	m	
Cell Radius	300		

Table 4-2
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 Minimum Call Length		90 5	sec. sec.	
Voice activity		60%		Includes SID signalling.
DTX		Enabled		
Link adaptation		Disabled		
BTS output power		20	W	
Power control Dynamic Range Step Size		RxQual/RxLev 14 2	 dB dB	
Noise figure		10	dB	Reference temperature 25c
Inter-site Lognormal Correlation Coefficient		0		
Channel Allocation		Random		
Traffic data models for GPRS		See clause 7.5		Web-browsing & FTP/MMS

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 done in the SAIC feasibility study to define realistic models and the outcome of this work is recaptured in this clause.

Defining realistic link level models is clearly impossible without investigating the interference statistics 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 clause 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 into account such effects as delay, power control, DTX, etc..

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[1]. Although widely used, for evaluation, this ideal one interferer scenario happens very rarely in practice especially when the network is highly 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 to capture this is the Dominant to rest of Interference Ratio (DIR), which is the power of the dominant interferer to the sum of the powers of the rest of the interferers plus N_o. This ratio is defined as:

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

where I_{max} is the average power of the dominant interfering signal (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].

Figures 5-1 through 5-3 are examples of interferer statistics for network configuration 2[2]. The figures clearly demonstrate how the interferer statistics in a network are 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.

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[1] CIR is also referred to in this document as CINR = Carrier to Interference plus Noise Ratio

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