Technical Specification Group Services and System Aspects
Meeting #6, Nice, France, December 15-17, 1999

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Title **CRs on Tandem Free Operation (TFO)**

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S4-99499	08.62	7.0.0	A001		R98	Introduction of AMR in 08.62

Joint 3GPP TSG-S4#8 - SMG11#13 Meeting
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CHANGE REQUEST

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08.62	**CR**	**A001**	Current Version:	7.0.0

GSM (AA.BB) or 3G (AA.BBB) specification number ↑ — *↑ CR number as allocated by MCC support team*

For submission to:	TSG-SA#6	for approval	X	strategic	X	*(for SMG use only)*
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Proposed change affects: *(at least one should be marked with an X)*	(U)SIM		ME		UTRAN / Radio	X	Core Network	

Source:	TSG-SA WG4 Codec	**Date:**	16/12/1999
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Category:	F	Correction		**Release:**	Phase 2	
	A	Corresponds to a correction in an earlier release			Release 96	
(only one category	B	Addition of feature	X		Release 97	
shall be marked	C	Functional modification of feature			Release 98	X
with an X)	D	Editorial modification			Release 99	
					Release 00	

Reason for change:	Introduction of AMR
Clauses affected:	All

Other specs affected:	Other 3G core specifications		→ List of CRs:	
	Other GSM core specifications		→ List of CRs:	
	MS test specifications		→ List of CRs:	
	BSS test specifications		→ List of CRs:	
	O&M specifications		→ List of CRs:	

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TS 100 XXX V7.0.0 (1999-02)

Technical Specification

Digital cellular telecommunications system (Phase 2+);
Inband Tandem Free Operation (TFO) of Speech Codecs;
(GSM 08.62 version 7.0.0 Release 1998)

GLOBAL SYSTEM FOR
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ETSI

Postal address

F-06921 Sophia Antipolis Cedex - FRANCE

Office address

650 Route des Lucioles - Sophia Antipolis
Valbonne - FRANCE
Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16
Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Internet

secretariat@etsi.fr
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Contents

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Foreword

This Technical Specification has been produced by ETSI Technical Committee Special Mobile Group (SMG).

The contents of the present document is subject to continuing work within SMG and may change following formal SMG approval. Should SMG modify the contents of the present document it will be re-released with an identifying change of release date and an increase in version number as follows:

Version 7.x.y

where:

7 indicates Release 1998 of GSM Phase 2+

x the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

y the third digit is incremented when editorial only changes have been incorporated in the specification.

Scope

This specification document details :

- The Inband Signalling Protocol between Transcoder/Rate Adaptor Units for speech traffic channels for the Tandem Free Operation (TFO) of Speech Codecs,
- How the BTS and the BSC can be involved in TFO when the AMR speech service is supported.

This specification should be considered together with ETS GSM 08.60 (Inband control of remote transcoders and rate adaptors for Full Rate traffic channels), ETS GSM 08.61 (Inband control of remote transcoders and rate adaptors for Half Rate traffic channels) and in the case of the AMR speech service with the ETS GSM 08.58 and GSM 05.09.

Annex A is mandatory and describes the general Inband Signalling (IS) Principle.

Annex B is informative and gives the rules for In Path Equipment (IPE).

Annex C is the formal SDL description of the TFO Protocol as given in chapter 10. Chapter 10 has precedence in case of ambiguities. A part of Annex C is in electronic format. Annex C is informative. It supports the formal verification of the TFO Protocol.

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.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] GSM 01.04: "Digital cellular telecommunication system (Phase 2+); Abbreviations and acronyms".

[2] GSM 02.53: "Digital cellular telecommunication system (Phase 2+); Tandem Free Operation (TFO) of Speech Codecs; Service Description; Stage 1".

[3] GSM 03.05: "Digital cellular telecommunication system (Phase 2+); Technical performance objectives".

[4] GSM 03.53: "Digital cellular telecommunication system (Phase 2+); Tandem Free Operation (TFO) of Speech Codecs; Service Description; Stage 2".

[5] GSM 06.01: "Digital cellular telecommunications system (Phase 2+); Full rate speech processing functions".

[6] GSM 06.10: "Digital cellular telecommunications system (Phase 2+); Full rate speech transcoding".

[7] GSM 06.11: "Digital cellular telecommunications system (Phase 2+); Substitution and muting of lost frames for full rate speech channels".

[8] GSM 06.12: "Digital cellular telecommunications system (Phase 2+); Comfort noise aspect for full rate speech traffic channels".

[9] GSM 06.20: "Digital cellular telecommunications system (Phase 2+); Half rate speech transcoding".

[10] GSM 06.21: "Digital cellular telecommunication system (Phase 2+); Substitution and muting of lost frames for half rate speech traffic channels".

[11] GSM 06.22: "Digital cellular telecommunication system (Phase 2+); Comfort noise aspects for half rate speech traffic channels".

[12] GSM 06.31: "Digital cellular telecommunications system (Phase 2+); Discontinuous Transmission (DTX) for full rate speech traffic channel".

[13] GSM 06.32: "Digital cellular telecommunications system (Phase 2+); Voice Activity Detection (VAD)".

[14] GSM 06.41: "Digital cellular telecommunication system (Phase 2+); Discontinuous Transmission (DTX) for half rate speech traffic channel".

[15] GSM 06.42: "Digital cellular telecommunication system (Phase 2+); Voice Activity Detection (VAD) for half rate speech traffic channels".

[16] GSM 06.51: "Digital cellular telecommunications system (Phase 2+); Enhanced Full Rate (EFR) speech processing functions; General description".

[17] GSM 06.60: "Digital cellular telecommunications system (Phase 2+); Enhanced Full Rate (EFR) speech transcoding".

[18] GSM 06.61: "Digital cellular telecommunications system (Phase 2+); Substitution and muting of lost frames for Enhanced Full Rate (EFR) speech channels".

[19] GSM 06.62: "Digital cellular telecommunications system (Phase 2+); Comfort noise aspect for Enhanced Full Rate (EFR) speech traffic channels".

[20] GSM 06.81: "Digital cellular telecommunications system (Phase 2+); Discontinuous Transmission (DTX) for Enhanced Full Rate (EFR) speech traffic channels".

[21] GSM 06.82: "Digital cellular telecommunications system (Phase 2+); Voice Activity Detection (VAD) for Enhanced Full Rate (EFR) speech traffic channels".

[22] GSM 08.08: "Digital cellular telecommunication system (Phase 2+); Mobile-services Switching Centre - Base Station System (MSC-BSS) interface Layer 3 specification".

[23] GSM 08.54: "Digital cellular telecommunication system (Phase 2+); Base Station Controller - Base Transceiver Station (BSC - BTS) interface Layer 1 structure of physical circuits".

[24] GSM 08.60: "Digital cellular telecommunication system (Phase 2+); Inband control of remote transcoders and rate adaptors for full rate traffic channels".

[25] GSM 08.61: "Digital cellular telecommunication system (Phase 2+); Inband Control of Remote Transcoders and Rate Adaptors for half rate traffic channels".

[26] GSM 06.71: Digital cellular telecommunication system (Phase 2+); Adaptive Multi-Rate (AMR) speech processing functions; General description”.

[27] GSM 06.90: Digital cellular telecommunication system (Phase 2+); “Adaptive Multi-Rate (AMR) speech transcoding”.

[28] GSM 06.85: Digital cellular telecommunication system (Phase 2+); “Subjective tests on the interoperability of the Half Rate/Full Rate/Enhanced Full Rate (HR/FR/EFR) speech codecs, single tandem and tandem free operation”.

[29] GSM 06.91: Digital cellular telecommunication system (Phase 2+); “Substituting and muting of lost frames for Adaptive Multi-Rate (AMR) speech traffic channels”.

[30] GSM 06.92: Digital cellular telecommunication system (Phase 2+); "Comfort noise aspects for Adaptive Multi-Rate (AMR) speech traffic channels".

[31] GSM 06.93: Digital cellular telecommunication system (Phase 2+); "Discintinuous Transmission (DTX) for Adaptitve Multi-Rate (AMR) speech traffic channels".

[32] GSM 06.94: Digital cellular telecommunication system (Phase 2+); "Voice Activity Detector (VAD) for Adaptive Multi-Rate (AMR) speech traffic channels; General description

[33] GSM 05.09 Digital Cellular telecommunications system (Phase 2+); "Link Adaptation".

[34] GSM 08.58 Digital Cellular telecommunications system (Phase 2+), "BSC - BTS interface Layer 3 specification".

[35] ITU-T Recommendation G.711, " Pulse Code Modulation of Voice Frequencies".

Definitions and Abbreviations

Definitions

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

TRAU Frame is used equivalent to "TRAU Speech Frame".

TFO Frame is used equivalent to "TFO Speech Frame".

Abis/Ater indicates that either the **Abis** or the **Ater** interface is used, depending on the location of the TRAU equipment.

AMR-8k is an AMR whose all modes are compatible with 8 kbit/s TFO frames.

AMR-16k is an AMR requiring 16 kbit/s TFO frames.

Abbreviations

For the purposes of the present document, the following abbreviations apply.

ACS	Active Codec Set
AMR	Adaptive Multi-Rate
BSC	Base Station Controller
BSS	Base Station Sub-system
BTS	Base Transceiver Station
CACS	Common Active Codec Set
CSCS	Common Supported Codec Set
DACS	Distant Active Codec Set
DSCS	Distant Supported Codec Set
EFR	Enhanced Full Rate
FR	Full Rate
HR	Half Rate
ICM	Initial Codec Mode
IPE	In Path Equipment
LACS	Local Active Codec Set
LSCS	Local Supported Codec Set
MACS	Maximum number of codecs in the Active Codec Set
MS	Mobile Station
MSC	Mobile Switching Centre
OACS	Optimized Active Codec Set
PCM	Pulse Coded Modulation
PCM_Alaw_Idle	PCM sample with value 0x54.

PCM_µLaw_Idle	PCM sample with value 0x00.
PCM_Alaw_Silence	PCM sample with value 0xD5.
PCM_µLaw_Silence	PCM sample with value 0xFF.
PCM sample	8-bit value representing the A_Law or µ_Law coded sample of a speech or audio signal; sometimes used to indicate the time interval between two PCM samples (125µs).
PCM_Silence	either PCM_Alaw_Silence, or PCM_µLaw_Silence, dependent on application
PCM_Idle	either PCM_Alaw_Idle, or PCM_µLaw_Idle, dependent on application
RATSCCH	Robust AMR Traffic Synchronized Control CHannel
SCS	Supported Codec Set
T_Bits	Time Alignment Bits
TCME	TFO Circuit Multiplication Equipment
TFO	Tandem Free Operation
TFO_ACK	TFO Acknowledgement Message
TFO_DUP	TFO (Half) Duplex Mode Message
TFO_FILL	TFO Fill Message
TFO_NORMAL	TFO Normal Mode Message
TFO_REQ	TFO Request Message
TFO_SYL	TFO Sync Lost Message
TFO_TRANS	TFO Transparent Mode Message
TRAU	Transcoder and Rate Adaptor Unit

Other abbreviations used in this TS are listed in GSM 01.04.

General Approach

Background

In case of mobile-to-mobile calls (MS-MS calls) in GSM networks without TFO, the speech signal is encoded within the first mobile station for transmission on the air interface, and decoded within the associated first "transcoder and rate adaptor unit" (TRAU). The PCM samples are then transported within the fixed part of the network to the second TRAU using 64 kbit/s traffic links. This second TRAU encodes the speech signal a second time for the transmission on the second air interface, and the associated mobile station decodes is again. The two Codecs (Encoder-Decoder pair) of the connection are in "Tandem Operation".

This **Tandem Operation** has several **disadvantages**:

- The two consecutive encoding/decoding processes degrade the speech quality more than necessary;
- The links between the TRAUs within the fixed network need 64 kbit/s, where 16 or 8 kbit/s would be sufficient;
- The unnecessary encoding within the TRAUs allocates DSP power.

Tandem Free Operation requires two (back and forth) "transparent" digital channels or paths between the TRAUs. Devices within these paths need to be transparent or to be switched off for the **TFO Messages** and the **TFO Frames**. To guarantee this digital transparency with **out_of_band signalling** is not trivial. Out_of_band signalling is especially not fast enough for fall back to normal operation in case of sudden interruption of the transparency of the links.

This TFO specification defines therefore an **inband signalling protocol** which **tests,** if:

- an MS-MS call is given;
- the paths between the TRAUs are digitally transparent;
- both TRAUs support TFO;
- the speech Codecs on both radio legs are identical.

establishes the TFO connection by:

- commanding the paths to go transparent and
- bypassing the decoder/encoder functions within the TRAUs.

guarantees a fast fall back procedure for sudden TFO interruption and **supports**:

- the resolution of Codec mismatch situations, and
- the cost efficient transmission within the fixed part of the network.

The Tandem Free Operation for FR, EFR and HR speech services is **fully compatible** with existing GSM equipment. In its basic operation **it affects only TRAUs**. The additional computational complexity is small compared to the encoding/decoding functions of the TRAUs. Mobile Station, BTS, MSC and other network elements are not at all affected in this basic operation.

The Tandem Free Operation for the AMR speech service involves the BTS and possibly the BSC in addition of the TRAU.

In an optional mode, the TFO supports the resolution of Codec mismatch situations, i.e. the situation where the SpeechCodecs at both radio-legs are different. For this, an additional communication channel between TRAU and BSS is necessary and the BSS has to perform a normal local intra cell handover to change the Codec type. That communication between TRAU and BSS is considered as manufacturer proprietary and not handled within this recommendation in case of the FR, HR and EFR speech services. In case of the AMR speech service see GSM 08.58, 08.60 and 08.61 for the transmission of the required information to solve Codec mismatch situations.

Once TFO functionality is implemented in TFO compatible TRAU equipment, it can be employed also for TFO connections to other systems, like ISDN phones, speech servers, Internet connections or connections to other systems, like UMTS.

The overall procedure that shall be followed to establish and maintain TFO is described in clause 13.

Principle of Tandem Free Operation

The TRAU shall be controlled by the BTS when it is positioned remote from the BTS. In this case, the speech/data information and TRAU control signals shall be transferred between the BTS and the TRAU in frames denoted "TRAU Frames" on the **Abis** respectively **Ater** interface.

In Tandem Free Operation similar frames, denoted ”**TFO Frames**”, are transferred between the two TRAUs on the **A-interface** by inband signalling, i.e. inserting them into the PCM sample bit stream.

In the case of Half Rate codec speech traffic, these TFO Frames shall be carried by 8 kbit/s traffic channels mapped onto the least significant bit (LSB) of the PCM samples.

In the case of Full Rate and Enhanced Full Rate speech traffic, these TFO Frames shall be carried by 16 kbit/s traffic channels mapped onto the two least significant bits of the PCM samples.

In case of the AMR either 16 kbit/s or 8 kbit/s traffic channels (see sub-clause 5.3), depending on the ACS, are mapped onto the least or two least significant bits of the PCM samples.

Like TRAU Frames the TFO Frames have a fixed size (and length) of:

- 160 bits (20 ms) for the 8 kbit/s format;
- 320 bits (20 ms) for the 16 kbit/s format:

Prior and parallel to these TFO Frames also other ***TFO Messages*** are transferred on the A-interface. TFO Messages conform to the IS_Message Principles described in Annexes A and B.

The TFO protocol between the TRAUs is independent of the position of the TRAUs within the GSM networks.

A possible configuration of two TRAUs is shown in Figure 1, which is intended as a reference model.

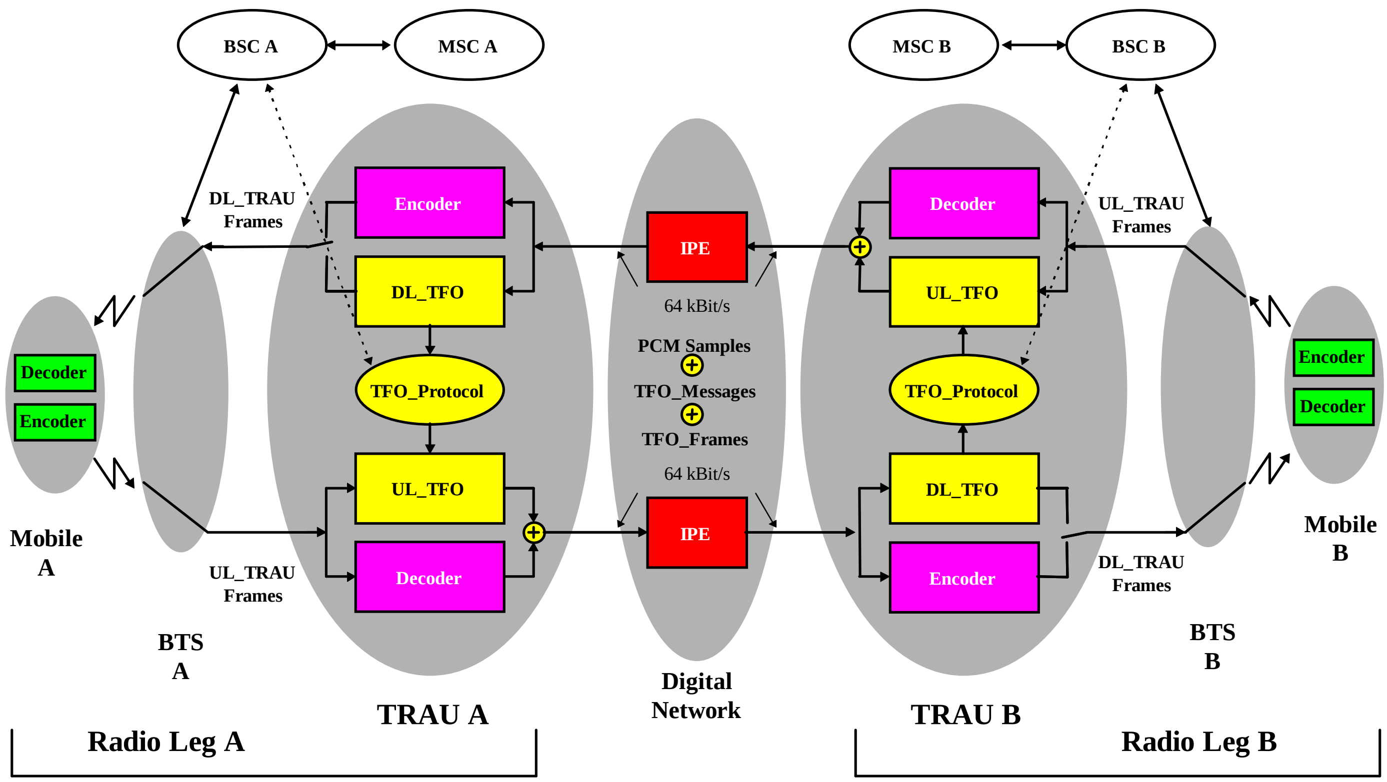


Figure 1: Functional Entities for Handling of Tandem Free Operation in MS-MS calls

TFO shall provide a virtually transparent digital channel from Encoder of Mobile A to Decoder of Mobile B and vice versa.

TFO standard Version

This specification applies to the version 0 of the TFO standard. This version applies for the FR, HR, and EFR. It also applies to the AMR. Future versions backward compatible with version 0 can apply to the AMR.

The version number is indicated in the Ver (Version number) field of the AMR-ACS and AMR_SCS Extension Blocks (see sub-clause 6.11.3).

If Local and Distant version numbers differ, the smallest version number has precedence and shall be applied by both Local and Distant BSS.

TFO Frame Structure

16 kbit/s TFO Frames

TFO Frames for Full Rate and Enhanced Full Rate

Full Rate (Enhanced Full Rate) TFO Frames are structured similar to **uplink** Full Rate (Enhanced Full Rate) TRAU Frames.

Table 1: The coding of the Control Bits (C1 .. C21) for FR and EFR TFO Frames

Control Bit	Description	Comment
C1 - C4	**Frame Type** FR EFR	C1 C2 C3 C4 0 . 0 . 0 . 1 1 . 1 . 0 . 1 All other code words are reserved.
C5	**EMBED**	Indicates the presence of an embedded TFO Message
C6 - C11	spare	(is Time Alignment in TRAU frame)
C12	**BFI**	Copied from uplink TRAU frame
C13 - C14	**SID**	Copied from uplink TRAU frame
C15	**TAF**	Copied from uplink TRAU frame
C16	spare	
C17	**DTXd**	Copied from uplink TRAU frame
C18 - C21	spare	

Any spare control bits should be coded binary "1". They are reserved for future use and may change.

The **Synchronisation Pattern** is similar to the Synchronisation Pattern in 08.60, with some exceptions:

EMBED: C5 equal "0": the Synchronisation Pattern is exactly as described in 08.60;

C5 equal ”1”: the Synchronization Pattern is changed by embedding a TFO Message.

For the coding of the **Data Bits** see GSM 08.60.

For the coding of the **Time Alignment Bits** (T_Bits, T1.. T4) see GSM 08.60.

The T_Bits correspond normally to the T_Bits received in the up-link TRAU Frame.

For the purpose of this description the 320 bits of one TFO Frame are arranged in 40 rows (0..39),

with 8 bit (1..8: one octet) each (see GSM 08.60).

TFO frame for the Adaptive Multi Rate

Adaptive Multi Rate TFO Frames are structured similar to Adaptive Multi rate TRAU Frames (see GSM 08.60).

Table 2: The coding of the Control Bits (C1 .. C25) for AMR TFO Frames (16kbit/s)

Control Bit	Description	Comment
C1 - C4	**Frame Type** AMR	C1 C2 C3 C4 0 . 0 . 1 . 1 All other code words are reserved.
C5	**EMBED**	Indicates the presence of an embedded TFO Message
C6 - C11	spare(1)	(Time Alignment, Phase Alignment or TFO Information in TRAU frame)
C12	**RIF**	Copied from uplink TRAU frame
C14 – C16	**Config_Prot**	Copied from uplink TRAU frame or replaced by 0.0.0 (see sub-clause 8.4.1.2)
C17 C18	**Mess N°**	Copied from uplink TRAU frame
C19	**DTXd**	Copied from uplink TRAU frame
C20	**TFOE**	Copied from uplink TRAU frame
C21 – C22	**Frame_Class**	Copied from uplink TRAU frame
C23 – C25	**(see GSM 08.60)**	Copied from uplink TRAU frame

Any spare control bits should be coded binary "1". They are reserved for future use and may change.

(1) Bits C6 .. C11 are spare bits except when the command “Handover_Soon” is received by the UL TRAU, then these bits are copied from the UL TRAU frame to the TFO frame. In DL when “Handover_Soon” is received in the TFO frame it is copied in the corresponding DL TRAU frame.

The **Synchronisation Pattern** is similar to the Synchronisation Pattern in 08.60, with some exceptions:

EMBED: C5 equal "0": the Synchronisation Pattern is exactly as described in 08.60;

C5 equal ”1”: the Synchronization Pattern is changed by embedding a TFO Message.

For the coding of the **Data Bits** see GSM 08.60.

For the coding of the **Time Alignment Bits** (T_Bits, T1.. T4) see GSM 08.60.

The T_Bits correspond normally to the T_Bits received in the up-link TRAU Frame.

For the purpose of this description the 320 bits of one TFO Frame are arranged in 40 rows (0..39),

with 8 bit (1..8: one octet) each (see GSM 08.60).

Transmission of the bits of 16 kbit/s TFO frames

The bits of 16 kbit/s TFO Frames are transmitted in the following order:

Bit m of octet n, shall be transmitted in the **Least** Significant Bit of the

PCM sample $k = n*4 + (m+1)/2$ for $m = (1, 3, 5, 7)$ and $n = (0..39)$.

Bit m of octet n shall be transmitted in the **second Least** Significant Bit of the

PCM sample $k = n*4 + m/2$ for $m = (2, 4, 6, 8)$ and $n = (0..39)$.

PCM sample (k=1) is the first PCM sample of the corresponding decoded speech frame (k=(1..160)).

8 kbit/s TFO frames

TFO Frame for Half Rate

Half Rate TFO Frames are always structured similar to **uplink** Half Rate TRAU Frames for **8 kbit/s** submultiplexing, see GSM 08.61 sub-clauses 5.2.1 and 5.2.4.1.

If Half Rate TRAU Frames with 16 kbit/s submultiplexing are used on the Abis/Ater interface, then the Control and Extended Control Bits for the 8 kbit/s TFO Frame need to be generated on basis of the received Control Bits from the TRAU Frame.

The coding of the **Control Bits** (C1 .. C9) is according to the following table 3:

Table 3: The coding of the Control Bits (C1 .. C9)

Control Bit	Description	Comment
C1 - C4	**Frame Type** HR	C1 . C2 . C3 . C4 0 . 0 . 0 . 1 All other code words are reserved.
C5	**EMBED**	Indicates the presence of an embedded TFO Message
C7 - C8	spare	
C9	**DTXd**	Copied from uplink TRAU frame

Any spare control bits should be coded binary "1". They are reserved for future use and may change.

The **Synchronisation Pattern** is similar to the Synchronisation Pattern in 08.61, with some exceptions:

EMBED: C5 equal "0": the Synchronisation Pattern is exactly as described in 08.61;

C5 equal ”1”: the Synchronization Pattern is changed by embedding a TFO Message.

The coding of the **Extended Control Bits (XC1.. XC6)**:

XC1 is copied from the uplink TRAU Frame.

XC2 .. XC6: These bits are normally copied from the 8 kbit/s TRAU frame corresponding to this TFO Frame.

All other codes are reserved.

For the coding of the **Data Bits** see GSM 08.61.

For the coding of the **Time Alignment Bits** see GSM 08.61.

The T_Bits correspond normally to the T_Bits received in the up-link TRAU Frame.

For the purpose of this description the 160 bits of one frame are arranged in 20 rows (1..20), with 8 bit (1..8: one octet) each (see GSM 08.61).

TFO Frame for the Adaptive Multi Rate

In 8kb/s AMR TRAU frames, only the “No_Speech” frames can convey a full set of TFO parameters. (the rates below or equal to 5.9kb/s contain Config_Prot and Message_No fields, see sub-clause 8.4.1.5). For these frames, parameters are embedded in the data bits, for the TRAU and TFO frames. If parameters are already in a TRAU frame (and that these parameters are useful for the remote side), the TRAU has just to copy that frame into a TFO frame. If TRAU has to send parameters to the remote side, it shall embed these parameters in a TFO frame at the positions given in sub-clause 8.4.1.5. If no parameters are to be sent, the TFO frame shall be copy of the TRAU frame.

Transmission of the bits of 8 kbit/s TFO frames

The bits of 8 kbit/s TFO Frames are transmitted in the following order:

Bit m of octet n shall be transmitted in the **Least** Significant Bit of the

PCM sample k = (n-1)*8+m;   with m = (1..8) and n = (1..20).

PCM sample (k=1) is the first PCM sample of the corresponding decoded speech frame (k=(1..160)).

Determination of the TFO frame format

The TFO frame format, i.e. either 16 or 8 kbit/s, is determined based on:

- the common codec type,
- additionally for the AMR the Common Active Codec Set (see clause 12).

The FR and EFR TFO frames format is 16 kbit/s (see sub-clause 5.1.1). The HR TFO frames format is 8 kbit/s (see sub-clause 5.2.1).

In case of AMR, 8 kbit/s TFO frame format (see sub-clause 5.2.2) shall be used if the common ACS does not include the AMR codec mode 7,4 kbit/s and upward (e.g. 7,95 or 10,2), otherwise 16 kbit/s TFO frame format (see sub-clause 5.1.2) shall be used. Thus the TRAU and TFO frame formats can differ and format conversion shall be then performed.

NOTE 1: After a modification of ACS while TFO is ongoing the size of the TFO frame can change, the handling of the IPE must be correct, see sub-clause 8.1.3.

NOTE 2: If AMR is supported by the TRAU then both TRAU frame formats shall be supported as well.

TFO Message Structure

Several TFO Messages are defined, based on the general IS_Message principle, as defined in Annex A.

Definition for ***<u>Sender</u>*** side:

TFO_REQ (): Identifies the source of the message as a TFO capable device, using a defined speech Codec Type.

TFO_REQ contains the following parameters ():

- the System_Identification of the sender;
- the specific Local_Signature of the sender (e.g. TRAU or TCME);
- the Local_Used_Codec at sender side;
- possibly additional attributes for the Local_Used_Codec.

TFO_ACK (): Is the response to a TFO_REQ Message.

TFO_ACK contains the corresponding parameters to TFO_REQ, but the Local_Signature is replaced by the Reflected_Signature, copied from the received TFO_REQ Message.

TFO_REQ_L (): Is sent in case of Codec Mismatch or for sporadic updates of information.

TFO_REQ_L contains the following parameters ():

- the System_Identification of the sender;
- the specific Local_Signature of the sender (e.g. TRAU or TCME);
- the Local_Used_Codec at sender side;
- possibly additional attributes for the Local_Used_Codec.
- the Local_Codec_List of alternative Codecs;
- possibly additional attributes for the alternative Codecs.

TFO_ACK_L (): Is the response to a TFO_REQ_L Message.

TFO_ACK_L contains the corresponding parameters to TFO_REQ_L, but the Local_Signature is replaced by the Reflected_Signature, copied from the received TFO_REQ_L Message.

TFO_REQ_P (): Is used to indicate during ongoing TFO that an other Codec Type would be preferred.

TFO_REQ_P contains the following parameters ():

- the System_Identification of the sender;
- the specific Local_Signature of the sender;
- the Preferred_Codec at sender side (only used by TCME);

- possibly additional attributes for the Preferred_Codec;
- possibly a Codec_List extension of alternatives codecs;
- possibly additional attributes for the alternative Codecs.

TFO_TRANS (): Commands possible IPEs to let the TFO Frames pass transparently within the

LSB (8 kBit/s) or the two LSBs (16 kBit/s). TFO_TRANS contains the following parameter ():

- the Local_Channel_Type (8 kBit/s or 16 kBit/s).

TFO_NORMAL: Commands possible IPEs to revert to normal operation.

TFO_NORMAL has no parameters.

TFO_DUP: Informs the distant partner that TFO Frames are received, while still transmitting PCM samples.

TFO_DUP has no parameters.

TFO_SYL: Informs the distant partner (if still possible) that TFO Frames are no longer received.

TFO_SYL has no parameters.

TFO_FILL: Message without specific meaning, used to pre-synchronise IPEs or to bridge over gaps in TFO

protocols. TFO_FILL has no parameters.

Extendibility

A mechanism for future extensions is defined in a way that existing implementations in the field shall be able to ignore future, for them unknown Codec Types and their potential attributes. The existing implementations shall be able to decode the reminder of the messages (which is known to them) uncompromised. This mechanism allows to extent:

- the number of Used_Codec Types from 15 (short form) up to 255 (long form) for one System_Identification;
- the Codec_List;
- the Codec_Attributes (if needed).

In case of the TFO_REQ or TFO_ACK messages the attributes of the Used_Codec shall be sent in the Codec specific way, without a preceding Codec_Attribute_Head Extension_Block.

In case of the TFO_REQ_L or TFO_ACK_L messages the simple Codec_List shall be sent immediately after the SIG_LUC and possible Codec_x Extension_Blocks. Then the attributes of all alternative Codec Types shall follow in the order of preference. Each set of Codec attributes shall be preceded by the Codec_Attribute_Head Extension_Block (with Codec_Type Identifier and Length indicater), followed by the Codec specific attributes.

TFO_REQ_P shall not contain the list of alternative Codecs, i.e. it shall be based on TFO_REQ and not on TFO_REQ_L.

Regular and Embedded TFO messages

A TFO Message is called **"regular**", if it is sent inserted into the PCM sample stream. A TFO Message is called "**embedded**", if it is sent together with (embedded into) TFO Frames, see also subclause 7.2. The bit stealing scheme (see Annex A) is identical for regular and embedded TFO Messages. Control bit C5 marks redundantly (in general) all TFO Frames that are affected by embedding a TFO Message. Due to the specific construction of the TFO Messages, they replace some of the synchronisation bits of the TFO Frames. TFO Frame synchronisation is in case of embedded TFO Messages therefore different, however, not endangered. Data and other control bits of the TFO Frames are not affected by embedded TFO Messages.

Note: In case of the Adaptive Multi-Rate Codec Type with 8 kBit/s TFO Frame format the C5 bit is not available. Embedded TFO Messages are in this case not specifically marked. The receiver is, however, able to identify embedded TFO Messages due to their specific construction (see sub-clause 8.1.4.1).

Cyclic Redundancy Check:

The Extension_Blocks, defined in the following sub-clauses, shall be protected by three CRC parity bits. These shall be generated as define in GSM 08.60 for the Enhanced Full Rate. For simplicity this specification is reprinted here:

"These parity bits are added to the bits of the subset, according to a degenerate (shortened) cyclic code using the generator polynomial:

$$g(D) = D^3 + D + 1$$

The encoding of the cyclic code is performed in a systematic form which means that, in GF(2), the polynomial:

$$d(m)D^n + d(m+1)D^{n-1} + ...+ d(m + n-3)D^3 + p(0)D^2 + p(1)D + p(2)$$

where p(0), p(1), p(2) are the parity bits, when divided by g(D), yields a remainder equal to:

$$1 + D + D^2$$

For every CRC, the transmission order is p(0) first followed by p(1) and p(2) successively."

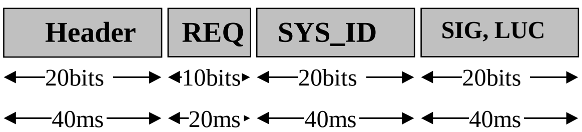
Definition of the TFO_REQ and TFO_ACK Messages

Symbolic Notation:
TFO_REQ (Sys_Id, LSig, Used_Codec[, Used_Codec_Attributes]).
TFO_REQ_L (Sys_Id, LSig, Used_Codec[, Used_Codec_Attributes], Codec_List [, Alt_Codec_Attributes]).

TFO_REQ_P (Sys_Id, LSig, Preferred_Codec[, Preferred_Codec_Attributes][, Codec_List [, Alt_Codec_Attributes]]).

The TFO_REQ and TFO_ACK Messages conform to the IS_REQ Message, respectively the IS_ACK Message, defined in the Annex A, with IS_System_Identification, followed by the SIG_LUC Extension_Block, optionally the Codec_x Extension_Block, the Codec_List Extension_Block(s) and the Codec_Attribute Extension_Blocks.

The shortest TFO_REQ takes 140 ms for transmission, see Figure 2a.
The shortest TFO_REQ_L takes 180 ms (Figure 2b).
The shortest TFO_REQ_P takes 180 ms for transmission (Figure 2c).



EMBEDFigure 2a: Construction of the shortest possible TFO_REQ Message

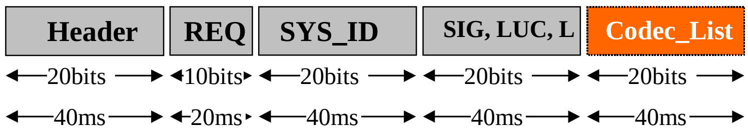


Figure 2b: Construction of the shortest possible TFO_REQ_L Message

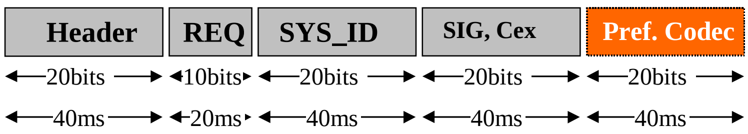


Figure 2c: Construction of the shortest possible TFO_REQ_P Message

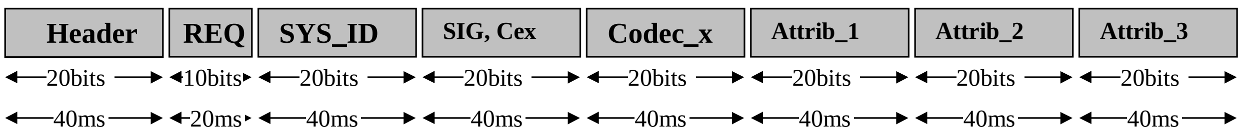


Figure 2d:Example of a TFO_REQ Message with a Codec with an index higher than 15 and with three Attribute Extension_Blocks (300 ms length)

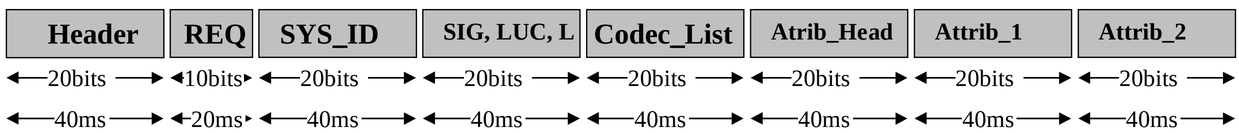


Figure 2e: Example of a TFO_REQ_L Message with Codec_List and one alternative Codec with two Attribute Extension_Blocks (300 ms length)

Definition of the SIG_LUC Extension_Block

The SIG_LUC Extension_Block consists of 20 bits, as defined in Table 4. It shall follow always immediately after the SYS_ID Extension_Block. It differentiates between TFO_REQ and TFO_REQ_L messages, respectively between TFO_ACK and TFO_ACK_L messages.

In case of a TFO_REQ_P messages it shall be followed immediately by the Codec_x Extension_Block (Table 5). The Codec_x Extension_Block shall also be used in case a given system supports more than 15 different Codec_Types.

Table 4: SIG_LUC Extension_Block

Bit	Description	Comment
Bit 1	"**0**"	normal IS-Message Sync Bit, constant.
Bit 2	**List_Ind**	Indicates, whether the Codec_List is included in the TFO Message or not **0: TFO_REQ** or **TFO_ACK**: Codec_List is not included **1: TFO_REQ_L** or **TFO_ACK_L**: Codec_List is included
Bit 3..10	**Sig**	An 8-bit random number to facilitate the detection of circuit loop back conditions and to identify the message source
Bit 11	"**0**"	normal IS-Message Sync Bit, constant
Bit 12.. 15:	**Codec_Type** (short form)	Identifies the Local_Used_Codec_Type, which is currently used by the sender **0000…1110: reserved for 15 Codec Types** **1111: Codec_X** Extension_Block follows immediately, e.g. for "Preferred Codec" Type (Codec_Type, long form)
Bit 16..18:	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX** EX == "0.0" EX == "1.1"	The normal 2 bits for IS_Message Extension. No other extension block follows An other extension block follows

Definition of the Codec_x Extension_Block

The Codec_x Extension_Block consists of 20 bits, as defined in Tabel 5. It shall follow always immediately after the SIG_LUC Extension_Block, if the Codec_Type field is set to “1111”.

Table 5: Codec_x Extension_Block

Bit	Description	Comment
Bit 1	”**0**”	normal IS-Message Sync Bit, constant.
Bit 2	**Codec_Sel**	Differentiates the Codec_x Extension_Block **0: Used_Codec_Type** is defined in Codec_Type_x field **1: Preferred_Codec_Type** is defined in Codec_Type_x field Note: The Preferred_Codec_Type is only defined in TFO_REQ Messages. It is reserved for future use in TFO_ACK messages.
Bit 3..10	**Codec_Type_x** (long form)	Identifies the Local_Used_Codec_Type, which is currently used by the sender **0000.0000 … 1111.1111 reserved for 255 Codec Types** 0000.1111 is undefined and shall not be used.
Bit 11	”**0**”	normal IS-Message Sync Bit, constant
Bit 12.. 15:	“1010”	reserved for future use, set to “1010” to minimise audible effects
Bit 16..18:	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX**	The normal 2 bits for IS_Message Extension. 00: No other extension block follows 11: An other extension block follows

Definition of the Codec_List_Extension_Block

The Codec_List Extension Block consists of 20 bits, as defined in Table 6. It identifies the Codec Types that are supported by the sender, respectively the BSS subsystem, including the mobile station and the radio resource, at sender side. The Codec_List must at least contain the Local_Used_Codec. If a system supports more than 15 Codec Types, then possibly other Codec_List Extension_Blocks (Table 7) may follow.

Table 6: Codec_List Extension Block

Bit	Description	Comment
Bit 1	”**0**”	normal IS-Message Sync Bit, constant.
Bit 2..10	**Codec_List_1**	First part of Codec_List. For each Codec one bit is reserved. If the bit is set to ”0” then the specific Codec_Type is not supported; if the bit is set to ”1” then the specific Codec_Type could be used.
Bit 11	”**0**”	normal IS-Message Sync Bit, constant
Bit 12.. 14:	**Codec_List_2**	Second part of the Codec_List; All three bits are reserved for future Codec_Types (up to Codec_Type 12)
Bit 15	**Codec_List_x**	If set to “1” a further Codec_List Extension_Block follows; otherwise set to “0”
Bit 16..18:	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX**	The normal 2 bits for IS_Message Extension: 00: No other extension block follows 11: An other extension block follows

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Table 7: Further Codec_List Extension Block(s)

Bit	Description	Comment
Bit 1	"**0**"	normal IS-Message Sync Bit, constant.
Bit 2..10	**Codec_List_1x**	First part of Codec_List. For each Codec one bit is reserved. If the bit is set to "0" then the specific Codec_Type is not supported; if the bit is set to "1" then the specific Codec_Type could be used. Bit 2: Codec_Type 13 (+ x*12; x=1..2..3) Bit 4: Codec_Type 14 (+ x*12; x=1..2..3) and so on
Bit 11	"**0**"	normal IS-Message Sync Bit, constant
Bit 12.. 14:	**Codec_List_2x**	Second part of the Codec_List;All three bits are reserved for future Codec_Types (up to Codec_Type 24 (+x*12; x=1..2..3)
Bit 15	**Codec_List_xx**	If set to "1" a further Codec_List Extension_Block follows; otherwise set to "0"
Bit 16..18:	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX**	The normal 2 bits for IS_Message Extension: 00: No other extension block follows 11: An other extension block follows

Definition of the Codec_Attribute_Head Extension_Block

The Codec_Attribute_Head Extension_Block (Table 8) shall precede the Codec Attribute Extension_Blocks of an (alternative) Codec_Type, if this Codec Type needs additional attributes. Then this Codec_Attribute_Head identifies the Codec Type and the number of additional Extension_Blocks for it.

Table 8: Codec_Attribute_Head Extension_Block

Bit	Description	Comment
Bit 1	"**0**"	normal IS-Message Sync Bit, constant.
Bit 2	**PAR_Sel**	Differentiates this Extension_Block **0:** Parameters included in **PAR** field: Simple Codec_List_Extension **1:** Length Indicator (**LI**) included: Parameters follow in subsequent Extension_Blocks
Bit 3..10	**Codec_ID**	This field identifies the alternative Codec Type for which the subsequent attributes are valid. The same coding as in the Codec_x Extension_Block is used (long form)
Bit 11	"**0**"	normal IS-Message Sync Bit, constant
Bit 12.. 15:	**LI / PAR**	If Par_Sel==1: LI: Length Indicator: 0000: reserved; 0001: one other Extension_Block follows, etc. If Par_Sel==0: PAR: Codec specific definition of these four bits
Bit 16..18:	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX**	The normal 2 bits for IS_Message Extension: 00: No other extension block follows 11: An other extension block follows

Note : this Extension_Block shall be used for the codecs introduced in the future. It will precede the Attribute Extension Blocks. This allows earlier versions to skip the blocks they don't understand. Consequently it shall not be used for the FR, HR, EFR and AMR codecs. The three former codecs have no attribute while the AMR Attributes are pre-defined (see sub-clause 6.11.3.1).

Definition of the TFO_ACK Messages

Symbolic Notation:
TFO_ACK (Sys_Id, RSig, Used_Codec[, Used_Codec_Attributes])

TFO_ACK_L (Sys_Id, RSig, Used_Codec[, Used_Codec_Attributes], Codec_List [, Alt_Codec_Attributes]).

TFO_ACK_P: undefined, reserved for future use.

The TFO_ACK Messages conform to the IS_ACK Message, defined in the Annex A, with IS_System_Identification := GSM_Identification, followed by the SIG_LUC Extension_Block, optionally the Codec_x Extension_Block, the Codec_List Extension_Block(s) and the Codec_Attribute Extension_Blocks.
TFO_ACK and TFO_REQ Messages differ only in the ACK / REQ Command block and the construction of the Signature: Local_Signature in case of TFO_REQ, Reflected_Signature in case of TFO_ACK.

The shortest TFO_ACK takes 140 ms for transmission.
The shortest TFO_ACK_L takes 180 ms.

Definition of the TFO_TRANS Messages

Symbolic Notation: TFO_TRANS (Channel_Type).

Two TFO_TRANS Messages are defined in conformity to the IS_TRANS Messages in Annex A.

For GSM Half Rate traffic channels the "**TFO_TRANS (8k)**" is used and is identical to "IS_TRANS_1_u".

For GSM (Enhanced) Full Rate traffic channels the "**TFO_TRANS (16k)**" is used and is identical to "IS_TRANS_2_u".TFO_TRANS takes 100 ms for transmission.

For GSM Adaptive Multi Rate "**TFO_TRANS (8k)**" and "**TFO_TRANS (16k)**" depending on the TFO frame format, see sub-clause 5.3.

In most cases the respective TFO_TRANS Message shall be sent twice: once as a regular TFO Message, exactly before any series of TFO Frames, and once embedded into the first TFO Frames, see clause 10.

Definition of the TFO_NORMAL Message

Symbolic Notation: TFO_NORMAL.

The TFO_NORMAL Message is identical to the IS_NORMAL Message defined in the Annex A.

It shall be sent at least once whenever an established tandem free operation need to be terminated in a controlled way.

TFO_NORMAL takes 100 ms for transmission.

Definition of the TFO_FILL Message

Symbolic Notation: TFO_FILL.

The TFO_FILL Message is identical to the IS_FILL Message, defined in the Annex A.

TFO_FILL may be used to pre-synchronise IPEs. Since IS_FILL is one of the shortest IS Messages, this is the fastest way to synchronize IPEs, without IPEs swallowing other protocol elements. By default three TFO_Messages shall be sent at the beginning; this number may be, however, configuration dependent.

One TFO_FILL takes 60 ms for transmission.

Definition of the TFO_DUP Message

Symbolic Notation: TFO_DUP

The TFO_DUP Message is identical to the IS_DUP Message, defined in Annex A.

TFO_DUP informs the distant TFO Partner, that TFO Frames have been received unexpected, e.g. during Establishment. This enables a fast re-establishment of TFO after a ***local*** handover.

TFO_DUP takes 60 ms for transmission.

Definition of the TFO_SYL Message

Symbolic Notation: TFO_SYL

The TFO_SYL Message is identical to the IS_SYL Message, defined in Annex A.

TFO_SYL informs the distant TFO Partner, that tandem free operation has existed, but suddenly no TFO Frame were received anymore. This enables a fast re-establishment of TFO after a ***distant*** handover.

TFO_SYL takes 60 ms for transmission.

Specification of the TFO Messages for GSM

The GSM Codec Types

The GSM Codec_Types are defined in long form (Codec_Type_x) as
Bit 3…Bit10: Codec_Type
0000.0000: GSM Full Rate
0000.0001: GSM Half Rate
0000.0010: GSM Enhanced Full Rate
0000.0011: GSM Adaptive Multi-Rate – FR (TCH/F)
0000.0100: GSM Adaptive Multi-Rate – HR (TCH/H)
other codes: reserved for future use.
The short form exists for all Codec_Types with indices below 15 and consists of the last four bits of the long form.

The GSM Codec List

For GSM the Codec_List is defined as:

Bit 2: GSM Full Rate
Bit 3: GSM Half Rate
Bit 4: GSM Enhanced Full Rate
Bit 5: GSM Adaptive Multi-Rate – FR (TCH/F)
Bit 6: GSM Adaptive Multi-Rate – HR (TCH/H)
The remaining bits are reserved for future Codec_Types.

The GSM Codec Type Attributes

The GSM Codec Types Full Rate, Half Rate and Enhanced Full Rate do not need additional attibutes. They are fully defined by their Codec Type. Exact specification of procedures for DTX can be found in the GSM 06-series.

6.11.3.1 The GSM AMR Codec Type Attributes

The GSM Adaptive Multi-Rate Codec Type, for both the Full Rate and Half Rate radio channels, needs several attributes within the TFO_REQ/TFO_ACK as well as in the TFO_REQ_L/TFO_ACK_L Messages.

There are two kind of attributes : the ACS (Active Codec Set) and SCS (Supported Codec Set). The ACS is related to the Codec_Used and is part of the Used_Codec_Attributes or Preferred_Codec_Attributes while the SCS is related to the AMR channel modes flagged in the Codec_List. Since the AMR channel modes are independently signalled either in the SIG_LUC or Codec_List Extension_Blockd there exist ACS and SCS for both of them, i.e. ACS(F) and ACS(H), respectively SCS(H) and SCS(F).

All the attributes consist of one single Extension_Block. No Codec_Attribute_Head Extension_Block is required.

GSM AMR Used_Codec_Attributes

Within the TFO_REQ(_L) and TFO_ACK(_L) Messages one AMR_ACS Extension_Block shall be added at the end of the Messages, after the SIG_LUC Extension_Block, if the AMR is the Local_Used_Codec. Otherwise the ACS shall not be added.

The AMR_ACS Extension_Block is related to the Codec_Used as shown in Table 9. In case the ACS is not known it shall be set to “0”.

Table 9: AMR Used_Codec Attributes

Codec_Used	Codec_Attribute_Head:	Ext 1
AMR FR	Not present	ACS(F)
AMR HR	Not present	ACS(H)

In case the ACS is not known Bits 2 to 9 (see Table 10) shall be set to “0”. For ACS(H) Bits 2 and 3 (see Table 6.7) shall be set to "0". ACS_Change Category refers to the possibility to use ratscch, and if the BTS can use it without the BSC to be inform first (see subclause 8.3.2.2).

Table 10: GSM_AMR_ACS Extension Block

Bit	**Description**	**Comment**
Bit 1	”**0**”	Normal IS-Message Sync Bit, constant.
Bit 2..9	**Active Codec Set (ACS)**	Active Codec Set: For each Codec_Mode of the AMR one bit is reserved. If the bit is set to ”0” then the specific Codec_Mode is not in the ACS, otherwise it is in. Bit 2: AMR_Mode 12,2 kbit/s Bit 3: AMR_Mode 10,2 kbit/s Bit 4: AMR_Mode 7,95 kbit/s Bit 5: AMR_Mode 7,40 kbit/s Bit 6: AMR_Mode 6,70 kbit/s Bit 7: AMR_Mode 5,90 kbit/s Bit 8: AMR_Mode 5,15 kbit/s Bit 9: AMR_Mode 4,75 kbit/s
Bit 10	spare	Set to "0" (for future use)
Bit 11	”**0**”	Normal IS-Message Sync Bit, constant
Bit 12 & 13	Change_Category	ACS Change Category (see subclause 8.3.2.2) 00 reserved for future use 01 No change 10 Slow Change 11 Fast change
Bit 14 & 15	**Ver#**	Version Number of the AMR TFO Scheme
Bit 16..18	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19..20:	**EX**	The normal 2 bits for IS_Message Extension: 00: No other extension block follows 11: An other extension block follows

GSM AMR Alt_Codec_Attributes

Within TFO_REQ_L and TFO_ACK_L Messages the Codec_List follows immediately after the AMR_ACS Extension_Block if the GSM AMR is the Used_Codec. If AMR-FR and/or AMR-HR are flagged in the Codec_List then Alt_Codec_Attributes shall be present as shown in Table 11.

Table 11: AMR Codec Attributes

Configuration in the Codec_List	Codec_Attribute_Head	Ext 1	Ext 2
AMR FR only	Not Present	SCS(F)	
AMR HR only	Not Present	SCS(H)	
AMR FR - HR	Not Present	SCS(F)	SCS(H)

The AMR_SCS extension block contains the information on what are the AMR codec modes that are supported and that could be used. As a convention SCS(H) means that the SCS applies for TCH-AHS and respectively SCS(F) for TCH-AFS. When both TCH-AFS and TCH-AHS are flagged the first Alt_Codec_Attribute corresponds to the TCH-AFS and the second one to the TCH-AHS.

Table 12 gives the description of the SCS Extension_Block.

In case the SCS is not known it shall be set identical to the ACS.

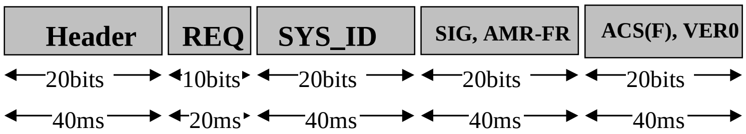
It can be noted that if AMR is the Codec-Used, one SCS Extension_Block corresponds to this Codec_Type since it is flagged in the Codec_List. This is not really an Alternative codec but for sake of simplicity and generality it is left in this class of Attributes.

Table 12: GSM_AMR_SCS Extension Block

Bit	**Description**	**Comment**
Bit 1	”**0**”	Normal IS-Message Sync Bit, constant.
Bit 2…9	**Supported Codec Set** **SCS**	Supported Codec Set: For each Codec_Mode of the AMR one bit is reserved. If the bit is set to ”0” then the specific Codec_Mode is not supported by the radio leg; if the bit is set to ”1” then the specific Codec_Mode is supported and may be used. Bit 2: AMR_Mode 12,2 kbit/s Bit 3: AMR_Mode 10,2 kbit/s Bit 4: AMR_Mode 7,95 kbit/s Bit 5: AMR_Mode 7,4 kbit/s Bit 6: AMR_Mode 6,7 kbit/s Bit 7: AMR_Mode 5,9 kbit/s Bit 8: AMR_Mode 5,15 kbit/s Bit 9: AMR_Mode 4,75 kbit/s
Bit 10	spare	Set to "0" (for future use)
Bit 11	”**0**”	normal IS-Message Sync Bit, constant
Bit 12…13	**MACS**	The maximally supported number of Codec_Modes in this radio leg. Coding: "0.1" 1 Mode "1.0" 2 Modes "1.1" 3 Modes "0.0" 4 Modes
Bit 14…15	**Ver#**	Version Number of the AMR TFO Scheme
Bit 16..18	**CRC**	3 CRC bits protecting Bits 2 to 10 and 12 to 15
Bit 19 20	**EX**	The normal 2 bits for IS_Message Extension: 00: No other extension block follows 11: An other extension block follows

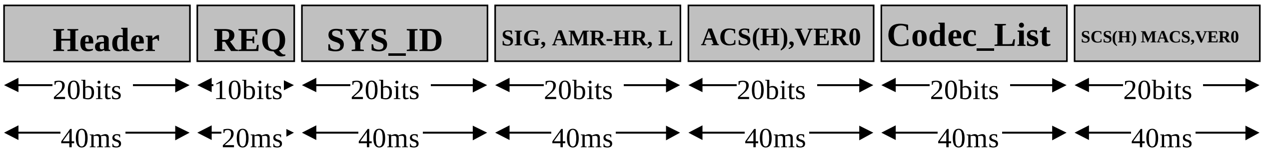
Examples of GSM TFO Messages

For information and better understanding the following examples for TFO Messages are given. They are not comprehensive. All these message are TFO_REQ or TFO_REQ_L but similar TFO_ACK and TFO_ACK_L could be presenrted.



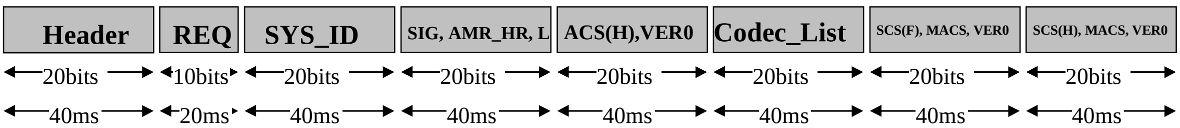
This figure shows a typical AMR TFO REQ with the information on ACS and the AMR TFO version which is set to 0 by default. The receiver – if also an GSM AMR – could check if the ACS and the Version is compatible.

A TRAU will understand this Codec Type even if it does not support the AMR. It will possibly pass these information to the BSS will send a TFO_REQ_L back.

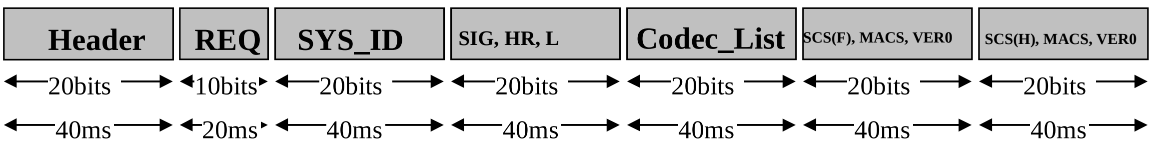


This figure shows the example of an TFO_REQ_L Message, where the AMR-HR (TCH-AHS) is the used Codec and at the same time only one radio channel mode for the AMR is supported. The receiver – if also an GSM AMR – could check, if a common ACS can be found by using the SCS and version.

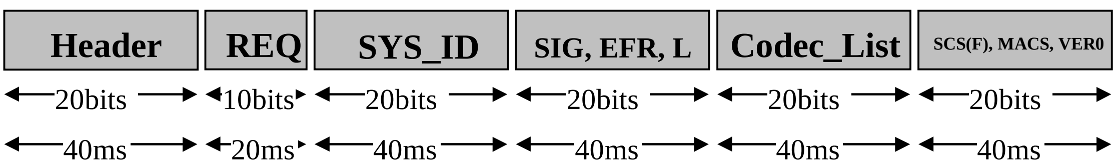
If a TRAU which does not support the AMR receives this message, it can pass the Codec_List to the Local BSS.



This figure now shows a TFO_REQ_L with the AMR-HR as used Codec, but indicates that AMR-FR could also be supported. The TRAU will signal to the BTS what is the distant configuration which can be used to optimize a possible TFO. The ACS indicates what is the configuration of the Used_Codec while the SCSs indicate what are the other possible configurations that could be used in TFO.



This figure shows that GSM-HR is the Codec_Used but indicates also that both AMR-HR and AMR-FR are supported. No ACS is present since none of the AMR channel modes (HR or FR) are used. However the supported modes for these two Codec-Types are indicated in case Codec optimization for TFO is feasible.



This figure show that the Used_Codec is EFR but also that the AMR-FR is supported. It's the only one AMR Channel mode supported and consequently only one corresponding SCS Extension_Block is present.

Time Alignment of TFO Frames and TFO Messages

The time alignment procedures for the downlink TRAU Frames, as specified in GSM 08.60 (full rate traffic) and GSM 08.61 (half rate traffic) on the Abis/Ater interface, are not affected by the TFO procedures on the A interface. The relative TRAU Frame phase positions of the two TRAUs using TFO across the A interface are arbitrary and depend on the local timing structure of the relevant BTSs. The TFO Protocol does not change this.

TFO Frames and embedded TFO Messages are always exactly aligned with each other and follow the uplink TRAU Frames with a small, neglegible, constant delay (Tultfo: some PCM samples).

Time Alignment of TFO Messages

At start up of the TFO Protocol the first regular TFO Message is aligned to an uplink TRAU Frame in the same way as a TFO Frame, respectively an embedded TFO Message would be aligned (see sub-clause 7.2). Then, after that, all regular TFO Messages follow contiguously, without any phase shift in time alignment, until the first TFO Frame needs to be sent (in general after the TFO_TRANS Message). Then the necessary number of T_Bits (if any) is inserted before the first TFO Frame, see sub-clause 7.2. Consequently all following, embedded TFO Messages are always aligned with the TFO Frames in a way, that the first bit of any TFO Messages is placed into the LSB of the first sample of a TFO Frame. Due to this definition, embedded TFO Messages only modify some of the synchronisation bits of the TFO Frames and control bit C5.

Time Alignment of TFO Frames

The contents of the Uplink TRAU Frame, received from the BTS via the Abis/Ater Interface, undergo the small, constant delay (Tultfo) required to perform the modifications of the C5 and Sync bits, before being forwarded to the other TRAU over the A Interface as TFO Frame. Since this delay is substantially smaller than the delay for the decoded speech signal, the TFO Frames precede the corresponding speech samples. Figure 3 shows the relations. Please note that no exact delay value for Tultfo is defined or need to be defined.

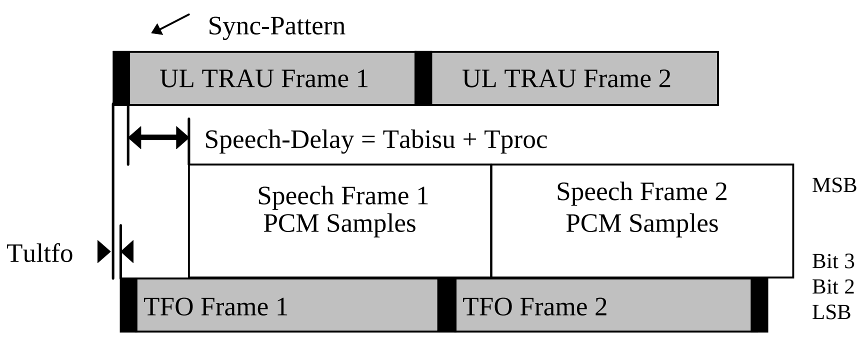


Figure 3: Uplink TFO Frame Time Alignment

On the transition between the sending of regular TFO Messages and the first TFO Frame on the A interface, a sufficient number (up to a maximum of 159) of Time Alignment Bits, also called "T_Bits", are inserted into the LSBs of the PCM samples to align the TFO Frame as described above.

This insertion of Time Alignment Bits (if necessary) is started exactly with the 16th PCM sample after the last bit of the last regular TFO Message (i.e. the TFO_TRANS Message).

Whenever, in a later stage, the phase of the uplink TRAU Frame changes, then again T_Bits need to be inserted between two consecutive TFO Frames or deleted from the tail of the last TFO Frame to ensure proper alignment.

The insertion of T_Bits as a result of timing changes shall occur ***between*** TFO Frames and not within TFO Frames.

If the time alignment is necessary while a TFO Message is embedded into a series of TFO Frames, then the TFO Message may be cut into two parts with the T_Bits in between. Therefore, whenever an adjustment of the phase of the TFO Frames is necessary, then one additional TFO Message shall be embedded into the next TFO Frames (after the possibly ongoing TFO Message). If nothing else is to be transmitted, then the TFO_FILL Message shall be used. One TFO_TRANS Message is ***always*** embedded into the first TFO Frames. See the following Figure 4:

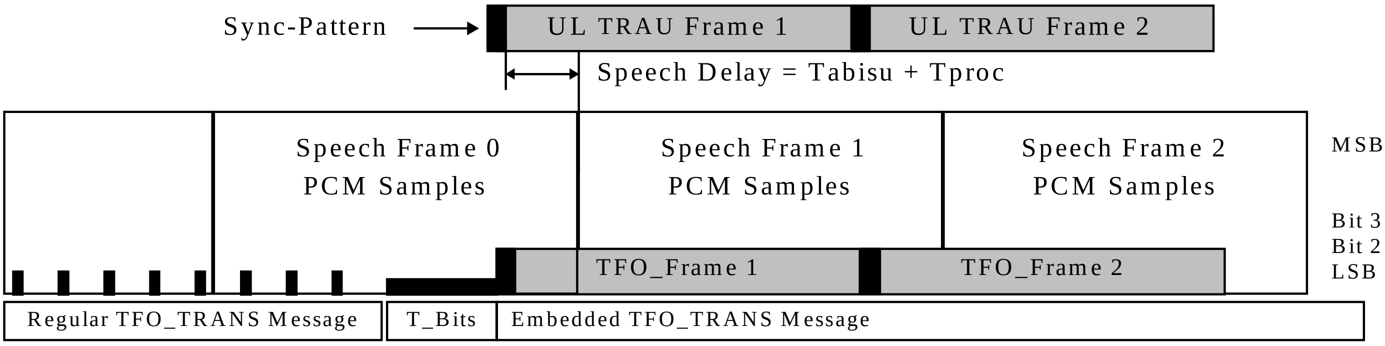


Figure 4: Time Alignment by inserting T_Bits and embedding one TFO_TRANS Message

Time Alignment of TFO Frames to Downlink TRAU Frames

The TFO Protocol does not affect the phase position of the downlink TRAU Frames.

The phase difference between the received TFO Frames and the downlink TRAU Frames is in general constant, but arbitrary between 0 and 159 PCM samples. The time alignment of the TFO Frames to the downlink TRAU Frames must therefore be managed by buffering the TFO Frames within the receiving downlink TRAU. This can be done in one of two methods:

The received TFO Frame is buffered for a period between 0 to 159 PCM samples in addition to the processing delay *(Tbfh)* required *to perform a suitable Bad Frame Handling on parameter level.* Transmission of the downlink TRAU Frame may in this case begin ***prior*** to receipt of the complete TFO Frame.

NOTE 1: In this first method the overall one way signal delay will be between *30 ms and 10 ms lower than the delay* in normal tandem connections.

Alternatively the received TFO Frame is buffered for a period between 160 to 319 PCM samples in addition to the processing delay required *to perform a suitable Bad Frame Handling on parameter level (Tbfh).* Transmission of the downlink TRAU Frame will in this case always begin ***after*** the receipt of the complete TFO Frame.

NOTE 2: In this second method the overall one way signal delay will always *be up to 10ms lower or up to 10 ms higher* than the delay in normal tandem connections.

NOTE 3: The two methods differ in one way signal delay always by exactly 20 ms. Figure 6 highlights the relations for an arbitrarily selected relative phase difference between TFO and TRAU Frames of 80 samples (10 ms). *Tbfh is in the order of some PCM samples only, if error concealment is done "in advance" based on the parameters of the previous TFO Frame, before the actual TFO Frame is even received.*

NOTE 4: The first method should be preferred in case the AMR codec is used.

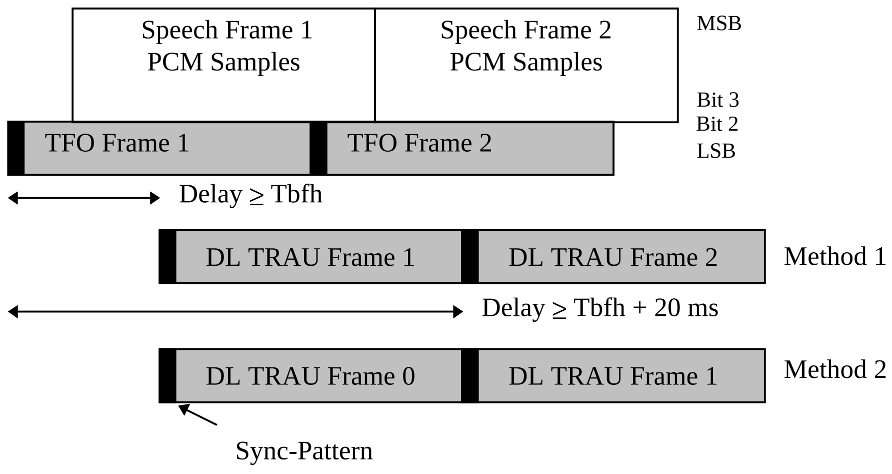


Figure 5: Downlink Time Alignment of TFO Frames

Processes for Tandem Free Operation

TFO implies that the different entities of the BSS collaborate. This is achieved by the distribution of TFO processes on these entities.

The Figure 6 provides an overview of the processes inside the BSS which are in place in order to enable Tandem Free Operation. This figure shows also the interfaces enabling communications between these processes.

This model is assumed in the rest of this clause. Codec mismatch or AMR ACS mismatch resolutions are optional. The model is still valid since no mismatch resolution is achieved by not indicating what can be the alternatives in the List of supported Codec types or in the SCS.

The TFO involves the following different processes:

- TFO_TRAU,
- TFO_BTS,
- TFO_BSC.

The interfaces as shown in figure 6 are:

① The Abis/Ater Interface (traffic), TFO information are embedded in the TRAU frames in case of AMR,

② A proprietary interface between the BSC and the TRAU, which is used for FR, EFR and HR speech services, to exchange messages on the remote and local codec configurations.

③ Abis interface (LAPD) to exchange Layer 3 signalling as defined in the GSM 08.58 for AMR TFO purposes.

④ Abis/Um interface (LAPDm) to exchange Layer3 signalling between the BSC and the MS when it is required to change the codec type to solve codec mismatch.

⑤ Um interface (RATSCCH, see GSM 05.09) is used to change the ACS used by the terminal in case of AMR TFO.

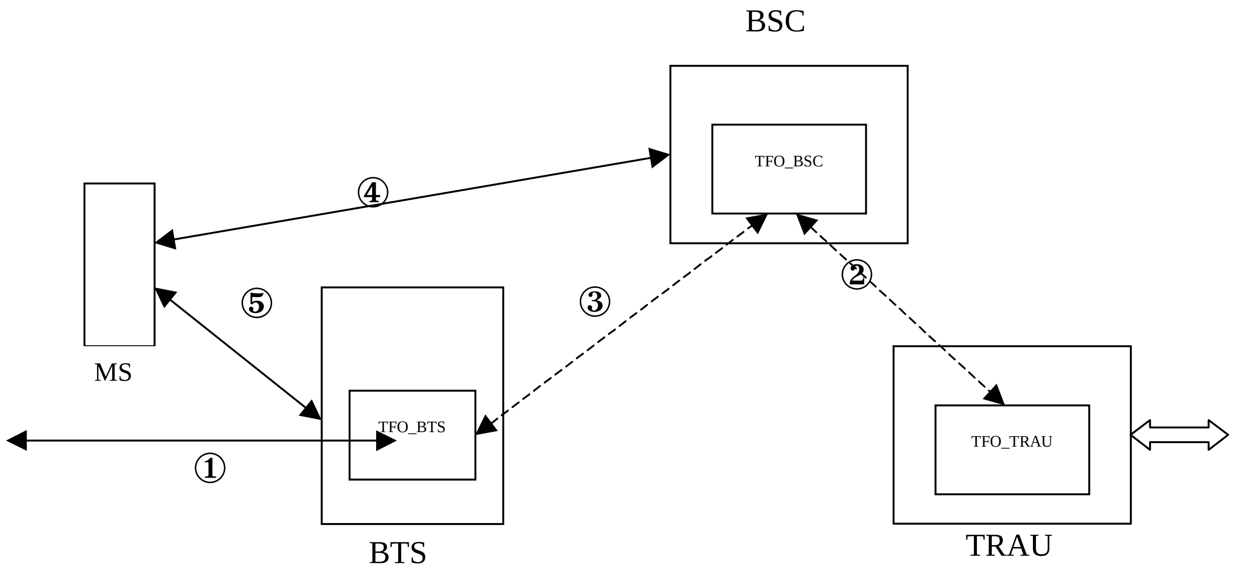


Figure 6: Processes and Interfaces for TFO

The different processes as well as the inter-processes dialogues are described in the following sub-clauses.

TFO_TRAU

The following chapters describe the actions within the TRAU to establish and maintain Tandem Free Operation in terms of a State Machine, respectively TFO Processes, handling synchronisation and protocol. The description of the TFO Protocol does not reflect implementation details for the I/O Processes, but they may need to be considered for the exact understanding of the behaviour. Only the TFO_Protocol Process is detailed, which is responsible for the handling of the TFO Protocol.

The SDL-Simulation, as described in Annex C, however, takes the necessary details into account and can serve as example implementation for all processes, as far as the TFO Protocol is concerned.

The TFO_TRAU can be regarded as consisting of five processes, which are strongly coupled to each other, which run in parallel, but phase shifted. The TFO_Protocol Process communicates with the TFO I/O processes and, optionally, with its corresponding process within the BSS (BSC) to resolve Codec Mismatch, see figure 7.

Under normal circumstances (exceptions occur during time alignments or octet slips) all TFO I/O Processes are triggered every 160 samples or every speech frame of 20 ms. All events and actions are quantized in time into these smallest intervals.

It can be assumed that the processing times for the TFO Processes are very short and negligible.

However, it must be ensured that no timing ambiguity occurs between the Processes.

This means the processing and exchange of information between them do not overlap in time. Care must be taken especially when time alignment occurs, which may be completely independent in uplink and downlink.

During these time alignments the TFO Frames or TFO Messages may shift in time and consequently the triggering point for the related TFO Processes changes, too.

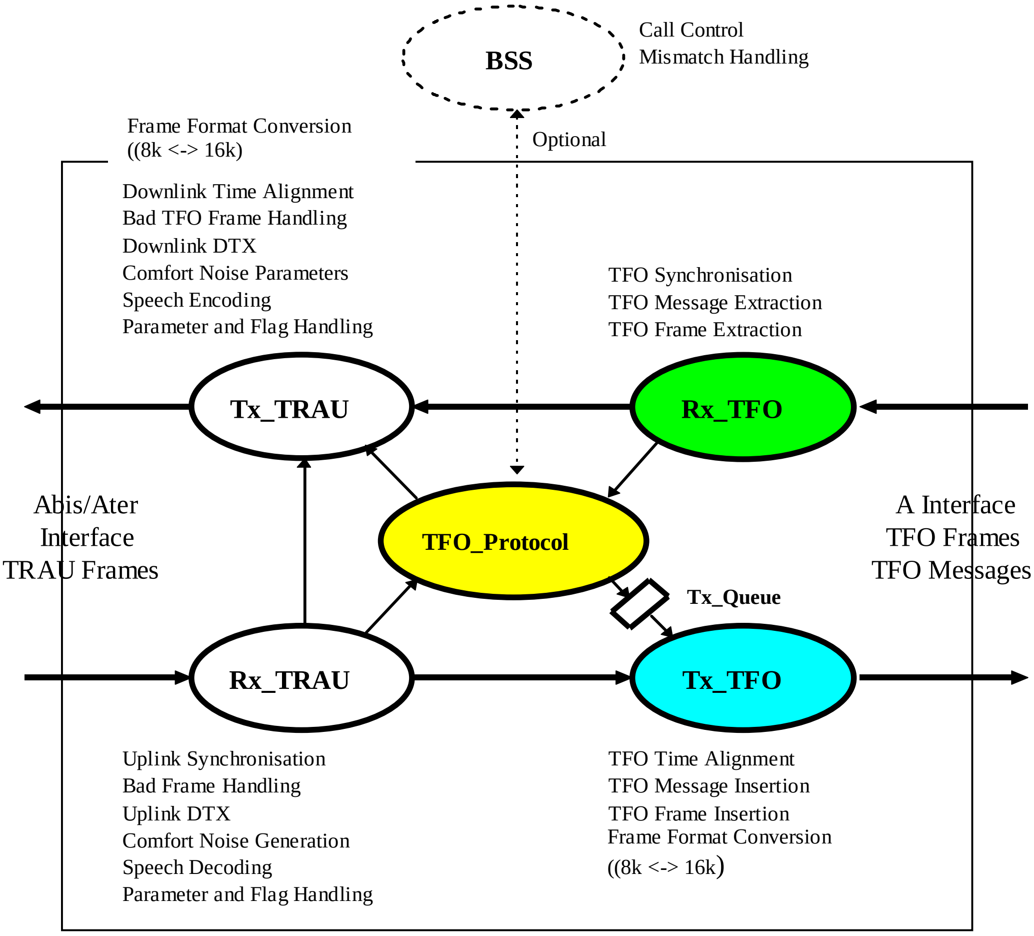


Figure 7: The TFO_TRAU consists of five Processes

8.1.1 Rx_TRAU Process

The Rx_TRAU Process receives Uplink TRAU Frames from the Abis/Ater Interface and synchronises to them, i.e. checks correct synchronisation and contents. It performs all actions of a conventional Uplink TRAU (see GSM 08.60 respectively GSM 08.61). It extracts the data bits and calls, if appropriate, the Bad Frame Handler, the Uplink DTX functions and Comfort Noise Generator and finally the Speech Decoder.

The resulting speech samples are handled to the Tx_TFO Process for output to the A interface. In addition Rx_TRAU passes the Uplink TRAU Frames directly and unaltered to Tx_TFO.

It further extracts the control bits, the “TFO bits” (see sub-clause 8.4.2), respectively commands, from the Uplink TRAU Frames and sends corresponding Rx_TRAU Messages to the Tx_TRAU Process (see GSM 08.60, respectively GSM 08.61) and the TFO_Protocol Process (see sub-clause 8.1.5).

In case of AMR, the TFO can be disabled (respectively enabled) by the TFOE bit (see sub-clause 8.4.1.4). When this bit changes, the event TFO_Disabled (respectively TFO_Enabled) are detected by the Rx_TRAU and reported to the TFO_Protocol controller.

8.1.2 Tx_TRAU Process

The Tx_TRAU Process builds autonomously the relevant Downlink TRAU Frames and sends them in the correct phase relation onto the Abis/Ater-Interface as commanded by the time alignment from the BTS.

Tx_TRAU has three major States: TFO == OFF (default at beginning), TFO == ON, and TFO_SOON (see Figure 8).

TFO_Protocol with Accept_TFO, Ignore_TFO, Stop_TFO and Announce_TFO commands toggling between these States.

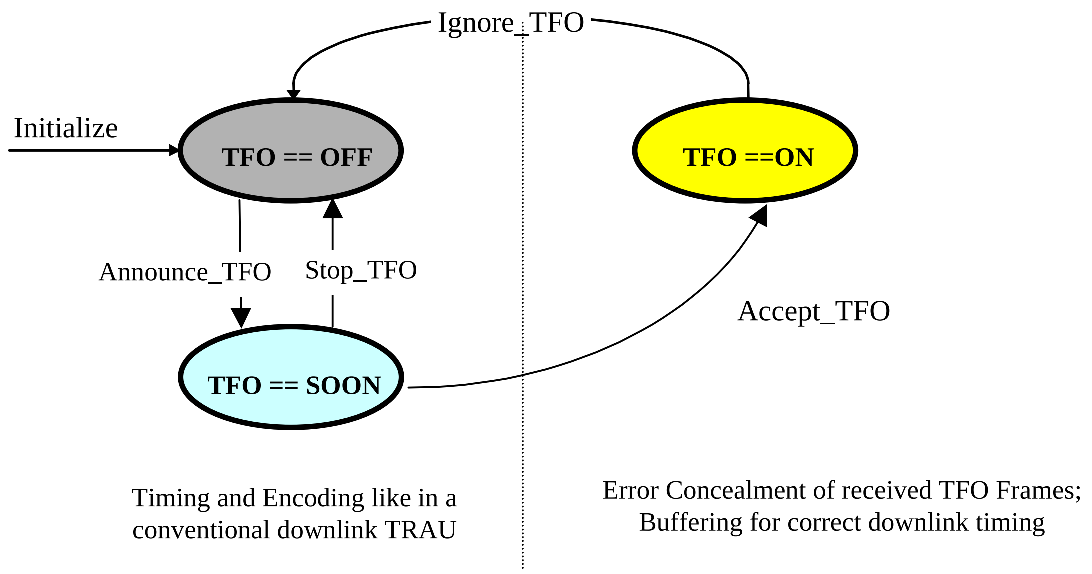


Figure 8: States of the Tx_TRAU Process

- During TFO == OFF or TFO==SOON, Tx_TRAU performs all actions of a conventional downlink TRAU (see GSM 08.60 and respectively GSM 08.61): On command from Rx_TRAU it performs necessary downlink time alignments and starts or stops sending of TRAU Frames.

  In case of AMR, Tx_TRAU furthermore switches the AMR codec mode according to the change of the UL CMR. It samples one frame of speech samples in the correct phase position and calls the Speech Encoder. The resulting speech parameters are then transmitted downlink on the Abis/Ater interface. It modifies the CMI/CMR phase alignment when requested by the Rx_TRAU.

- In TFO == SOON or TFO == ON on command of the TFO_Protocol the Tx_TRAU sends the Distant TFO parameters by either mapping (see sub-clause 8.5.4) the Distant TFO parameters in a DL TRAU frame or by stealing a DL TRAU frame to transmit them to the BTS.

During TFO == ON, Tx_TRAU performs Bad Frame Handling and Comfort Noise Parameter Handling on parameter level on the received TFO Frames, if necessary for FR, EFR and HR. The resulting speech parameters and control bits are buffered until they are passed as Downlink TRAU Frames in correct phase position to the BTS (see also sub-clause 7.3). Nothing specific is performed in case of AMR.

Finally in case of AMR, if the Time Alignment Field is not used for another purpose, Tx_TRAU sends the TFO status, (TFO_OFF, TFO_SOON or TFO_ON) to the BTS according to the protocol described in sub-clause 8.4.2.

There are four possible cases regarding DTX in a Mobile-to-Mobile communication, as reflected in Table 13.

Table 13: DTX configurations in Mobile-To-Mobile communications

Case	Local TRAU: Downlink	Distant TRAU: Uplink
0	No-DTX	No-DTX
1	No-DTX	DTX
2	DTX	DTX
3	DTX	No-DTX

8.1.2.1 Downlink Speech Transmission if TFO is ON

8.1.2.1.1 FR, EFR and HR cases

During TFO == ON and if neither Uplink nor Downlink DTX is active (case 0 in Table 13), the Tx_TFO Process receives TFO Frames from the A Interface with SID == "0". It synchronises to them, i.e. checks correct synchronization and contents. It extracts the data bits and calls, if appropriate (e.g. if BFI == "1" or if the TFO Frame is not valid, see sub-clause 8.4.2), a Bad Frame Handler to derive suitable parameters for Downlink TRAU Frames. This Bad Frame Handler on parameter level is subject to manufacturer dependent future improvements and is not part of this recommendation.

While TFO == ON and if distant Uplink DTX is active, but not local Downlink DTX (case 1 in table 13), then the Tx_TFO Process receives TFO Frames containing speech parameters (SID == "0": handling as in case 0, see above), but also TFO Frames containing SID parameters (SID == "1" or "2") and TFO Frames marked with BFI == "1" during speech inactivity. Tx_TFO then calls a Comfort Noise Generator to derive suitable "speech" parameters for Downlink TRAU Frames. The SP flag shall always be set to SP = "1". The Downlink TRAU Frames shall not contain the SID codeword, but parameters that allow a direct decoding. Also this Comfort Noise Generator on parameter level is subject to manufacturer dependent future improvements and is not part of this recommendation.

8.1.2.1.2 AMR case

During TFO == ON the Tx_TRAU transmits the DL TRAU frames received from the Rx_TFO. No Error concealment and Comfort Noise Generation is performed by the Tx_TRAU.

8.1.2.2 DTX Procedures in Downlink Direction if TFO is ON

8.1.2.2.1 FR, EFR and HR cases

During TFO == ON and if distant Uplink DTX and local downlink DTX are active (case 2 in table 13), then the Tx_TFO Process receives TFO Frames containing either Speech parameters (SID == "0, handling see sub-clause 8.2.1) or SID parameters (SID == "1" or "2") or TFO Frames marked with BFI == "1" during speech inactivity due to transmission errors.

If a TFO Frame marked as a valid SID frame (SID == "2", BFI == "0") is received, it shall be stored in Tx_TRAU and its parameters shall be sent directly as Downlink TRAU SID Frame with correct timing. The DL_TRAU SID Frames produced from the valid stored frame are output repeatedly to the Abis/Ater interface whilst invalid SID frames (SID == "1") or frames marked as bad (BFI == "1") are received. These Downlink TRAU SID Frames shall be marked with the SP flag = "0" and shall all contain the SID codeword.

The stored SID Frame shall be considered as being valid for SID frame generation purposes until the receipt of the second instance of TAF == "1" (in a TFO Frame) following its initial storage. On expiry of the stored SID frame a suitable Bad Frame Handler for SID Frames shall be invoked to mute the Comfort Noise. Also this Bad Frame Handler for SID Frames on parameter level is subject to manufacturer dependent future improvements and is not part of this recommendation.

During TFO == ON and if distant Uplink DTX is not active, but local downlink DTX is on (case 3 in table 13), i.e. only TFO Frames containing speech parameters are received, then one of the following alternative methods shall be used:

Downlink DTX need not to be used.
The speech parameters are extracted from the TFO Frames and are passed to the BTS. This is virtually identical to case 0 in table 13, with no speech pauses detected, and handled like described above.

Alternatively, a voice activity detector makes the decision as to whether the frame contains speech or not based on the PCM samples received from the A interface. During periods decided as "Active Speech" the TFO Frame parameters are used as described above. During periods of "Speech Pause" Comfort Noise Parameters are calculated.

These operations are manufacturer dependent and not detailed here.

Alternatively, decoding of the speech parameters received in TFO Frames may be undertaken and these PCM samples may be used for normal downlink VAD and DTX functions.

8.1.2.2.2 AMR case

During TFO == ON the Tx_TRAU transmits the DL TRAU frames received from the Rx_TFO exactly as for the Speech frames. Nothing specific is performed.

8.1.2.3 Synchronisation and Bit Errors in Received TFO Frames

8.1.2.3.1 FR, EFR and HR cases

If Rx_TFO detects an error in the received TFO Frame synchronization or control bits or if a CRC error is detected, and the error is detected **prior** to beginning the output of the same frame (as a Downlink TRAU Frame), then Tx_TRAU shall either substitute parameters from the last good TFO Frame, or shall encode the received PCM samples for the duration of this frame.

If Rx_TFO detects an error in the received TFO Frame synchronization or control bits or if a CRC error is detected, and the error is detected **after** beginning of the output of the same frame (as a Downlink TRAU Frame), then Tx_TRAU shall deliberately corrupt the remaining, still unsent synchronization bits by setting them all to "0" and deliberately shall corrupt the remaining CRC bits. This will result in the BTS discarding this TRAU Frame, and transmitting a Layer 2 Fill frame or CRC-Inverted frame to the Mobile station (see GSM 08.60 and GSM 08.61). The effect of the frame error will subsequently be masked by the Mobile station’s handling of bad frames.

8.1.2.3.2 AMR case

8.1.2.3.2.1 No format conversion

When TFO and TRAU frames have the same format i.e. 16 or 8 kbit/s the received TFO frame is relayed as a DL TRAU frame toward the BTS.

8.1.2.3.2.2 With format conversion

If a CRC error is detected the corresponding, if any, CRC should be inverted in the DL TRAU frame.

If a synchronization error is detected, it should be corrected as far as possible in the DL TRAU frame.

8.1.3 Tx_TFO Process

The Tx_TFO Process gets directly the unaltered Uplink TRAU Frames (containing the speech parameters and the control bits) and the decoded speech PCM samples from Rx_TRAU. It further gets internal messages (commands) from TFO_Protocol via the Tx_Queue.

Tx_TFO has two major States: TFOtx == OFF (default at beginning) and TFOtx == ON, see Figure 9.

Toggling between these two States is commanded by TFO_Protocol with Begin_TFO respectively Discontinue_TFO.

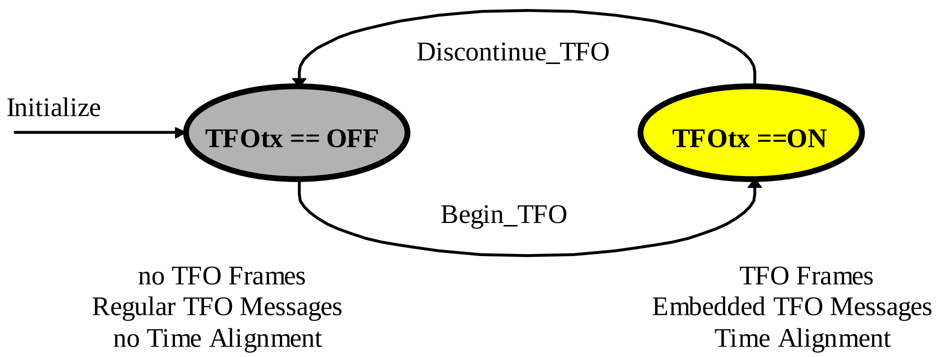


Figure 9: States of the Tx_TFO Process

During TFOtx == OFF, decoded speech PCM samples and regular TFO Messages (if any) are sent onto the A interface. Time Alignment takes place only once, just before the beginning of the first regular TFO Message.

During TFOtx == ON, TFO Frames and embedded TFO Messages (if any) are sent. Time Alignment takes place just before the first TFO Frame and then whenever required in between two TFO Frames.

The Tx_TFO Process builds the relevant TFO Frames and sends them in the correct phase relation onto the A-Interface. Time alignment of TFO Messages and TFO Frames are handled autonomously and independent of the TFO_Protocol Process. Rx_TRAU informs Tx_TFO about any changes in the phase position of the Uplink TRAU Frame and Tx_TFO inserts automatically the correct number of T_Bits before the next TFO Frame, and embeds autonomously the next TFO_Message or a TFO_FILL Message, if necessary.

The TFO_Protocol Process can send internal messages into the **Tx_Queue** (First In, First Out). Tx_TFO shall take the message from the Tx_Queue one by one, shall process them autonomously and shall send the resulting TFO Messages in correct order and phase position, as regular or as embedded TFO Messages. Tx_TFO shall generate a Runout Message to TFO_Protocol, if the last TFO_Message is sent without guarantee of a direct continuation by another TFO Message, i.e. if the (possible) IPEs may have run out of synchronisation (see chapter 10). TFO_Protocol may delete messages from Tx_Queue, as long as they are in there:
Command "Clear Tx_Queue", at time *Tc*.

Basically, messages or commands that are already in processing by Tx_TFO at *Tc* can not be stopped, deleted or interrupted. The TFO Protocol is designed to work properly with that default handling, although not with fastest processing.

But: Tx_TFO shall investigate at *Tc*, how far the transmission of the current TFO Message is proceeded and shall **"Modify on the Fly"** this last TFO_Message before *Tc* into the first one after *Tc*, see Figure 10.

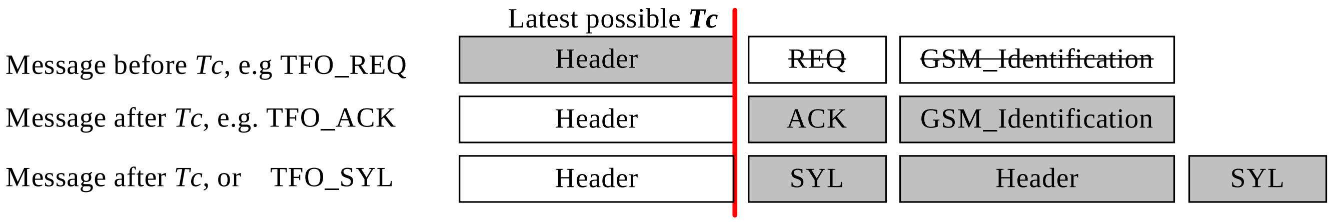


Figure 10: Modification on the Fly within the Header Transmission, examples

When the AMR codec is the Used_Codec_Type, the TFO frame format can change because the ACS is changed and it either includes modes which require 16 kbit/s format while TFO frame generated up to this point were 8 kbit/s, or all the modes fit in 8 kbit/s while 16 kbit/s frame were generated up to this point. According to sub-clause 5.3 the Tx_TFO shall then change the TFO frame format. Two options are possible depending on the current state:

- Option 1 :
  TFO is interrupted. The TRAU enters in First_Try state
- Option 2 :
  When changing from 16 kbit/s to 8 kbit/s the Tx_TFO shall first change the TFO frame format and next shall embed the TFO_TRANS8k message (see sub-clause 6.6).
  When changing from 8 kbit/s to 16 kbit/s the Tx_TFO shall first embed the TFO_TRANS16k (see sub-clause 6.6) message and next shall change the TFO frame format.

The detailed description is provided in the state machine description clause 10.

8.1.4 Rx_TFO Process

The Rx_TFO Process receives TFO Messages and TFO Frames from the A-Interface and synchronises to them, i.e. checks correct sync and contents. It bypasses all PCM samples and TFO Frames directly to Tx_TRAU for further processing. The Rx_TFO Process further extracts all the control bits and TFO Messages and sends corresponding Rx_TFO Messages to the TFO_Protocol Process.

If Embedded messages are detected in the TFO frames '1' bits shall replace the altered synchronization bits in the corresponding DL TRAU frame.

When the Rx_TFO received distant TFO parameters it relay them to the TFO _Protocol.

8.1.4.1 Search for and Monitoring of TFO Synchronization

The monitoring of TFO Frame or TFO Message synchronisation shall be a continuous process. Typically, TFO Messages and TFO Frames follow each other with a well-defined phase relation. Insertion of T_Bits or octet slips may, however, disturb that regular phase relation every now and then and shall be taken into account. In all error cases, the receiver shall investigate, if sync has been lost due to octet slip, phase adjustment or other events and shall try to resynchronize as fast as possible.

Typically, TFO Frame synchronisation is similar or identical to TRAU Frame synchronisation, see GSM 08.60 and 08.61.

During Tandem Free Operation, however, it is sometimes necessary, to exchange TFO Messages by embedding them into the TFO Frame flow. This is indicated by a control bit (C5) for the 16 kbit/s TFO frame and the GSM HR TFO frame. Some of the TFO Frame synchronization bits are then replaced by bits of the TFO Message. TFO Messages follow specific design rules, which can be used to check if synchronisation is still valid. For the 8 kbit/s AMR TFO frames when the synchronization pattern is corrupted it is checked whether this corresponds to a TFO message.

The first TFO Message or the first TFO Frame (whatever comes first) shall be completely error free to be acceptable by Rx_TFO. After that all "valid" (see sub-clause 8.1.4.2) TFO Messages shall be reported to TFO_Protocol with a respective message. If a TFO Message has been received before and synchronisation is not found again for more than 60 ms, i.e. no "present" or "valid" TFO Message can be found during that time, then Rx_TFO shall generate a MSL (Message_Sync_Lost) Message to TFO_Protocol. A "not-valid", but "present" TFO Message shall not be reported, but also no MSL shall be reported, i.e. synchronisation is regarded as not lost, but the TFO Message is ignored.

Similar, the first five "valid" TFO Frames shall be reported to TFO_Protocol with frame number n (n == 1,2,..,5). Further valid TFO Frames do not need to be reported.

Similar, if for the first time after the PCM_Idle period, PCM_Non_Idle samples are received, then a PCM_Non_Idle Message shall be sent to TFO_Protocol. Further PCM_Non_Idle samples need not be reported.

If TFO Frame Synchronization is lost, or if too many errors are detected in TFO Frames (no present TFO Frames), then the Rx_TFO shall generate a FSL (Frame_Sync_Lost) Message to TFO_Protocol with frame number n (n == 1,2,3), the number of lost TFO Frames since the last valid TFO Frame. No more than three FSL Messages need to be reported in a series.

NOTE: The MSL and FSL Messages shall not be mixed up with the TFO_SYL Message, by which the distant TFO Partner reports lost synchronisation.

TFO Messages with Extension_Blocks that can not be understood by the receiving TRAU, but which follow the design rules for IS_Extension_Blocks, shall be ignored. This guarantees future expandability.

8.1.4.2 Errors in TFO Messages and TFO Frames

Some Definitions, which may serve as a guideline:

A TFO Message is called "**error-free**", if no error can be detected within the whole message.

A TFO Message is called "**single-error**", if no more than one bit position differs either in the IS_Header or the IS_Command_Block or the GSM_Ident_Block or the IPE_Mode_Block or the Sync bits and no errors are detectable within the CRC fields or the EX-fields.

A TFO Message may be regarded as "**correctable**", if the phase position is as in preceding TFO Messages and

- no more than 2 bit positions differ in the IS_Header; and
- no more than 1 error is detected within the IS_Command_Block; and
- no more than 3 errors are detected within the IPE_Mode_Block; and
- no more than 3 errors are detected within the GSM_Ident_Block; and
- no more than 1 error is detected within the Sync-Bit(s); and

- no more than 0 error is detected within the EX-field(s); and
- no more than 0 error is detected within the CRC-fields; and
- the total number of detected errors is not higher than 3.

TFO Message, which are error-free, single-error or correctable are also called "valid" TFO Messages. All other TFO Messages are called "not-valid".

A TFO Message may be regarded as "**present**", if the phase position is as in preceding TFO Messages and

- no more than 4 bit positions differ in the IS_Header; and
- no more than 2 errors are detected within the IS_Command_Block; and
- no more than 3 errors are detected within the IPE_Mode_Block; and
- no more than 3 errors are detected within the GSM_Ident_Block; and
- no more than 2 errors are detected within the Sync-Bit(s); and
- no more than 1 error is detected within the EX-field(s); and
- no more than 1 error is detected within the CRC-fields; and
- the total number of detected errors is not higher than 5.

Sequences, which differ in more than "present" may not be recognized as TFO Messages at all ("**not-present**").

Note that the insertion of T_Bits may change the phase position of the TFO Frames and of bits of an embedded TFO Message. The TFO Message shall in that case be classified after the removal of the T_Bits.

An octet slip may also change the phase position of bits within a regular or embedded TFO Message.

If an error-free or a single-error TFO Message can be found after considering a hypothetical octet slip (±1 sample), then it may be regarded as error-free or single-error and the new phase position shall be regarded as valid, if not valid or present TFO Message can be found at the old phase position.

A **TFO Frame** is called "**error-free**", if no error can be detected within the whole frame.

A TFO Frame is called "**single-error**", if no more than one bit position differs either in the synchronisation bits or the T_Bits and if no other errors can be detected. TFO Frames, which are error-free, or single-error are also called "**valid**" TFO Frames. All other TFO Frames are called "**not-valid**".

A TFO Frame may be regarded as "**present**", if

- no more than 4 bit positions differ in the synchronisation bits
- no more than 2 errors are detected within the T_Bits;
- no more than 1 error is detected within the control bits;
- no more than 1 error is detected within the CRC block; and
- the total number of detected errors is not higher than 5.

Sequences, which differ in more than "present" may not be recognized as TFO Frames at all ("**not-present**").

Note that the insertion or deletion of T_Bits may change the phase position of the TFO Frames .The TFO Frame shall in that case be classified after considering the T_Bits.

An octet slip may also change the phase position of bits within a TFO Frame. Typically a TFO Frame can not be corrected after an octet slip, but the next TFO Frame shall be found again.

The parameters of a valid TFO Frame shall be regarded as "bad", if the BFI flag is set to BFI == "1" or the Tx_Type set to Bad Speech Frame (e.g. for AMR). Similar definitions hold for other valid TFO Frames, equivalent to Uplink TRAU Frames (see GSM 08.60 and 08.61).

8.1.5 TFO_Protocol Process

The TFO_Protocol Process is typically invoked whenever a message is received, either from Rx_TRAU, Rx_TFO, Tx_TFO or the local BSS (i.e. the BSC).

Two events are due to modifications of the local MS-BSS configuration,

- a modification of the used speech Codec (New_Local_Codec), and
- a modification of the list of the alternative speech Codecs (New_Local_Codec_List).

The New_Local_Codec is extracted from the uplink TRAU Frames and reported by Rx_TRAU.

The New_Local_Codec_List is reported by the BSS in a manufacturer dependent way in case Used_Codec_Type is FR, HR or EFR.

It may happen during an established TFO connection that the used Codec is identified as not optimal. Then the distant partner (e.g. a TCME) may inform the TRAU by a TFO_REQ_P Message that another Codec would be preferred.

The TRAU has to inform the local BSS about the preferred Codec, but continues with TFO until an optional In_Call_Modification is performed by the local BSS.

Note: The default initial state shall be: - TFO_Enabled for Full Rate, Enhanced Full Rate and Half Rate

- TFO_Disabled for AMR.

8.1.5.1 Messages from Rx_TRAU or local BSS

Rx == New_Speech_Call (Local_Used_Codec);	Rx_TRAU is activated by BTS.
Rx == New_Local_Codec (New_Local_Used_Codec);	In Call Modification to other Codec Type.
Rx == Data_Call;	In Call Modification to Data_Call.
Rx == Local_Configuration_Parameters;	Optional, from BSS.
Rx == TRAU_Idle;	Manufacturer dependent, either from BTS or BSS.
Rx == TFO_Enable;	Enable the TFO process
Rx == TFO_Disable;	Disable the TFO process

8.1.5.2 Messages to Tx_TRAU

Tx_TRAU := Accept_TFO;	If TFO Frames are correctly received, they shall be used.
Tx_TRAU := Ignore_TFO;	TFO Frames, even if received correctly, shall be ignored.
Tx_TRAU := Announce_TFO	TFO is about to be established
Tx_TRAU := Stop_TFO	Exit from TFO

8.1.5.3 Optional Messages to the local BSS

BSS := TFO (Distant_Used_Codec, Distant_Codec_List, Distant_Preferred_Codec, …).

8.1.5.4 Messages to and from Tx_TFO

The symbol () indicates that these Messages contain parameters, see clause 6.

Tx := TFO_REQ ();	main TFO_REQ Message.

Tx := TFO_ACK ();	main TFO_ACK Message, response only to TFO_REQ.
Tx := TFO_REQ_L ();	used in Mismatch, Operation and Periodic_Retry to inform about alternative Codecs.
Tx := TFO_ACK_L ();	response only to TFO_REQ_L.
(Tx := TFO_REQ_P ());	undefined for TRAU, defined only for TCME.
Tx := TFO_TRANS ();	command IPEs to go transparent.
Tx := TFO_NORMAL;	reset IPEs into their normal operation.
Tx := TFO_FILL;	mainly to pre-synchronise IPEs.
Tx := TFO_DUP;	"I receive TFO Frames in Establishment".
Tx := TFO_SYL;	"I lost TFO Frame synchronisation".
Tx := Begin_TFO;	Insert TFO Frames from now on.
Tx := Discontinue_TFO;	Discontinue inserting TFO Frames.
Clear Tx_Queue;	Clears all remaining commands from Tx_Queue.
Rx == Runout;	Reports that the continuous stream of outgoing TFO Messages may be interrupted.

8.1.5.5 Messages from Rx_TFO

The symbol () indicates that these Messages contain parameters, see clause 6.

Rx == TFO_REQ ().	
Rx == TFO_ACK ().	
Rx == TFO_REQ_L ().	
Rx == TFO_ACK_L ().	
Rx == TFO_REQ_P ()	;requests an other, preferred Codec, plus Codec_List.
Rx == TFO_TRANS ()	;may serve as alternative TFO_ACK in some cases!.
Rx == TFO_NORMAL.	
Rx == TFO_FILL.	
Rx == TFO_DUP.	
Rx == TFO_SYL.	
Rx == TFO_Frame ()	;TFO_Frame (Distant_Used_Codec; Number_of_Received_Frames).
Rx == Frame_Sync_Lost ()	;Frame_Sync_Lost (Number_of_Lost_Frames).
Rx == Mess_Sync_Lost	;Message_Sync_Lost.
Rx == PCM_Non_Idle	;at the beginning of a period with several samples/frame different from PCM_Idle.

The message "TFO_Frame ()" needs to be sent only at the first five occurrences, either after a not valid TFO Frame, or if the Distant_Used_Codec changed.

The message "Frame_Sync_Lost ()" needs to be sent only at the first five occurrences of errors in TFO Frames or loss of synchronisation, after a correctly received TFO Frame.

The message "Mess_Sync_Lost" is sent, when after a valid TFO Message no following TFO Message is found.

8.2 TFO_BTS

The TFO_BTS does nothing when FR, HR and EFR are being used in TFO. **The following sub-clauses apply when AMR is the Used_Codec_Type and when TFO is enabled.**

8.2.1 TFO_States and Transitions

For the AMR link adaptation and the optimal handover procedure it is important that the BTS has knowledge about the status of the connection with respect to TFO. While the TRAU differentiates quite some states, it is important for the BTS to distinguish five TFO related states as described in sub-clause 8.2.1.1.

8.2.1.1 TFO_States within the BTS

The TFO_BTS state machine is made of five states:

- TFO_Disabled: No Tandem Free Operation is allowed and is also not ongoing;
- TFO_No: Tandem Free Operation is enabled, but is neither ongoing nor under establishment;
- TFO_Maybe: Tandem Free Operation is under establishment, but is still not ongoing;
- TFO_Yes: Tandem Free Operation is ongoing.
- TFO_Terminating: Tandem Free Operation is still ongoing, but will terminate soon.

At resource allocation the BTS enters either TFO_Disabled or TFO_No, depending on the Configuration Message from the BSC (see sub-clause 8.3.2.1). The transition from one state to another one is triggered by the reception of a message, either from the BSC or the TRAU. According to the TFO_State the BTS shall initiate different actions.

In TFO_Disabled and TFO_No the BTS may perform Time and Phase Alignment. In all other States (TFO_Maybe, TFO_Yes, TFO_Terminating which are often gathered under the expression TFO ongoing (see GSM 08.60)) the BTS should not send Time or Phase Alignment Messages to the TRAU, since the TRAU shall not obey them. In State TFO_Yes the BTS may perform Phase Alignment on the air interface (see GSM 05.09).

The following TFO_State diagram shows the five States and the most important transitions.

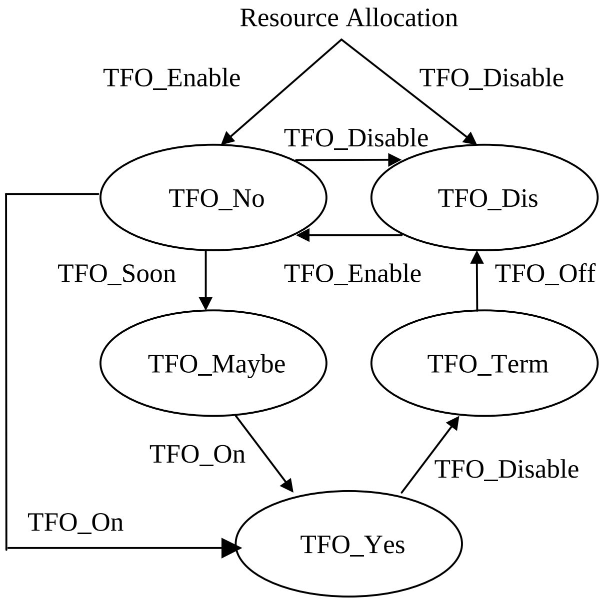


Figure 11: Main TFO _State Diagram within the BTS

8.2.1.2 Messages and most important transitions and actions.

TFO_Enable and *TFO_Disable* are not messages per se, but are included in Configuration Messages from the BSC (see sub-clause 8.3.1) by setting or resetting the TFO_Enable bit. In any case the Configuration Message shall be sent to the TRAU immediately.

TFO_Soon, *TFO_On* and *TFO_Off* are sent from the TRAU within the Time Alignment field, either with or without configuration parameters from the distant side.

TFO_Enable at resource allocation brings the BTS into TFO_No. TFO_Enable is relayed to the TRAU by the BTS (TFOE bit in TRAU frames). The TRAU shall then start TFO_Negotiation with a potential TFO_Partner.

TFO_Enable in State *TFO_Disabled* or *TFO_Terminating* starts the same procedure and brings the BTS also into State TFO_No. In any other State the TFO_Enable has no effect on the ongoing procedures.

TFO_Disable at resource allocation brings the BTS into TFO_Disabled. The TRAU shall not initiate nor respond to any TFO_Negotiation. It shall terminate TFO operation or Negotiation.

TFO_Disable in *TFO_Yes* brings the BTS into State *TFO_Terminating*. **TFO_Disable** in any other State brings the BTS immediately into *TFO_Disabled*.

If TFO is enabled the TRAU will get the knowledge about the remote side by the first received TFO_REQ or TFO_ACK Message. As soon as the TRAU gets knowledge that a TFO_Partner exists with AMR capabilities and that TFO is possible - at least with some Common_Codec_Mode(s) - it shall inform the BTS in downlink about the Distant AMR configuration (**Dis_Req** see sub-clauses 8.4.1 and 8.4.2) and shall send a **TFO_Soon** Message.

TFO_Soon from the TRAU in State *TFO_No* brings the BTS into *State TFO_Maybe*. The BTS shall select the suitable Codec_Mode for TFO_Setup (TFO_Setup_Mode). This TFO_Setup_Mode is defined by implicit rules, which lead to identical results on both ends of the connection. The BTS then brings the AMR Adaptation in uplink and downlink to that TFO_Setup_Mode. This is always achieved before the TRAUs switches to TFO.

TFO_On from the TRAU reports that finally TFO is ongoing, i.e. TFO Frames are exchanged in both directions. The BTS enters State TFO_Yes. Depending on the constellation of the Active_Codec_Sets on both ends of the TFO Connection the BSS may need to modify the local AMR Configuration in order to establish the common Active Codec_Set, also defined by implicit rules, i.e. the ICM of the Common ACS (see clause 12). Then the BSS enables the AMR Adaptation, now considering both radio legs for the selection of the optimal Codec_Mode.

TFO_Off from the TRAU brings the BTS immediately into the State TFO_No. The BSC should be informed.

8.2.2 Handling of downlink DTX in TFO

If TFO is ongoing and the BTS receives downlink TRAU frames classified with "SID_First or "SID_Update", it shall in State TFO_Yes use one of the following options:

- Option 1) The BTS performs normal DTX operation in downlink if DTX DL is enabled.
- Option 2) The BTS shall send the SID_First, SID_Update frames as in normal DTX, but shall send SID_Filler frames between SID frames when DTX DL is disabled.

See GSM 06.93 for the definition of the SID_Filler frames.

Note : In all cases ONSET frames shall be ignored, see GSM 05.09.

8.2.3 Handling of Errors in the TFO related information embedded in the TRAU Frames

The BTS shall check the consistency of the data sent by the TRAU regarding the distant BSS-MS configuration. If they're inconsistent they're ignored, i.e. no report is made to the BSC, no change of the MS-BTS ACS is attempted, no acknowledgement is sent back.

8.2.4 Procedures for Round Trip Delay Measurements

In case of AMR, the link adaptation may need information on the round trip delay between the local BTS and the local TRAU or - in case of TFO ongoing- the distant BTS. Therefore the BTS shall count the number of elapsed TRAU frames between the sending of a “Con_Req” (see sub-clause 8.4.2) message and the receipt of the corresponding acknowledgement. This number, multiplied by 20 ms, gives an estimate of the round trip delay between the BTS and its partner. The type of acknowledgement indicates the type of partner, i.e. whether the local TRAU or the distant BTS has answered.

This procedure may be repeated whenever the status of the connection changes. The BTS may report the round trip delay measurement result to the BSC by sending a round Trip Delay Report (see GSM 08.58). Any substantial change (more than 60 ms difference) in the round trip delay may be reported, too.

8.2.5 Procedures for freezing the AMR link adaptation

When the BTS receives the PRE-HANDOver NOTIFication (see GSM 08.58) message from the BSC, it shall freeze the adaptation by steering the AMR codec mode to the ICM contained in the PRE-HANDOver Notification according to the rules described in GSM 05.09. It shall also send the “Handover_Soon” (see sub-clause 8.4.2.1) message to the TRAU.

The CMI/CMR field of the TRAU frames are converged to the ICM contained in the PRE_HANDOver Notification.

It initiates a Timer to 3s. It shall furthermore set ADAPE (see GSM 08.60 and sub-clause 8.4.1.4) to ‘0’ in all the UL TRAU frames until the Channel release or the Timer elapses. In case of Handover failure the BSC should inform the BTS (see sub-clause 8.3.2.3) as soon as possible, the BTS then enables adaptation.

When the BTS has received "Handover_Soon" and is in TFO_Yes state it shall steer the UL AMR codec mode to the mode corresponding to CMR field received in the DL TRAU frame. The Adaptation resumes when the ADAPE is toggled to '1' in two successive DL TRAU frames. The “Handover_Soon” message shall not be acknowledged.

8.3 TFO_BSC

The role of the BSC in TFO will depend on the speech service, which is used and on the degree of flexibility desired.

For the FR, EFR and HR the only one task, which is dedicated to the BSC, is the Resolution of Codec Mismatch and Codec optimization (see sub-clause 8.3.1).

For the AMR the role of the BSC can be much more important (see sub-clause 8.3.2).

8.3.1 Resolution of Codec Mismatch and Codec Type Optimization

The BSC is in charge of solving the Codec Mismatches. The BSC receives from the TRAU (via the BTS in case of AMR) the distant speech service configuration (i.e. the codec in use and the other possible codecs).

The BSC transmits to the TRAU the Local configuration, via the BTS for AMR. It may have to refresh this information if it changes along the time.

The BSC implements the rule provided in the clause 11. This rule ensures that both BSCs obtain the same result. The BSC can then initiate an intra-cell Handover if a different codec is required to ensure Tandem Free Operation.

8.3.2 Role of the BSC for AMR TFO

The AMR introduces a degree of complexity due to its multi-rate nature, to its link adaptation, and to the different options it allows. It is required that the AMR configurations of the two terminals and two BSS be aligned. There are in principle 162 different possible ACS for TCH/F and 56 in TCH/H.

The ACS can vary and depends on the BTS generation, BTS manufacturer or on Operators' preferences. The ACS can be tailored to cope with the environment of a given cell, e.g. a dense urban area or a flat rural area.

The MS can be AMR-FR only or AMR-FR and AMR-HR. The BSS can in principle support between a single mode and the fourteen possible modes (8 in TCH/F and 6 in TCH/H). The ACS includes between 1 and 4 modes.

The BSC can facilitate TFO and help to maintain it ongoing as far as possible, by:

① Solving the codec type mismatch,

② Determining the common ACS,

③ Keep as many as possible modes of the ACS before and after handovers,

④ Keep the same active AMR codec mode constant during Handover (i.e. before and after the change of Radio Traffic Channel).

The point ① is not AMR specific and the BSC shall apply the rule provided in the chapter 11.

8.3.2.1 Configuration of the AMR speech service.

The MS is configured by the BSC at Call set-up and during handovers through Layer 3 signalling (see GSM 04.08). The BTS is configured through the CHANnel ACTIVation message (see GSM 08.58). The TRAU circuit pools are managed by the MSC on request of the BSC (see GSM 08.08).

The AMR configuration of the MS and BTS can be changed during the call by:

- Intra-Cell Handover (see GSM 04.08 and 08.58),
- Mode-Modify (see GSM 04.08 and 08.58),
- RATSCCH (see GSM 05.09 and 08.58).
- Restriction of ACS only on Abis interface when contiguity rule (see subclause 12.5.3) applies.

The first three procedures are initiated by the BSC. The RATSCCH can in addition be delegated to the BTS by the BSC at the Channel Activation. This can modifie the way TRAU handles TFO setup. (see subclause 8.3.2.2)

The RATSCCH is the most efficient technique from a speech quality point of view since it can be faster and can minimize the number of lost frames.

The Intra-Cell Handover is a synchronized handover and creates less speech frame losses than the typical Handovers.

The Mode Modify offers the advantage of keeping the same radio resource but can introduce long speech blanks.

The restriction of ACS is made by the BTS when contiguity rule is verified with remote configuration sent by TRAU in TRAU frames. The MS is not aware of this change, it does not see any CMR outside the restricted ACS. Thus the BTS has to convert CMR and CMI since they are relatively-coded on the radio.

8.3.2.2 Resolution of AMR ACS Mismatch

The resolution of the AMR ACS mismatches is based on similar principles as the Codec Mismatch. A rule is defined in chapter 12, when followed a common ACS, if possible, is adopted by the two BSS.

In case the contiguity rule is verified, BTS restrict the ACS to the CACS. The MS is not aware of this ACS change

If the contiguity rule is not verified, the resolution of ACS mismatch depends on the possibility to use ratscch or not. Furthermore, if ratscch can be used, it depends on the possibility for the BTS to use ratscch without asking first to the BSC. These cases give the ACS_Change Category that the TRAU uses to decide whether it is possible to setup immediately TFO. The 3 categories are the following:

1	No Change	Ratscch is not supported
2	Slow Change	Ratscch is suported but the BSC must be informed first
3	Fast Change	Ratscch is supported and the BTS can handle it alone.

In cases 1 and 2, the BTS provides the BSC with the remote AMR codec configuration (see 08.58 sub clause 4.15). This set of parameters together with the corresponding local parameters is input to the rule to apply to find the common ACS.

The configuration of the AMR codec is changed using one of the first three methods listed in the sub-clause 8.3.2.1. This solves the point ② of the list provided in the sub-clause 8.3.2.

8.3.2.3 Handovers and the AMR TFO

Handover in an ongoing AMR-TFO connection needs more attention. It can be handled more efficiently, if the BSC takes the configurations (the active local one in the serving BTS, the future local one in the new BTS and the distant one) into account and informs the serving BTS and the new BTS before performing the handover ("Pre-Handover Notification", see sub-clause 8.2.6). The sending of the Pre-Handover Notification should take into account the round-trip delay if it has been reported by the BTS (see sub-clause 8.2.5).

The BSC, as a central point of the BSS, manages the AMR Speech Service configuration along the communication. This is done in such a way that the point ③ of the list provided above can be achieved.

The BSC has at any time control over the ongoing call, especially over all used resources. Some AMR specific adaptation procedures are, however, handled by lower layer inband signalling directly, e.g. time alignment, CMI/CMC phase alignment and Codec_Mode adaptation.

This is why the “Pre-Handover Notification” message results in freezing the adaptation to the ICM to be used in the new BTS (see sub-clause 8.2.5). The CMC to the distant MS corresponds then to this ICM.

8.4 The TFO_TRAU and TFO_BTS dialogue

The TFO is transparent to the BTS when FR, EFR or HR is the codec used. The following sections address how BTS and TRAU dialogue, as well as the local and distant BTS in case of AMR.

8.4.1 AMR TFO information elements in TRAU/TFO frames

8.4.1.1 Configuration Protocol Format

TRAU and TFO frames contain AMR and TFO parameters. These parameters are exchanged by the following configuration protocol between several entities (local BTS to local TRAU, local BTS to distant BTS, local TRAU to distant BTS and local TRAU to local BTS).Three fields are defined for each TFO and TRAU frames:

- Config_Prot field defines the meaning of the embedded parameters (ACK, REQ), the sender and the recipient (TRAU or BTS);
- Message No field is a protocol counter;
- Parameters field (TFO and AMR parameters).

When transmitted, each TFO (or TRAU) frames contain a set or a subset of these parameters. Some exceptions exist (12,2 kb/s for instance, see mapping of Configuration Parameters Sub-clause 8.4.1.5)

8.4.1.2 Config_Prot field

This field serves for the Configuration Protocol on the Abis/Ater interface and the A interface in both directions to indicate the source and meaning of the configuration parameters. It is defined in the UL TRAU frames, in DL TRAU frames and in TFO frames.

Table 14: Coding of the Config_Prot

Config_Prot B0.B1.B2	**Name**	**Exists on**	**Meaning**	**sent by**	**recipient**
0.0.0	No_Con	UL, TFO frame, DL	No configuration included, receiver shall not acknowledge		
0.0.1	Con_Req	UL, TFO frame, DL	local configuration	BTS in UL	Distant BTS Or Local TRAU
0.1.0	Dis_Req	DL	(subset of) distant configuration	TRAU in DL	Local BTS
0.1.1	Con_Ack	UL, TFO frame, DL	ackowledge Con_Req	Loc/Dist BTS	Dist/Loc BTS
1.0.0	Ratscch Req	UL, TFO frame, DL	Distant side do a ratscch in your ul with this ACS	Local BTS	Distant BTS
1.0.1	UL_Ack	UL	acknowledge Dis_Req	Local BTS	Local TRAU
1.1.0	DL_Ack	DL	acknowledge Con_Req	TRAU in DL	Local BTS
1.1.1	spare	-	for future use		

For the mapping of these bits on TRAU/TFO frames, see sub-clause 8.4.1.5
For the use of the Config_Prot, see sub-clause 8.6

8.4.1.3 Message_No Field

The Message_No is used to mark a configuration request message at sender side in order to bind the acknowledge from the receiver side.

It is two bits long, N0 & N1. For the mapping of these bits on TRAU/TFO frames, see sub-clause 8.4.1.5

8.4.1.4 Configuration Parameters Field

The configuration parameters are:

TFO Configuration:
TFOE: TFO Enable
ACF: AMR_Codec_Flag
CL: Codec_List
PCT: Preferred_Codec_Type
Sys_ID: System_Identification

AMR Configuration:
ACS/UCT: Active_Codec_Set/Used_Codec_Type

SCS-F: Supported_Codec_Set for AMR-FR
MACS-F: Max_Codec_Modes for AMR-FR
SCS-H: Supported_Codec_Set for AMR-HR
MACS-H: Max_Codec_Modes for AMR-HR
Ver: TFO standard version number
ADAPE: Adaptation Enable

The coding of the configuration sub-fields is

TFO enabled (TFOE):
Bit P1 set to 0: TFO disabled; set to 1: TFO enabled.
By this bit set to 1 the BTS enables the TRAU to perform TFO negotiation and to go into Tandem Free Operation (TFO), if possible. Respectively, if this bit is set to 0, the TRAU shall terminate TFO as soon as possible and shall not initiate or respond to any TFO negotiation message.

AMR_Codec_Flag (ACF) :
Bit P2 set to 0: Used_Codec is not AMR; set to 1: Used_Codec is AMR.
In uplink this bit is always set to 1. In downlink, if the TRAU reports the configuration of the remote TFO partner, then this bit may be set to 0, indicating that the remote partner is TFO capable, but does not use the AMR currently.

Codec_List (CL):

Bit P3	Full Rate Codec
Bit P4	Half Rate Codec
Bit P5	Enhanced Full Rate Codec
Bit P6	Adaptive Multi Rate Codec, full rate traffic channel
Bit P7	Adaptive Multi Rate Codec, half rate traffic channel
Bits P8 to P14	Reserved for future use, set to "0"
P15	Set to "0". Extension bit. To extend to another codec list, for future use.

Preferred_Codec_Type (PCT):
Bits P16 to P19:

0.0.0.0 Full Rate Codec
0.0.0.1 Half Rate Codec
0.0.1.0 Enhanced Full Rate Codec
0.0.1.1 Adaptive Multi Rate Codec, full rate traffic channel
0.1.0.0 Adaptive Multi Rate Codec, half rate traffic channel
1.1.1.1 No Preferred_Codec

All other codes Reserved for future use.

System_Identification (Sys_ID):
Bits P20 to P27:

0.0.0.0 . 0.0.0.0 "GSM" is sending this frame. Other codes may be defined in future to identify the (remote) TFO partner system (e.g. IS-136, UMTS).

CRC_A (P28 to P30): 3-bit CRC over the bits P1 to P27 (see sub-clause 6.3).

Used_Codec_Type (UCT):
The Used_Codec_Type is defined, if ACF is set to 0 (i.e. the Used_Codec_Type is not AMR).

Bits P31 to P34:

0.0.0.0 Full Rate Codec
0.0.0.1 Half Rate Codec
0.0.1.0 Enhanced Full Rate Codec
0.0.1.1 not used here (Adaptive Multi Rate Codec)
all other codes reserved for future use

Bits P35 to P38 are reserved for future use and are currently set to "1.1.1.1".

Active_Codec_Set (ACS) (see GSM 05.09):
The Active_Codec_Set is defined, if ACF is set to 1 (i.e. the Used_Codec_Type is AMR).

P31 Codec_Mode 12,2 kbit/s
P32 Codec_Mode 10,2 kbit/s
P33 Codec_Mode 7,95 kbit/s
P34 Codec_Mode 7,40 kbit/s
P35 Codec_Mode 6,70 kbit/s
P36 Codec_Mode 5,90 kbit/s
P37 Codec_Mode 5,15 kbit/s
P38 Codec_Mode 4,75 kbit/s

If one of these bits is set, then the corresponding Codec_Mode is in the Active_Codec_Set. Max_Codec_Set defines the maximum number of these eight bits that may be set. These 8 bits are at the same position as UCT bits. The ACF indicates if these 8 bits are UCT or ACS.

Supported_Codec_Set for AMR-FR (SCS-F):
The Supported_Codec_Set for AMR-FR is defined as follows:

P39 Codec_Mode 12,2 kbit/s
P40 Codec_Mode 10,2 kbit/s
P41 Codec_Mode 7,95 kbit/s
P42 Codec_Mode 7,40 kbit/s
P43 Codec_Mode 6,70 kbit/s
P44 Codec_Mode 5,90 kbit/s
P45 Codec_Mode 5,15 kbit/s
P46 Codec_Mode 4,75 kbit/s

All these bit shall be set to 0 when AMR-FR is not supported.

If one of the bits is set, then the corresponding Codec_Mode is in the Supported_Codec_Set. The number of Codec_Modes in the SCS-F may be up to eight. This field allows considering implementation restrictions in a given BSS.

Maximum number of codecs in the Active Codec Set for AMR-FR (MACS-F):
The Max_Codec_Modes is defined, if ACF == 1 (i.e. the Used_Codec_Type is AMR). Otherwise all bits are reserved for future use and shall be set to "0.0" meanwhile.

P47..P48:

0.0 maximally four Codec Modes are allowed in the Active_Codec_Set
0.1 maximally one Codec Mode is allowed
1.0 maximally two Codec Modes are allowed
1.1 maximally three Codec Modes are allowed.

This field allows considering implementation restrictions in a given BSS.

Supported_Codec_Set for AMR-HR (SCS-H):
The Supported_Codec_Set for AMR-HR is defined, if ACF == 1 (i.e. the Used_Codec_Type is AMR).

P49 Codec_Mode 7,95 kbit/s
P50 Codec_Mode 7,40 kbit/s
P51 Codec_Mode 6,70 kbit/s
P52 Codec_Mode 5,90 kbit/s
P53 Codec_Mode 5,15 kbit/s
P54 Codec_Mode 4,75 kbit/s

All these bit shall be set to 0 if AMR-HR is not supported.

If one of the bits is set, then the corresponding Codec_Mode is in the Supported_Codec_Set. The number of Codec_Modes in the SCS may be up to six. This field allows considering implementation restrictions in a given BSS.

Maximum number of codecs in the Active Codec Set for AMR-HR (MACS-H):
The Max_Codec_Modes is defined, if ACF == 1 (i.e. the Used_Codec_Type is AMR). Otherwise all bits are reserved for future use and shall be set to "0.0" meanwhile.

P55..P56:

0.0 maximally four Codec Modes are allowed in the Active_Codec_Set
0.1 maximally one Codec Mode is allowed

1.0 maximally two Codec Modes are allowed
1.1 maximally three Codec Modes are allowed.

This field allows considering implementation restrictions in a given BSS.

Version Number (Ver) :

P57-P58: 0.0 Version Number 0

This is the version number of TFO standard for the AMR.

Adaptation Enable (ADAPE) :

This bit is spare (set to 1), if CMI is present in the Speech_Frame and not the CMR. By this bit the BTS may disable the Codec_Mode adaptation and freeze the Codec_Mode to the one defined within the CMR field in the same frame (CMR_abs field in case of No_Speech), see GSM 08.60 and 08.61. The TRAU, respectively the distant TFO partner shall not use any other Codec_Mode (except DTX modes, if DTX is enabled). This is especially helpful in handover situations and when the (local) AMR configuration has to be modified.

P59 set to 0: Adaptation is disabled; Code_Mode as commanded by CMR shall be used;

set to 1: Adaptation is enabled;ACS_Change Category (Category):

These two bits give the indication whether the BTS supports Ratscch and whether the BTS can handle it without telling the BSC.

P60..P61:

01: Ratscch is supported and the BTS is allowed to handle it alone by the BSC

10: Ratscch is supporte but the BTS must wait for theBSC agreement to use it.

00: Ratscch is not supported.

CRC_B (P62 to P63) : 3-bit CRC over the bits P31 to P61 (see sub-clause 6.3).

8.4.1.5 Mapping of the Configuration Parameters on 16 and 8 kbit/s TRAU/TFO frames

The following table gives the mapping of the protocol fields for each frame (TRAU/TFO) format:

Table 15: Mapping of the configuration parameters in the TRAU frames

	8 kbit/s			16 kbit/s		
	No_Speech	≤5,9 kbit/s	≥6,7 kbit/s	≤7,95 kbit/s & No_Speech	10,2kbit/s	12,2kbit/s
Config_Prot	D55..D57	D55..D57	#	C14..C16	C14..C16	C14..C16
Message_No	D58..D59	D58..D59	#	C17..C18	C17..C18	C17..C18
TFOE	D64	#	#	C20	C20	C20
ACF	D65	#	#	D1	D1	#
Codec List(1)	D66..D78	#	#	D2..D14	D2..D14	#
PCT	D79..D82	#	#	D15..D18	D15..D18	#
Sys_ID	D83..D90	#	#	D21..D28	#	#
CRC_A	D91..D93	#	#	D29..D31	#(2)	#
ADAPE	D94	#	#	D20	D20	#
ACS / UCT	D95..D102	#	#	D234..D241	D234..D241	#
SCS-F	D103..D110	#	#	D242..D249	D242..D249(3)	#
MACS-F	D111..D112	#	#	D250..D251	D250..D251(3)	#
SCS-H	D113..D118	#	#	D226..D231	#	#
MACS-H	D119..D120	#	#	D232..D233	#	#
Ver.	D121..D122	#	#	D252..D253	D252..D253	#
Category	D50..D51	#	#	D224..D225		
Spare (for future use)	#	#	#	D19	D19	#
CRC_B	D123..D125	#	#	D254..D256	#(4)	#

The bit positions refer to the 08.60 and 08.61: D bits are data bits, C bits are control bits.

The ordering implied in the previous descriptions (see sub-clauses 8.4.1.2, 8.4.1.3 and 8.4.1.4) corresponds directly in the ordering of the mapping of table 12, e.g. B0 on D55, B1, D56 and B2 on D57.

(1) When the PCT (Preferred Codec) is indicated, i.e. the disabling code 1.1.1.1 is not used, then the Codec List shall contain the list of alternative preferred codecs (see clause 6 and sub-clause 11.3).

(2) D93..D95 are already used for the CRC of the first subframe. The bits protected by CRC_A are actually protected by CRC1 (see GSM 08.60).

(3) When the Codec_List flags only one of the two possible AMR channel modes, the SCS-F and MACS-F fields shall be used for this mode. If it is AMR-H then the two upper modes (12,2 and 10,2) are never flagged in the SCS-F.

(4) D254..D256 are already used for the CRC of the fourth subframe. The bits protected by CRC_B are actually protected by CRC4 (see GSM 08.60).

Note for the 8 kbit/s frames: Only the “No_Speech” frames convey parameters. Thus, a speech frame has to be stolen every time this information has to be sent. The frames with a rate lower or equal to 5,9 kbit/s can convey the Config_Prot, for example to acknowledge without stealing a frame.

Note for the 16 kbit/s frames: All the parameters are included in the rates below or equal to 10,2 kbit/s (except the Sys_ID, SCS-H and MACS-H fields for the 10,2 kbit/s). The 12,2kbit/s conveys TFO enable and the Config_Prot only. Thus a frame must be stolen to send configuration parameters except if only the Config_Prot can be used (to acknowledge for example).

8.4.2 Status of the Connection

8.4.2.1 Status Messages

The TRAU shall inform the BTS of its status with three messages:

- TFO_Off TFO is not established.
- TFO_Soon TFO is likely to be established.
- TFO_On TFO is established and ongoing.

The BTS shall inform the TRAU with one message

- Handover_Soon Handover is to be expected soon.

8.4.2.2 Notification of Status of Connection

The Messages "TFO_Soon", "TFO_On" and "TFO_Off" are sent by the Tx_TRAU within the Time Alignment Field.

The BTS shall acknowledge the correct receipt by sending the received message back to the TRAU. If the TRAU does not get a correct acknowledgement within *N_out* frames, then it shall repeat the message. *N_out* shall be initialised at resource allocation to [4], but shall be adapted to the round trip delay between TRAU and BTS during the connection.

The Message “Handover_Soon” is sent by the BTS to the TRAU within the Time Alignment. The TRAU shall acknowledge by sending the received message back if TFO is not ongoing. *N_out* is set to 10. It should be adapted according to the round-trip delay. The TRAU doesn't acknowledge if "Handover_Soon" is received in the TFO frame, it relays it to the BTS. The BTS shall not acknowledge the receipt of Handover_Soon.

The Time Alignment Field is used for several purposes, including Time Alignment Request and Acknowledgement. The TRAU and BTS may initiate requests independently and uncoordinated. In case of conflicts the following priority shall be obeyed: Acknowledgements shall always have higher priorities than requests. With other words: an ongoing exchange shall first be terminated before a new one is started.

In case of ongoing TFO all uplink TRAU frames shall be relayed with minimal delay onto the A interface as TFO frames. Likewise the received TFO frames shall be relayed as TRAU frames down to the BTS. The time alignment field of the TFO frames shall be ignored.

Note that the TFO_State may have impact on the way In_Call_Modification and handover should be performed. Further, if TFO_On is signalled, the TRAU must not follow the Codec_Mode_Commands sent by the BTS uplink directly, but shall relay the CMC in the TFO frames.

8.5 The TFO_BTS and TFO_BSC dialogue

This sub-clause addresses AMR case only.

The BTS and the BSC exchange messages through Layer 3 signalling. The BTS is also in contact with the TRAU and extracts the information sent by the TRAU in the TRAU frames. These pieces of information are afterward sent to the BSC. The layer 3 messages are specified in GSM 08.58.

Reciprocally the BTS relays information received from the BSC toward the TRAU within the TRAU frames.

8.5.1 BSC to BTS messages

The BSC at Channel activation informs the BTS of the local codec configuration. It enables or disable TFO too. It can also delegate the MS ACS modification to the BTS (MultiRate Control).

The BSC can enable or disable TFO at any moment during a call whether TFO is ongoing or not (TFO MODIFICATIONREQUEST).

The BSC shall inform the BTS of any change of the local configuration if the Codec Mismatch resolution and/or AMR optimization is supported.

The BSC should notify to the BTS when an handover procedure is about to be launched (PRE-HANDOVer NOTIFication). It should also notify the BTS is the handover procedure has failed launched (PRE-HANDOVer NOTIFication).

8.5.2 BTS to BSC messages

The BTS should report to the BSC the status of the TFO, i.e. when TFO starts and stops (TFO REPort).

The BTS should report the Round trip delay it has estimated (Round Trip Delay REPort). It should report it every time a significant change (e.g. 60 ms) is detected in the round trip delay (see sub-clause 8.2.4).

The BTS shall report to the BSC the distant codec configuration (REMOTE CODEC CONFiguration REPort). It shall report any modification of this configuration if the Codec Mismatch resolution and/or AMR optimization is supported.

8.6 Configuration Parameter Exchange on Abis/Ater and A Interfaces for AMR

The TFO Speech Service Configuration parameters for TFO are sent from the BSC via the BTS to the TRAU;

The following block diagram is intended for guidance only. If no TFO is ongoing, then the Config_Prot ends always in the (local) TRAU. If TFO is ongoing, then a mirrored (distant) BSS´ exists. Between the local TRAU and the distant TRAU´ an unknown transit network exists, which is transparent for the TFO Messages and the TFO Frames, but may contain devices involved in the TFO connection (e.g. TFO specific Circuit Multiplication Equipments, TCMEs, for cost efficient transmission).

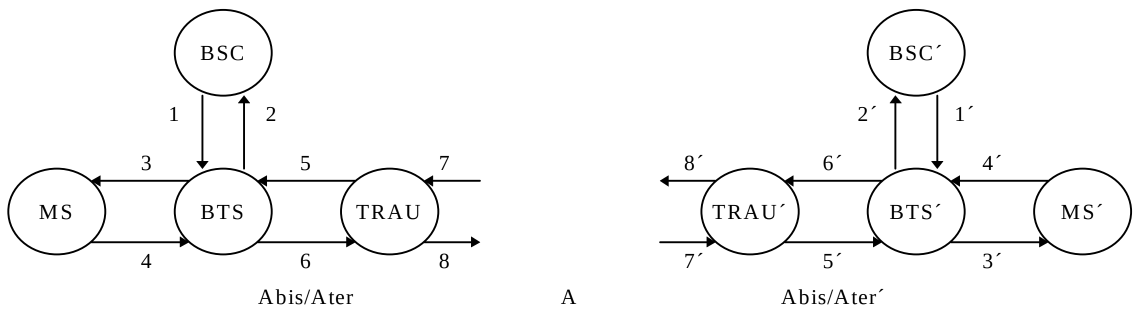


Figure 12: Block diagram of the transmission paths for the exchange of Configuration Parameter

The Configuration parameters received from the BSC (1) shall be sent uplink to the TRAU by inband signalling. on the Abis/Ater interface (6). In most Codec_Modes the TRAU speech frames have sufficiently spare capacity to transmit these configuration parameters in addition. Otherwise a No_Speech frame (mainly a No_Data Frame) shall be used, i.e. a speech frame shall be stolen. No_Data Frames are naturally used at call setup or after handover.

8.6.1 Protocol for the Exchange of Configuration Parameters

A simple protocol is defined to ensure correct receipt. It uses the ***Config_Prot*** field to code a Request or Acknowledge message and the ***Message_No*** field to bind Request and Acknowledge together. Both are defined in sub-clauses 8.4.1.2 and 8.4.1.3.

All Requests have defined configuration parameters, while the Acknowledgements have none. If no configuration is to be exchanged, then the Config_Prot field shall be set to "No_Con". In this case the configuration parameter field is undefined. The receiver shall not acknowledge a No_Con message.

The configuration exchange shall start always with a Request from one side and shall end with an Acknowledgement from the other side. If the Acknowledgement is not received before *N_Out* frames are elapsed, then the Request shall be repeated. *N_Out* is at resource allocation initialised (e.g. *N_Out* := 4), but shall be adapted to the round trip delay during the connection (see sub-clause 8.2.5).

The sender of the Request shall always use a new Message_No, e.g. by incrementing a counter. The receiver shall acknowledge by sending the appropriate Acknowledge_Code and the received Message_No back, if the Request was received without detectable errors. Otherwise, in case of detected errors, it shall not acknowledge, but wait for a repetition.

Typically no new request shall be sent before the previous configuration exchange is terminated. Exceptions exist at Resource Allocation, because it is not clear if and when the path between BTS and TRAU is connected through.

8.6.2 Initial Configuration at Resource Allocation

The BTS shall send "Con_Req" Messages. Typically at resource allocation no speech is received from the air interface or at least some FACCH arrive. Therefore "No_Data" frames are used. The local TRAU acknowledges with "DL_Ack".

As long as No_Speech frames are sent in uplink direction the BTS shall increment the Message_No and send the configuration in every new frame, until a DL_Ack is received, i.e. the TRAU is synchronized. The exchange is considered as terminated, when the last sent Message_No is received back.

If, however, already speech frames are received in uplink direction from the air interface before the TRAU is synchronized then appropriate speech frames shall be sent. If the configuration parameters can be included in these speech frames (e.g. as for all Codec_Modes below 12,2 kbit/s in 16 kbit/s sub-multiplexing), then the procedure is exactly as described for No_Speech frames. If, however, the configuration parameters cannot be included, then every 4th speech frame shall be stolen on the Abis/Ater interface and be replaced by a No_Speech (No_Data) frame to transmit the configuration.

8.6.3 Distant Configuration before TFO is established

After call set-up the TRAU may try to establish a TFO connection by using the TFO Protocol. During that time and before TFO is established the TRAU may get already knowledge about the distant configuration.

If distant and local configurations allow TFO then the TRAU shall immediately send DL the distant configuration parameters to its BTS by using "Dis_Req" together with TFO_SOON.

Otherwise the distant configuration parameters shall be sent DL when the information required for Codec Type and/or ACS mismatch resolutions are available.

"Dis_Req" shall be used by the TRAU to transmit DL the configuration parameters.

8.6.4 Configuration Exchange in TFO

If TFO is ongoing (the BTS is informed about that, by TFO_On, see sub-clause 8.4.2) then the configuration sent by the BTS with Con_Req shall be relayed through by the local TRAU and the distant TRAU´ down to the distant BTS´. All devices in the path (TRAUs, but maybe also others, e.g. TCMEs) are updated to the new configuration. The remote BTS´ shall acknowledge this by "Con_Ack". This takes the same way back. The exchange shall be considered terminated when the originating BTS received the Con_Ack.

Note: The round trip delay in TFO connections shall be considered.

TFO messages with the same piece of information will be transmitted in parallel. In case of discrepancy between the Config_Prot and the TFO messages, the former shall have precedence.

State Machine of the TFO_Protocol Process

A State Machine, consisting of 15 States can describe the TFO_Protocol Process: five main States with several sub-States:

Initialisation (• Not_Active, • Wakeup).

Establishment (• First_Try, • Continuous_Retry, • Periodic_Retry, • Monitor, • Mismatch).

Contact (• Contact).

Konnect (• Konnect).

Operation (• Operation).

Exception handling needs further States (see figure 14):

Local Handover (• Fast_Try, • Fast_Contact).

Distant Handover (• Sync_Lost, • Re_Konnect).

Misbehavour (• Failure).

It is assumed that Events (Conditions checking, Actions and Transition to another State) are handled almost instantaneous and in any case significantly shorter than the time required completing the transmission of any one TFO Message or TFO Frame.

The enabling of the TFO_Protocol is manufacturer specific in the case of FR, HR and EFR speech services. It is assumed in this specification that the TFO is enabled per default for the mentioned speech services. In case of AMR speech service it is explicitly enabled or disabled from the BTS by seting or reseting theTFOE flag (see sub-clause 8.4.1.4). In case of AMR the default state is disabled.

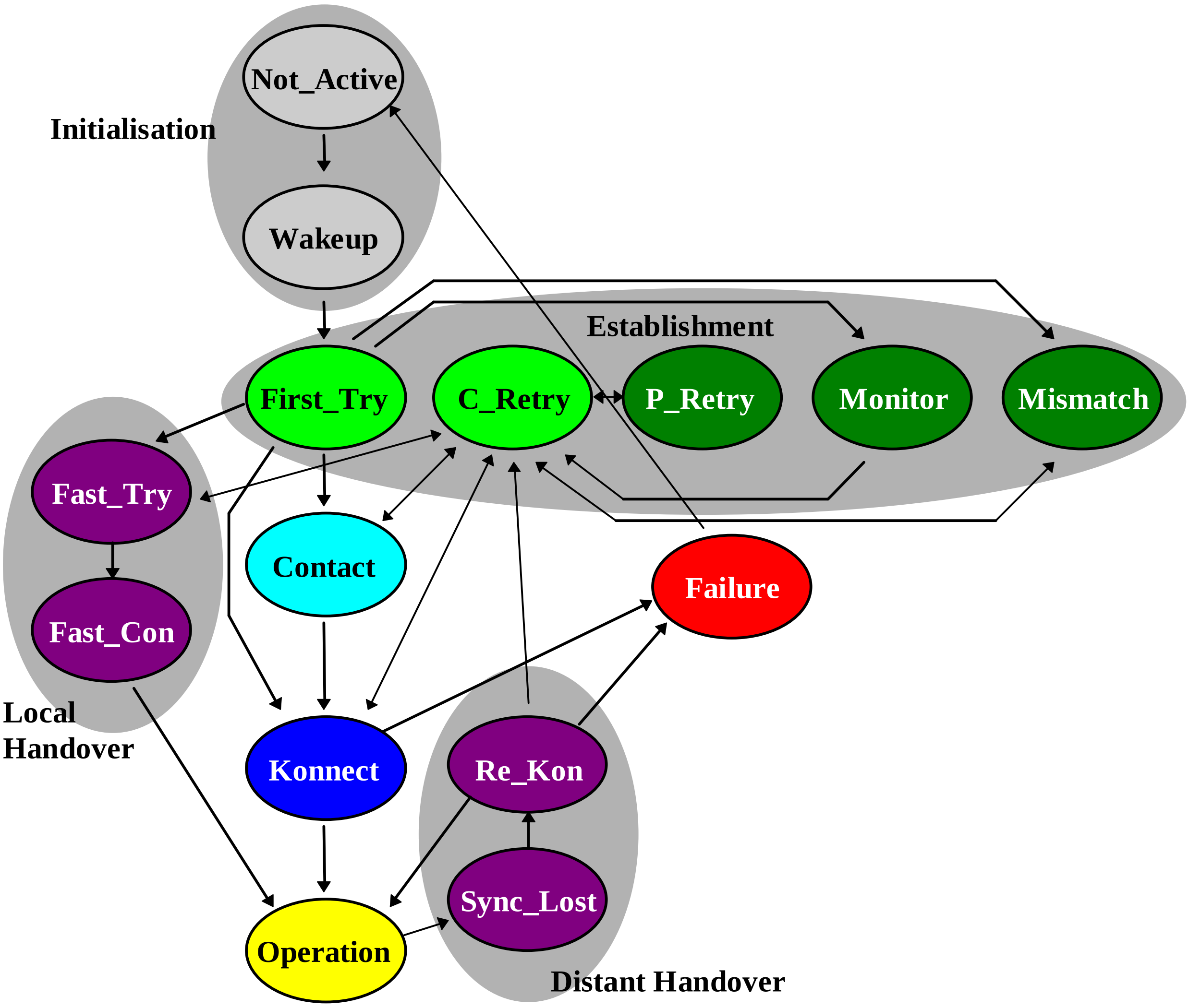


Figure 13: TFO_Protocol State Machine with most important transitions

Initialisation

Not_Active State

The TRAU in Not_Active receives and sends the PCM_Idle patterns from and onto the A interface. Similarly, it receives and sends Abis_Idle patterns from and onto the Abis/Ater interface. This is not described further.

The TRAU may also be in Data mode, which is also not described further, but is handled here as "Not_Active".

If PCM_Non_Idle patterns are received prior to TRAU Speech Frames, then these PCM_Non_Idle patterns shall be ignored - even if they contain possibly TFO Messages.

Wakeup State

The Wakeup State is entered, when the TRAU is activated by receiving uplink TRAU Speech Frames on the Abis/Ater interface, or when TFO is disabled. The TRAU then sends corresponding decoded PCM samples onto the A interface.

If TRAU Speech Frames are received, then the decoded PCM samples are sent to the A interface. If the TRAU receives PCM_Idle patterns from the A interface this Wakeup State may last for some while, until the normal (tandem) call connection is established and, PCM_Non_Idle samples are received. If the TFO is disabled when PCM_Non_Idle patterns are received, TRAU shall stay in Wakeup State and shall wait for the TFO_Enable command.

If the TFO_Enable command is received, but PCM_Idle are received from A interface, the TRAU shall stay in Wakeup state and shall wait for PCM_Non_Idle samples.

The transition to Establishment is performed, if TRAU Speech Frames PCM_Non_Idle patterns are received and TFO is enabled. This is the point in time where the time out for TFO Messages starts, i.e. a maximum number of TFO_Req Messages shall be sent after that.

Establishment

The Establishment summits several slightly different situations:

First_Try when the TRAU just has started; it sends TFO_REQ Messages continuously;

Continuous_Retry when Contact to a TFO Partner has existed but was interrupted recently;

Periodic_Retry when Contact to a TFO Partner had existed but was interrupted some time ago;

Monitor when no TFO partner could be found, but the TRAU continues to monitor the A Interface;

Mismatch when a TFO partner with a different Codec type (respectively ACS mismatch in case of AMR) has been identified.

Loopback is a specific situation, when the call is still not through connected and the TRAU receives the own sent signals. No specific State is allocated to describe this situation. Instead, loopback is handled in First_Try and Continuous_Retry.

Common to all these situations is that the TRAU does not know, if there is a distant TFO partner and/or if the links are digitally transparent. Typically, TFO_REQ Messages are sent and expected.

Due to handover cases it might, however, happen that a TRAU is initialised into an existing connection and therefore the other TFO Partner may be in any State and all other TFO Messages may be received, too.

Especially important is, when TFO Frames are received, since then it can be assumed that an existing TFO Connection was handed over to a newly initialised TRAU and the TFO should be continued - if possible uninterrupted - as soon as possible. The TRAU may see from the TFO Frames the Distant_Used_Codec of a GSM Partner and that the receiving path is digitally transparent, but it can not assume that the path to the other TRAU is also (already) transparent. TFO_Protocol enters the exceptional State: Fast_Try, sending a specific, short TFO_DUP Message to test the other direction.

First_Try State

The TRAU sends and receives PCM samples on and from the A interface. Regular TFO_REQ Messages are sent onto the A interface continuously for a certain maximum time. After that, if no TFO Partner answers before, Tx_TFO reports a Runout of TFO Messages, and TFO_Protocol enters automatically into the Monitor State.

If TFO_REQ Messages are received with the same, own Signature, then a circuit loop back is assumed, i.e. the call is still not through connected. The TRAU selects a new Signature and continues sending TFO_REQ Messages, until a different Signature is received. Since loop back delays may be substantial in some cases, the TRAU has to remember and compare also the previously selected own Signature. Care has to be taken that the Signature selection contains a true random element to avoid that two different TRAUs select by coincidence identical signatures again and again.

Continuous_Retry State

TFO Contact had existed, either by TFO Messages or by TFO Frames, but was interrupted and sync was lost. The TRAU sends a maximum number of regular TFO_REQ Messages continuously, to test, if TFO could be re-established. If Tx_TFO reports a Runout of TFO Messages, then the TFO_Protocol enters the Periodic_Retry State.

Periodic_Retry State

Entered from Continuous_Retry, TFO_Protocol tests from time to time by a single TFO_REQ_L, if TFO could be re-established. As soon as a TFO Message is received, TFO_Protocol leaves this State.

NOTE: Since no contiguous transmission of TFO Messages is ongoing, possible IPEs may be unsynchronized.

Monitor State

The TRAU monitors the A interface for TFO Messages or TFO Frames, but it does not send TFO Messages or TFO Frames. As soon as a TFO Message from a distant partner (a TRAU or a TCME) has been received, the TRAU knows that a TFO Partner exists and it knows that the transmission path from the partner is digitally transparent.

The TRAU may already now see, whether TFO is possible, but it must ensure that all IPEs are synchronised. It therefore transits into the Continuous_Retry State. In case of Codec Mismatch (respectively ACS mismatch in case of AMR), it terminates the TFO Protocol by sending TFO_REQ_L back, informs its local BSS and transits into Mismatch.

NOTE: Since no contiguous transmission of TFO Messages is ongoing, possible IPEs may be unsynchronized.

Mismatch State

From a previous contact it is obvious, that a distant TFO Partner exists, but the Codecs do not match.

The TRAU waits without sending TFO Messages or TFO Frames, if either the distant TFO Partner changes to the Local_Used_Codec, or the local BSS solves the Codec mismatch(respectively ACS mismatch in case of AMR) situation by an intra cell handover to the Distant_Used_Codec or a change of ACS in case of AMR.

NOTE: Since no contiguous transmission of TFO Messages is ongoing, possible IPEs may be unsynchronized.

Contact State

There is a distant TFO Partner, which has sent TFO_REQ. The Codecs do match and the ACSs are correct (see subclause 12.5.3). The link from the distant partner is transparent. Now TFO_ACK need to be sent to check the transparency of the link to the distant partner.

As soon as a TFO_ACK or TFO_TRANS from a distant partner has been received, the TRAU knows that the links in both directions are digitally transparent. The TRAU sends TFO_TRANS to bypass the IPEs and starts sending TFO Frames. It transits into Konnect State.

Konnect State

The TRAU sends TFO Frames and possibly embedded TFO Messages as long as it receives correct TFO Messages.

The first received TFO Frame causes the transition into the final Operation State.

If no TFO Frames are received within a certain period, the TRAU transits to the Failure State.

Operation State

In this State - the Main State of TFO_Protocol - the TRAU sends and receives TFO Frames, thus the TFO Connection is fully operating. TFO Messages may occur embedded into TFO Frames.

Local Handover

Fast_Try State

When the TRAU in First_Try receives suddenly TFO Frames and the Codecs do match. (the ACSs must be correct also in case of AMR, see subclause 12.5.3), then there is a high probability that a local handover has initialised the TRAU into an existing TFO connection and a fast TFO establishment is likely. The TFO_Protocol has still to check, whether the link to the distant TFO Partner is (already) transparent. This is done by the specific TFO_DUP Message.

Since the handover must have been a local handover, i.e. close to the (new) TRAU, it can be assumed that the possibly existing IPEs are still in transparent mode and TFO Messages therefore pass through directly.

Fast_Contact State

This State is entered from First_Try via Fast_Try, if TFO Frames and then TFO_SYL Messages are received. The TRAU continues to send TFO_DUP Messages, until TFO Frames are received again. Then it immediately starts to send TFO Frames, with a TFO_TRANS embedded into the first TFO Frames. The TRAU transits directly to Operation State.

Distant Handover, TFO Interruption

Sync_Lost State

If the TRAU was in Operation State and suddenly the TFO Frame synchronisation is lost, then the TRAU enters the Sync_Lost State for a short while, before it transits to Continuous_Retry.

If synchronisation was lost due to a distant handover, then a fast TFO establishment might be possible and the TRAU enters Operation State soon again. In Sync_Lost it expects TFO_DUP Message as confirmation of the distant handover. Then it transits to Re_Konnect.

Re_Konnect State

This State is entered from Operation via Sync_Lost, if TFO_DUP Messages are received. The TRAU starts immediately to send TFO Frames again, with a TFO_TRANS embedded into the first TFO Frames. The TRAU transits back to Operation State, as soon as TFO Frames are received, again.

Failure State

This State is entered when the distant partner shows an incorrect behaviour. The TRAU then sends pure PCM samples onto the A interface and waits for the failure to disappear. It does not send TFO Frames or TFO Messages.

Detailed Description of TFO_Protocol

The TFO_Protocol Process is always in one well-defined State. An Event triggers Actions and a Transition into another State. The TFO Protocol is described in a table-wise manner, with syntax as defined in table 16.

Table16: Definition of the Syntax for the State Machine Description

Event: Number:	<Received Message> <running number>	…	<Other Event> <running number>
Condition: &	[<Condition>] [<Condition>]		[<Condition>] [<Condition>]
Comment: **State:**	[<Comment>]		[<Comment>]
<Actual State>:	<Action Name>;[<Action Name>;] <Next State>; [<Comment>]		<Action Name>;[<Action name>;] <Next State>; [<Comment>]
…			
<Actual State>:	<Action Name>;[<Action Name>;] <Next State>; [<Comment>]		<Action Name>;[<Action Name>;] <Next State>; [<Comment>]

Several tables, table 19 to table 31, are necessary to describe the whole State Machine.

The Actions are described in table 18, with syntax as defined in table 17.

Table 17: Definition of Syntax for Action Table

Name	Action List	Comment
<Action Name>	<Action >;[<Action >;]	<Comment>
…		
<Action Name>	<Action >;[<Action >;]	<Comment>

Tx := TFO_REQ means, that TFO_Protocol places a command into Tx_Queue. Tx_TFO handles the details autonomously and generates a TFO_REQ Message for transmission over the A interface, when it comes to that command.

Tx := 31*TFO_REQ means: put 31 TFO_REQ commands into Tx_Queue. Not necessarily all will really trigger TFO_REQ Messages. In most cases Tx_Queue will be cleared before. Similar definitions hold for the other messages.

The Tx_Queue is a first_in_first_out command queue. It is filled by TFO_Protocol and read by Tx_TFO.

Clear Tx_Queue, means that all remaining commands are deleted from the Tx_Queue in that very moment (time *Tc*).

Note that due to the duration time to transmit a TFO_Message completely, the TFO_Protocol Process is often already within a different State while still TFO Messages commanded in earlier States are within the Tx_Queue or under transmission.

BSS := TFO () means that a message is sent to the local BSS; similar

Tx_TRAU := … means a message to Tx_TRAU.

An Event **TFO_REQ** means that a TFO_REQ Message was correctly received on the A interface. The Rx_TFO Process has sent a message to TFO_Protocol, containing the new values for the respective variables. TFO_Protocol updates its variables with the new values. Similar definitions hold for the other messages.

One Timer **T := <Time_out>** is necessary to describe time out situations. The notation **T := DIS** means that the Timer is disabled. Positive values are decremented in an hidden background process in steps of 20 ms. When T gets to the value "0", then the TFO_Protocol process is invoked.

TxTFO := TFO_Frame_16k means that TxTFO shall send TFO frames within 16 kb/s format.

TxTFO := TFO_Frame_8k means that TxTFO shall send TFO frames within 8 kb/s format.

Local_Used_Codec (short form: **Luc)** means the type of speech Codec used in the local TRAU and BSS (e.g. FR, EFR, HR).

New Local_Used_Codec (Nluc) refers to the new codec received in "In_Call_Modifications".

Distant_Used_Codec (Duc) means the type of speech Codec used by the distant partner, as reported in TFO_REQ… or TFO_ACK… (e.g. FR, EFR, HR).

Distant_Preferred_Codec (DPC) means the type of speech Codec that the distant partner would prefer, as reported in TFO_REQ_P (e.g. FR, EFR, and HR).

Local_Codec_List (LCL) means the list of all Codecs that could alternatively be used, i.e. that are supported by both the local MS and the local BSS. It always contains at least the Local_Used_Codec.

It is reported in TFO_REQ_L, TFO_ACK_L or TFO_REQ_P.

Distant_Codec_List (DCL) means the list of all Codecs that could alternatively be used, i.e. that are supported by the distant MS and the distant BSS. It always contains at least the Distant_Used_Codec.

All these variables are initialized to **UNKNOWN**, which means that the contents of the variables are not defined.

Local_Signature (Lsig) means the 8-bit random number in TFO_REQ, which identifies the local TFO_REQ Messages. It is also used in TFO_REQ_L.

Distant_Signature (Dsig) means the 8-bit random number as received in TFO_REQ, TFO_REQ_L and TFO_REQ_P,

in TFO_ACK and TFO_ACK_L

If received in TFO_REQ, TFO_REQ_L and TFO_REQ_P, then it should be different to the Local_Signature, otherwise loop back must be assumed (exceptions exist).

If received in TFO_ACK or TFO_ACK_L, then it should be identical to the Local_Signature, otherwise the TFO_ACK is not a response to an own TFO_REQ respectively TFO_REQ_L, but maybe was created during an handover situation.

Local Channel Type (LCh) and **distant Channel Type (DCh)** refer to the 8 or 16 kbit/s transparent channel used by the local Tx_TFO respectively received by the distant TFO_TRANS.

Error protection and error handling: It is assumed that the defined error protection is strong enough for the error rates encountered on typical A interface links. The few occuring errors are in practically all cases detected and possibly even corrected by Rx_TFO, before reported to TFO_Protocol. Therefore TFO_Protocol can rely on the correctness of the received Events. The protocol is, however, "selfhealing" and will handle the unlikely erroroneous reported Events, too.

TFO_Enable is given in that moment when the TFO parameters are available and the TFOE bit of AMR TRAU frames is set to 1. The condition TFO_Enabled is then True.

TFO_Disable is when TFOE bit of AMR TRAU frames toggles from 1 to 0. The condition TFO_Enabled is then False.

The Event "**PCM_Non_Idle**" is given if in State Wakeup, if more than one PCM samples that are received are different to PCM_Idle. The condition PCM_Non_Idle is then True.

Fast Handover handling: The defined protocol assumes that the new TRAU, to which the handover is performed, is already in State Wakeup before the A-Interface is switched to that TRAU. Only then the TFO Frames can be received by that TRAU and fast handover handling is possible.

Timing: If two Events occur by coincidence at the same time, then they shall be processed in the order given by the tables 19 to 31 (left to right). TFO Messages arrive always some time before the embedding TFO Frame and shall be handled therefore first.

Runout is the Event, when the last TFO Message has been taken from the Tx_Queue and the last 10 bits are going to be sent by Tx_TFO to the A interface. So there is still some time for TFO_protocol to react and place a further TFO Message into Tx_Queue, which then shall be transmitted without gap to the messages before.

Category (ACS_Change_Category) is the way BTS can handle ACS change with ratscch (see subclause 8.3.2.2). If ratscch is not supported, category is No_Change, if BTS supports ratscch but BSC has to be informed first, the category is slow, and if ratscch handling is delegated to BTS (see 08.58), category is fast.

ACS_Change is the Event, when ACS indicated in uplink TRAU frames is different from the current ACS. The new ACS is immediately taken into account and shall replace the old one in the actions trigerred by this event.

Switch_16_8 is the Event, when TFO frames (in TFO operation) are mapped onto 16kb/s and ACS change so that all modes can now be mapped onto 8kb/s TFO frames , i.e. all rates of CACS are below or equal 6.7 kb/s. A TFO TRANS message shall be sent to inform IPEs of the change. If the TRAU frames are on an 16 kb/s Abis link, the TRAU needs to convert them into 8kb/s TFO frames after the switch.

Switch_8_16 is the Event, when TFO frames are mapped onto 8kb/s and ACS has changed in TFO operation so one mode is more than 6.7 kb/s. TFO frames needs to be mapped onto 16kb/s. A TFO TRANS message shall be sent to inform IPEs of the change. If the TRAU frames are on an 8 kb/s Abis link, TRAU needs to convert them into 8kb/s TFO frames.

When AMR is supported, the following terms are defined:

> **LSCS**: The set of supported codecs for a given radio channel (FR or HR) on the local side. It is only defined when AMR is supported on the local side.
> **DSCS**: The set of supported codecs on the distant side. It is only defined when AMR is supported on the distant side.
> **CSCS**: The common supported codec set is defined in subclause 12.

When AMR is active on one or both side, the following terms are defined:

> **LACS** : The set of active codecs on the local side, only defined when AMR (FR or HR) is active on the local side.
> **DACS**: The set of active codecs on the local side, only defined when AMR (FR or HR) is active on the distant side.
> **CACS**: The Common Active Codec Set is defined in subclause 12.
> **OACS**: Optimized Active Codec Set is defined in subclause 12.

The contiguity rule is explained in subclause 12.5.3.

Table 18: Defined Actions

Name	Actions	Comments
C	Clear Tx_Queue; T := DIS;	Initialise Tx_Queue and disable the timer
T1	T := 1s;	Set Timeout to 1 second
T2	T := 2s;	Set Timeout to 2 seconds
T5	T := 5s;	Set Timeout to 5 seconds
NoAc	.	No Action required
S	Lsig := New_Random_Number;	Generate new Signature and set Old_Sig to unknown;
	Old_Sig := UNKNOWN;	if no Loopback is assumed.
SO	Old_Sig := Lsig;	Remember old Signature and generate a new Signature,
	Lsig := New_Random_Number;	if Loopback is assumed.
U	Old_Sig := UNKNOWN;	Reset Old_Sig before leaving FIT or COR
F	Tx := 3*TFO_FILL;	"Hello IPEs! Please synchronise!"
T	Tx := TFO_TRANS ();	"Hello IPEs! Please open a transparent channel!"
N	Tx := TFO_NORMAL;	"Hello IPEs! Please return to normal operation!"
REQ	Tx := 35*TFO_REQ;	“Hello Partner? Can You do TFO with me?”
ACK	Tx := 7*TFO_ACK;	“Yes, I can do TFO with You!”
SYL1	Tx := TFO_SYL;	"Hello Partner! I lost one or more TFO_Frames!"
SYL	Tx := 4*TFO_SYL;	"Hello Partner! Serious interruption of TFO_Frames!"
DUP	Tx := 5*TFO_DUP;	Handover? “Hey, I see Your TFO Frames, Fine!”
L1	Tx := TFO_REQ_L;	"Here is my Codec_List! Can you hear me?"
L	Tx := 6*TFO_REQ_L;	"Here is my Codec_List, please acknowledge!"
LA	Tx := TFO_ACK_L;	"Yes, I received Your Codec_List! Here is mine!"
BT	Tx := Begin_TFO;	Begin Transmission of TFO Frames
DT	Tx := Discontinue_TFO;	Discontinue Transmission of TFO Frames
IT	Tx_TRAU := Ignore_TFO;	Tx_TRAU works as conventional downlink TRAU
AT	Tx_TRAU := Accept_TFO;	Tx_TRAU bypasses TFO_Frames
Lch16	TxTFO := TFO_Frame_16k	TFO frame format is now 16kb/s
Lch8	TxTFO := TFO_Frame_8k	TFO frame format is now 8kb/s
B	BSS := TFO ();	"Hello BSS! Some news from the TFO_Scene!"

Table 19 Cases due to AMR introduction: enabling/desabling

Event:	**TFO_Enable**	**TFO_Disable**
Number:	1	2
Condition: &	PCM_Non_I dle	
Comment: State:	TFO gets active. Allow to begin TFO process	Command from BS_ Stop TFO
NAC: Not_Active .	---------- ----------	NoAc; NAC; .
WAK: Wakeup .	C;F;REQ; FIT; **Typ. 2nd Event**	NoAc; WAK; .
FIT: First_Try .	---------- ---------- .	C;N; WAK; .
COR: Continuous Retry	---------- ---------- .	C;N; WAK; .
PER: Periodic Retry	---------- ---------- .	C;N; WAK; .
MON: Monitor .	---------- ---------- .	C;N; WAK; .
MIS: Mismatch .	---------- ---------- .	C;N; WAK; .
CON: Contact .	---------- ---------- .	C;N; WAK; .
FAT: Fast Try	---------- ---------- .	C;N; WAK; .
FAC: Fast Contact	---------- ---------- .	C;N; WAK; .
KON: Konnect .	---------- ---------- .	C;DT;N; WAK; .
REK: Re_Konnect .	---------- ---------- .	C;DT;IT;N; WAK; .
SOS: Sync_Lost .	---------- ---------- .	C;IT;N; WAK; .
OPE: Operation .	---------- ---------- .	C;DT;IT;N; WAK; .
FAI: Failure .	---------- ---------- .	C; WAK; **Exit from FAI**

Table 20 Cases due to AMR introduction: TFO_REQ

Event:	**TFO_REQ**	**TFO_REQ**	**TFO_REQ**
Number:	3	4	5
Condition: &	Duc==Luc==AMR LACS==CACS Contiguity Rule of DACS is verified Dsig!=Lsig	Duc==Luc==AMR LACS != CACS and contiguity rule of DACS and LACS is verified Dsig!=Lsig	Duc==Luc==AMR contiguity rule is not verified for LACS or for DACS Dsig!=Lsig
Comment: State:	Immediate TFO Setup Good Sig ACS do match Local side ready ; Send ACK	Good Sig No Immediate TFO Tell the BTS	Good Sig No Immediate TFO Tell the BTS Send the SCS + list
NAC: Not_Active .	---------- ---------- .	---------- ---------- .	---------- ---------- .
WAK: Wakeup .	---------- ---------- .	---------- ---------- .	---------- ---------- .
FIT: First_Try .	C;U;ACK; CON; **typical**	T1;B; MIS; **Typical: Setup**	C;U;L;T2;B; MIS; **Typical: Setup**
COR: Continuous Retry	C;U;ACK; CON; typical	T1;B; MIS; .	C;U;L;T2;B; MIS; .
PER: Periodic Retry	C;F;ACK; CON; OK, Contact back	T1;B; MIS; .	C;F;L;T2;B; MIS; .
MON: Monitor .	C;F;REQ; FIT; IPEs?	T1;B; MIS; .	C;F;L;T2;B; MIS; .
MIS: Mismatch .	C;F;ACK; CON; Mismatch resolved	T1;B; MIS; .	C;L;T2;B; MIS; .
CON: Contact .	C;ACK; CON; **typical: wait**	T1;B; MIS; .	C;L;T2;B; MIS; .
FAT: Fast Try	C;REQ; COR; save way	C;T1;B; MIS; .	C;L;T2;B; MIS; .
FAC: Fast Contact	C;REQ; COR; save way	C;T1;B; MIS; .	C;L;T2;B; MIS; .
KON: Konnect .	C;DT;REQ;T1; COR; IPEs transparent!	C;DT;L;T1;B; MIS; .	C;DT;L;T2;B; MIS; .
REK: Re_Konnect .	C;DT;REQ;IT;B;T1; COR; IPEs transparent!	C;DT;L;T1;IT;B; MIS; .	C;DT;L;T2;IT;B; MIS; .
SOS: Sync_Lost .	C;IT;REQ;B;T1; COR; Contact is back	C;L;T1;IT;B; MIS; .	C;L;T2;IT;B; MIS; .
OPE: Operation .	---------- ---------- .	---------- ---------- .	---------- ---------- .
FAI: Failure .	NoAc; FAI; .	NoAc; FAI; .	NoAc; FAI; .

Table 21 Cases due to AMR introduction: TFO_ACK

Event:	**TFO_ACK**	**TFO_ACK**	**TFO_ACK**
Number:	6	7	8
Condition: &	Duc==Luc == AMR Dsig==Lsig Contiguity rule of LACS is not OK or DACS!=CACS	Duc==Luc == AMR Dsig==Lsig LACS == CACS == DACS	Duc==Luc == AMR Dsig==Lsig LACS != CACS contiguity rule for LACS OK DACS==CACS
Comment: State:	Should not happen LACS has changed? HO? Do the same as REQ with mismatch	Good Sig. Immediate TFO possible.	Immediate TFO Setup ACS do not match Tell the BTS Send SCS + list
NAC: Not_Active .	---------- ---------- .	---------- ---------- .	---------- ---------- .
WAK: Wakeup .	---------- ---------- .	---------- ---------- .	---------- ---------- .
FIT: First_Try .	C;U;L;T2;B; MIS; HO?	C;U;T;BT;T;T1; KON; **typical; IPEs!**	C;T1;B; MIS; **Typical: Setup**
COR: Continuous Retry	C;U;L;T2;B; MIS; .	C;U;T;BT;T;T1; KON; **typical; IPEs!**	C;T1;B; MIS; .
PER: Periodic Retry	C;F;L;T2;B; MIS; .	C;F;S;REQ; COR; rare case, test	C;T1;B; MIS; .
MON: Monitor .	C;F;L;T2;B; MIS; .	C;F;S;REQ; FIT; Rare case, test	C;T1;B; MIS; .
MIS: Mismatch .	C;L;T2;B; MIS; .	C;F;S;REQ; COR; rare case, test	C;T1;B; MIS; .
CON: Contact .	C;L;T2;B; MIS; .	C;T;BT;T;T1; KON; **typical: yes!**	C;T1;B; MIS; .
FAT: Fast Try	C;L;T2;B; MIS; .	C;REQ; COR; save way	C;T1;B; MIS; .
FAC: Fast Contact	C;L;T2;B; MIS; .	C;REQ; COR; save way	C;T1;B; MIS; .
KON: Konnect .	C;DT;L;T2;B; MIS; .	NoAc; KON; **Typical: wait**	C;DT;L;T1;B; MIS; .
REK: Re_Konnect .	C;DT;L;T2;IT;B; MIS; .	C;DT;REQ;IT;B;T1; COR; .	C;DT;L;T1;IT;B; MIS; .
SOS: Sync_Lost .	C;L;T2;IT;B; MIS; .	C;IT;REQ;B;T1; COR; Contact is back	C;L;T1;IT;B; MIS; .
OPE: Operation .	---------- ---------- .	---------- ---------- .	---------- ---------- .
FAI: Failure .	NoAc; FAI; .	NoAc; FAI; .	NoAc; FAI; .

Table 22: cases due to AMR introduction: ACS Change

Event:	**ACS_Change**	**ACS_Change**	**Switch_16_8**	**Switch_8_16**	**ACS_Change**	**ACS_Change**	**ACS_Change**

Number:	9	10	11	12	13	14	15
Condition: &	Duc==AMR Contiguity rule of DACS is not OK	Duc==AMR NACS==CACS Contig. Rule of DACS is OK	Duc==AMR NACS == OACS Contig. Rule of DACS is OK	Duc==AMR NACS == OACS Contig. Rule of DACS is OK	Duc==AMR NACS==OACS Contig. Rule of DACS is OK	Duc==AMR (NACS != CACS NACS != OACS) Contig. Rule of DACS is OK	Duc!=AMR
Comment: State:	Mismatch occurs	Local ACS mismatch resolved Send ACK	ACS have changed, 8k TFO frames possible now	ACS have changed, 16k TFO frames necessary now	Optimised ACS: Send ACK	Mismatch occurs	Mismatch occurs
NAC: Not_Active .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .
WAK: Wakeup .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	NoAc; WAK; .
FIT: First_Try .	C;REQ; FIT; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;REQ; FIT; .	C;REQ; FIT; .
COR: Continuous Retry	C;REQ; COR; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;REQ; COR; .	C;REQ; COR; .
PER: Periodic Retry	L1;T5; PER; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	L1;T5; PER; .	L1;T5; PER; .
MON: Monitor .	NoAc; MON .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	NoAc; MON .	NoAc; MON .
MIS: Mismatch .	L;T2;B; MIS; **Direct info.**	C;ACK CON; **Mismatch res.**	---------- ---------- .	---------- ---------- .	C;ACK CON; **Mismatch res.**	L;T2;B; MIS; **Direct info.**	L;T2;B; MIS; **Direct info.**
CON: Contact .	C;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;L;T2;B; MIS; .	C;L;T2;B; MIS; .
FAT: Fast Try	C;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;L;T2;B; MIS; .	C;L;T2;B; MIS; .
FAC: Fast Contact	C;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;L;T2;B; MIS; .	C;L;T2;B; MIS; .
KON: Konnect .	C;DT;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;DT;L;T2;B; MIS; .	C;DT;L;T2;B; MIS; .
REK: Re_Konnect .	C;DT;IT;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;DT;IT;L;T2;B; MIS; .	C;DT;IT;L;T2;B; MIS; .
SOS: Sync_Lost .	C;IT;L;T2;B; MIS; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	C;IT;L;T2;B; MIS; .	C;IT;L;T2;B; MIS; .
OPE: Operation .	C;DT;IT;L;T2;B; MIS; .	---------- ---------- .	C;Lch8;T; OPE; .	C;T;Lch16; OPE; .	NoAc; OPE; .	C;DT;IT;L;T2;B; MIS; .	C;DT;IT;L;T2;B; MIS; .
FAI: Failure .	NoAc; FAI; .	---------- ---------- .	---------- ---------- .	---------- ---------- .	---------- ---------- .	NoAc; FAI; .	NoAc; FAI; .

Table 23: cases due to AMR introduction: New_Local_Codec

Event:	**New_Local_Codec**	**New_Local_Codec**

Number:	16	17
Condition: &	Duc==Nluc==AMR ACS == CACS	Duc==Nluc==AMR and ACS != CACS
Comment: State:	in Call Modif. Mismatch resolv.	in Call Modif. Mismatch occurs (should not happen)
NAC: Not_Active .	---------- ---------- .	---------- ---------- .
WAK: Wakeup .	NoAc; WAK; .	NoAc; WAK; .
FIT: First_Try .	C;REQ; FIT; restart	C;REQ; T2;B; FIT; restart
COR: Continuous Retry	C;REQ; COR; .	C;REQ; T2;B; COR; .
PER: Periodic Retry	L1;T5; PER; .	L1;T5; T2;B; PER; .
MON: Monitor .	NoAc; MON .	NoAc; MON .
MIS: Mismatch .	C;F;REQ; COR; **Mismatch res.**	L;T2;B; MIS; **Direct info.**
CON: Contact .	---------- ---------- .	C;L;T2;B; MIS; .
FAT: Fast Try	---------- ---------- .	C;L;T2;B; MIS; .
FAC: Fast Contact	---------- ---------- .	C;L;T2;B; MIS; .
KON: Konnect .	---------- ---------- .	C;DT;L;T2;B; MIS; .
REK: Re_Konnect .	---------- ---------- .	C;DT;IT;L;T2;B; MIS; .
SOS: Sync_Lost .	---------- ---------- .	C;IT;L;T2;B; MIS; .
OPE: Operation .	---------- ---------- .	C;DT;IT;L;T2;B; MIS; .
FAI: Failure .	---------- ---------- .	NoAc; FAI; .

Table 24: cases due to AMR introduction: REQ_L and ACK_L

Event:	**TFO_REQ_L**	**TFO_ACK_L**
Number:	18	19

Condition: &	Duc==Nluc==AMR Dsig!=Lsig	Duc==Nluc==AMR Dsig==Lsig
Comment: State:	Send ACK_L Tell the BTS	Tell the BTS
NAC: Not_Active .	---------- ---------- .	---------- ---------- .
WAK: Wakeup .	---------- ---------- .	---------- ---------- .
FIT: First_Try .	C;U;LA;B; MIS; **typ: Setup**	NoAc; FIT; Ignore
COR: Continuous Retry	C;U;LA;B; MIS; .	NoAc; COR; Ignore
PER: Periodic Retry	C;F;LA;B; MIS; .	C;T1;B; COR; Start again
MON: Monitor .	C;F;LA;B; MIS; .	C;T1;B; FIT; test
MIS: Mismatch .	C;LA;B; MIS; **term. Protoc.**	C;T1;B; COR; test
CON: Contact .	C;LA;B; MIS; .	C;T1;B; COR; Save way!
FAT: Fast Try	C;LA;B; MIS; .	C;T1;B; COR; Save way!
FAC: Fast Contact	C;LA;B; MIS; .	C;T1;B; COR; Save way!
KON: Konnect .	C;DT;LA;B; MIS; .	C;DT;REQ;T1; COR; Save way!
REK: Re_Konnect .	C;DT;LA;IT;B; MIS; .	C;DT;REQ;T1; COR; Save way!
SOS: Sync_Lost .	C;LA;IT;B; MIS; **In_Call_Mod.**	C;IT;REQ;B;T1 COR; Save way!
OPE: Operation .	NoAc; OPE; .	C;LA;B; OPE; Ack List, stop
FAI: Failure .	NoAc; FAI; .	NoAc; FAI; .

Table 25: Call Setup and Loopback Handling

Event:	**New_Speech_Call**	**PCM_Non_Idle**	**TFO_REQ**	**TFO_REQ**
	.	.	.	.
Number:	24	29	0	0a
Condition:	.	.	Duc==Luc	Duc==Luc

&	.	.	Dsig==Lsig	Dsig==Old_Sig
Comment:	activate TRAU	A-Int. gets active	Loopback (LB)	Loopback (LB)
.	from BTS, e.g. by	occurs only at	or distant handover	or distant hand
State:	2 TRAU Frames	beginning	(HO)? wrong Sig	over (HO)?
NAC:	C;S;IT;	----------	----------	----------
Not_Active	WAK;	----------	----------	----------
.	**typ. 1rst Event**	.	.	.
WAK:	----------	C;F;REQ;	----------	----------
Wakeup	----------	FIT;	----------	----------
.	.	**typ. 2nd Event**	.	.
FIT:	----------	----------	C;SO;REQ;	NoAc;
First_Try	----------	----------	FIT;	FIT;
.	.	.	**LB!**	**Ignore LB**
COR:	----------	----------	C;SO;REQ;	NoAc;
Continuous	----------	----------	COR;	COR;
Retry	.	.	LB!?	**Ignore LB**
PER:	----------	----------	C;F;S;ACK;	----------
Periodic	----------	----------	CON;	----------
Retry	.	.	Dist. HO!	.
MON:	----------	----------	C;F;S;REQ;	----------
Monitor	----------	----------	FIT;	----------
.	.	.	Dist. HO!	.
MIS:	----------	----------	C;F;S;ACK;	----------
Mismatch	----------	----------	CON;	----------
.	.	.	Dist. HO!	.
CON:	----------	----------	C;SO;REQ;	----------
Contact	----------	----------	COR;	----------
.	.	.	save way	.
FAT:	----------	----------	C;SO;REQ;	----------
Fast	----------	----------	COR;	----------
Try	.	.	save way	.
FAC:	----------	----------	C;SO;REQ;	----------
Fast	----------	----------	COR;	----------
Contact	.	.	save way	.
KON:	----------	----------	C;DT;SO;REQ;T1;	----------
Konnect	----------	----------	COR;	----------
.	.	.	IPEs transparent!	.
REK:	----------	----------	C;DT;SO;REQ;IT;B;T1;	----------
Re_Konnect	----------	----------	COR;	----------
.	.	.	IPEs transparent!	.
SOS:	----------	----------	C;IT;S;REQ;B;T1;	----------
Sync_Lost	----------	----------	COR;	----------
.	.	.	Contact is back	.
OPE:	----------	----------	----------	----------
Operation	----------	----------	----------	----------
.	.	.	.	.
FAI:	----------	----------	NoAc;	----------
Failure	----------	----------	FAI;	----------

Table 26: Most Important Cases, Especially at Call Setup

Event:	**TFO_REQ**	**TFO_ACK**	**TFO_ACK**	**TFO_TRANS**	**TFO_FRAME**
	.	.	.	.	.
Number:	1	2	3	4	5
Condition:	Duc==Luc != AMR	Duc==Luc != AMR	Duc==Luc	DCh==LCh	Duc==Luc
&	Dsig!=Lsig	Dsig==Lsig	Dsig!=Lsig	.	n<3
Comment:	Distant REQ	Distant ACK	Wrong Response	similar to ACK	one or two
.	Good Signature	Good Signature	Handover?	As response	TFO Frames
State:	.	.	.	to loc ACK_?	.
NAC:	----------	----------	----------	----------	----------
Not_Active	----------	----------	----------	----------	----------
.	.	.	.	.	.
WAK:	----------	----------	----------	----------	----------
Wakeup	----------	----------	----------	----------	----------
.	.	.	.	.	.
FIT:	C;U;ACK;	C;U;T;BT;T;T1;	C;REQ;	NoAc;	C;U;DUP;
First_Try	CON;	KON;	FIT;	FIT;	FAT;
.	**typical**	**typical; IPEs!**	.	wait for Framee	**1: HO**
COR:	C;U;ACK;	C;U;T;BT;T;T1;	C;REQ;	NoAc;	C;U;DUP;
Continuous	CON;	KON;	COR;	COR;	FAT;
Retry	typical	**typical; IPEs!**	.	wait for Frames	1: Call is back?
PER:	C;F;ACK;	C;F;S;REQ;	C;F;REQ;	NoAc;	C;DUP;
Periodic	CON;	COR;	COR;	PER;	FAT;
Retry	OK, Contact is back	rare case, test	.	wait for Frames	1: Call is back?
MON:	C;F;REQ;	C;F;S;REQ;	C;F;REQ;	NoAc;	C;DUP;
Monitor	FIT;	FIT;	FIT;	MON	FAT;
.	IPEs?	Rare case, test	.	wait for Frames	1: Call is back?
MIS:	C;F;ACK;	C;F;S;REQ;	C;F;REQ;	NoAc;	C;DUP;
Mismatch	CON;	COR;	COR;	MIS;	FAT;
.	Mismatch resolved	rare case, test	.	wait for Frames	1: Call is back?
CON:	C;ACK;	C;T;BT;T;T1;	C;REQ;	C;T;BT;T;T1;	C;T;BT;T;T1;
Contact	CON;	KON;	COR;	KON;	KON;
.	**typical: wait**	**typical: yes!**	.	**yes! Fast way**	missed TRANS?
FAT:	C;REQ;	C;REQ;	C;REQ;	NoAc;	NoAc;
Fast	COR;	COR;	COR;	FAC;	FAT;
Try	save way	save way	save way	wait for Frames	**2: typ. Loc. HO**
FAC:	C;REQ;	C;REQ;	C;REQ;	NoAc;	C;BT;T;L;T2;AT;B;
Fast	COR;	COR;	COR;	FAC;	OPE;
Contact	save way	save way	save way	wait for Frames	**5: typ. Loc. HO**
KON:	C;DT;REQ;T1;	NoAc;	NoAc;	NoAc;	AT;L;T2;B;
Konnect	COR;	KON;	KON;	KON;	OPE;
.	IPEs transparent!	**Typical: wait**	.	**typical: wait**	**typ: call setup**
REK:	C;DT;REQ;IT;B;T1;	C;DT;REQ;IT;B;T1;	C;DT;REQ;IT;B;T1	NoAc;	AT;L;T2;B;
Re_Konnect	COR;	COR;	COR;	REK;	OPE;
.	IPEs transparent!	.	.	wait for Frames	**5: typ. Dis. HO**
SOS:	C;IT;REQ;B;T1;	C;IT;REQ;B;T1;	C;IT;REQ;B;T1;	NoAc;	C;BT;T;L;T2;B;
Sync_Lost	COR;	COR;	COR;	SOS;	OPE;
.	Contact is back	Contact is back	Contact is back	wait for Frames	short Interrupt?
OPE:	----------	----------	----------	NoAc;	NoAc;
Operation	----------	----------	----------	OPE;	OPE;
.	.	.	.	typ in HO	**Main! TFO!**
FAI:	NoAc;	NoAc;	NoAc;	NoAc;	NoAc;
Failure	FAI;	FAI;	FAI;	FAI;	FAI;

Table 27: In Call Modification and Handover

Event:	**New_Local_Codec**	**New_Local_Codec**	**TFO_FRAME**	**TFO_SYL**	**TFO_DUP**
	.	.	.	.	.
Number:	25	26	6	7	8
Condition:	Duc==Nluc != AMR	Duc!=Nluc	Duc==Luc	.	.
&	.	.	n>2	.	.
Comment:	in Call Modif.	In Call Modif.	Three or more	the dist. TRAU	the dist. TRAU
.	Mismatch resolv.	Mismatch occurs!	TFO Frames	lost sync	recognised HO
State:	(Luc!=Nluc)	(Luc!=Nluc)	.	in OPE	
NAC:	----------	----------	----------	----------	----------
Not_Active	----------	----------	----------	----------	----------
.	.	.	.	.	.
WAK:	NoAc;	NoAc;	----------	----------	----------
Wakeup	WAK;	WAK;	----------	----------	----------
.	.	.	.	.	.
FIT:	C;REQ;	C;REQ;	----------	NoAc;	NoAc;
First_Try	FIT;	FIT;	----------	FIT;	FIT;
.	restart	restart	.	HO? Ignore	HO? ignore
COR:	C;REQ;	C;REQ;	----------	NoAc;	NoAc;
Continuous	COR;	COR;	----------	COR;	COR;
Retry	.	.	.	ignore	ignore
PER:	L1;T5;	L1;T5;	----------	C;F;REQ;	C;F;REQ;
Periodic	PER;	PER;	----------	COR;	COR;
Retry	.	.	.	rare case, test	rare case, test
MON:	NoAc;	NoAc;	----------	C;F;REQ;	C;F;REQ;
Monitor	MON	MON	----------	FIT;	FIT;
.	.	.	.	rare case, test	rare case, test
MIS:	C;F;REQ;	L;T2;B;	----------	C;F;REQ;	C;F;REQ;
Mismatch	COR;	MIS;	----------	COR;	COR;
.	**Mismatch res.**	**Direct info.**	.	rare case, test	rare case, test
CON:	----------	C;L;T2;B;	----------	C;F;REQ;	C;F;REQ;
Contact	----------	MIS;	----------	COR;	COR;
.	.	.	.	rare case, test	rare case, test
FAT:	----------	C;L;T2;B;	NoAc;	NoAc;	C;F;REQ;
Fast	----------	MIS;	FAC;	FAC;	COR;
Try	.	.	.	**3: typ. Loc. HO**	rare case, test
FAC:	----------	C;L;T2;B;	C;BT;T;L;T2;AT;B;	NoAc;	C;F;REQ;
Fast	----------	MIS;	OPE;	FAC;	COR;
Contact	.	.	.	**4: typ. Loc. HO**	rare case, test
KON:	----------	C;DT;L;T2;B;	----------	NoAc;	NoAc;
Konnect	----------	MIS;	----------	KON;	KON;
.	.	.	.	wait, short int?	other TRAU?
REK:	----------	C;DT;IT;L;T2;B;	----------	C;DT;SYL;	NoAc;
Re_Konnect	----------	MIS;	----------	SOS;	REK;
.	.	.	.	IPEs not transp?	**4: typ. Dist. HO**
SOS:	----------	C;IT;L;T2;B;	----------	NoAc;	C;BT;T;T1;
Sync_Lost	----------	MIS;	----------	SOS;	REK;
.	.	.	.	short Inter?	**3: typ. Dis. HO**
OPE:	----------	C;DT;IT;L;T2;B;	NoAc;	NoAc;	NoAc;
Operation	----------	MIS;	OPE;	OPE;	OPE;
.	.	.	Main! TFO!	Short interrupt?	Typical
FAI:	----------	NoAc;	NoAc;	NoAc;	NoAc;
Failure	----------	FAI;	FAI;	FAI;	FAI;

Table 28: Special Matching TFO Messages

Event:	**TFO_REQ_L**	**TFO_REQ_L**	**TFO_ACK_L**	**TFO_ACK_L**	**TFO_REQ_P**	**TFO_REQ_P**
	.	.	.	.	.	.
Number:	9	10	11	12	13	14
Condition:	Duc==Luc	Duc==Luc != AMR	Duc==Luc != AMR	Duc==Luc	.	.
&	Dsig==Lsig	Dsig!=Lsig	Dsig==Lsig	Dsig!=Lsig	Dsig==Lsig	Dsig!=Lsig
Comment:	Only sent in	Only sent in	Only sent in	.	sent by GCME	sent by GCME
.	MIS/OPE/PER	MIS; / OPE / PER	MIS;	.	only	only
State:	HO? Loop?	Codec_List	HO?	HO?	embedded	embedded
NAC:	----------	----------	----------	----------	----------	----------
Not_Active	----------	----------	----------	----------	----------	----------
.	.	.	.	.	.	.
WAK:	----------	----------	----------	----------	----------	----------
Wakeup	----------	----------	----------	----------	----------	----------
.	.	.	.	.	.	.
FIT:	NoAc;	NoAc;	NoAc;	NoAc;	----------	----------
First_Try	FIT;	FIT;	FIT;	FIT;	----------	----------
.	ignore	ignore	ignore	ignore	.	.
COR:	NoAc;	NoAc;	NoAc;	NoAc;	----------	----------
Continuous	COR;	COR;	COR;	COR;	----------	----------
Retry	ignore	ignore	ignore	ignore	.	.
PER:	C;F;S;REQ;	C;F;REQ;	C;F;S;REQ;	C;F;REQ;	----------	----------
Periodic	COR;	COR;	COR;	COR;	----------	----------
Retry	start again	start again	test	test	.	.
MON:	C;F;S;REQ;	C;F;REQ;	C;F;S;REQ;	C;F;REQ;	----------	----------
Monitor	FIT;	FIT;	FIT;	FIT;	----------	----------
.	test	test	test	test	.	.
MIS:	C;F;S;REQ;	C;F;REQ;	C;F;S;REQ;	C;F;REQ;	S;LA;B;	LA;B;
Mismatch	COR;	COR;	COR;	COR;	MIS;	MIS;
.	test	test	test	test	acknowledge	acknowledge
CON:	C;S;REQ;	C;REQ;	C;S;REQ;	C;REQ;	----------	----------
Contact	COR;	COR;	COR;	COR;	----------	----------
.	save way!	Save way!	Save way!	Save way!	.	.
FAT:	C;S;REQ;	C;REQ;	C;S;REQ;	C;REQ;	S;LA;B;	LA;B;
Fast	COR;	COR;	COR;	COR;	FAT;	FAT;
Try	save way!	Save way!	Save way!	Save way!	Acknowledge	acknowledge
FAC:	C;S;REQ;	C;REQ;	C;S;REQ;	C;REQ;	S;LA;B;	LA;B;
Fast	COR;	COR;	COR;	COR;	FAC;	FAC;
Contact	save way!	Save way!	Save way!	Save way!	Acknowledge	acknowledge
KON:	C;DT;S;REQ;T1;	C;DT;REQ;T1;	C;DT;S;REQ;T1;	C;DT;REQ;T1;	S;LA;B;	LA;B;
Konnect	COR;	COR;	COR;	COR;	KON;	KON;
.	save way!	Save way!	Save way!	Save way!	Acknowledge	acknowledge
REK:	C;DT;S;REQ;T1;	C;DT;REQ;T1;	C;DT;S;REQ;T1;	C;DT;REQ;T1;	----------	----------
Re_Konnect	COR;	COR;	COR;	COR;	----------	----------
.	save way!	Save way!	Save way!	Save way!	.	.
SOS:	C;IT;S;REQ;B;T1;	C;IT;REQ;B;T1;	C;IT;S;REQ;B;T1;	C;IT;REQ;B;T1;	S;LA;B;	LA;B;
Sync_Lost	COR;	COR;	COR;	COR;	SOS;	SOS;
.	save way!	Save way!	Save way!	Save way!	Acknowledge	acknowledge
OPE:	S;L;T2;B;	C;LA;B;	C;B;	S;L;T2;B;	S;LA;B;	LA;B;
Operation	OPE;	OPE;	OPE;	OPE;	OPE;	OPE;
.	tx Codec_List	Ack List, stop	Ack ok, stop	exchange list	acknowledge	acknowledge
FAI:	NoAc;	NoAc;	NoAc;	NoAc;	NoAc;	NoAc;
Failure	FAI;	FAI;	FAI;	FAI;	FAI;	FAI;

Table 29: TFO Messages with mismatching CodecType

Event:	**TFO_REQ**	**TFO_REQ**	**TFO_ACK**	**TFO_REQ_L**	**TFO_REQ_L**	**TFO_ACK_L**
	.	.	.	.	.	.
Number:	15	16	17	18	19	20
Condition:	Duc!=Luc	Duc!=Luc	Duc!=Luc	Duc!=Luc	Duc!=Luc	Duc!=Luc
&	Dsig==Lsig	Dsig!=Lsig	Dsig==?	Dsig==Lsig	Dsig!=Lsig	Dsig==?
Comment:	Mismatch	Mismatch	Mismatch	Mismatch	Mismatch	Mismatch
.	Wrong Sig, HO?	Good Sig	w/wo HO	Codec_List	Codec_List	Codec_List
State:	.	.	.	Wrong Sig, HO?	.	.
NAC:	----------	----------	----------	----------	----------	----------
Not_Active	----------	----------	----------	----------	----------	----------
.	.	.	.	.	.	.
WAK:	----------	----------	----------	----------	----------	----------
Wakeup	----------	----------	----------	----------	----------	----------
.	.	.	.	.	.	.
FIT:	C;S;L;T2;B;	C;U;L;T2;B;	C;U;L;T2;B;	C;S;LA;B;	C;U;LA;B;	C;U;LA;B;
First_Try	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	rare	**typical: Setup**	HO?	rare	**typical: Setup**	HO?
COR:	C;S;L;T2;B;	C;U;L;T2;B;	C;U;L;T2;B;	C;S;LA;B;	C;U;LA;B;	C;U;LA;B;
Continuous	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
Retry	.	.	.	.	.	.
PER:	C;F;S;L;T2;B;	C;F;L;T2;B;	C;F;L;T2;B;	C;F;S;LA;B;	C;F;LA;B;	C;F;LA;B;
Periodic	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
Retry	.	.	.	.	.	.
MON:	C;F;S;L;T2;B;	C;F;L;T2;B;	C;F;L;T2;B;	C;F;S;LA;B;	C;F;LA;B;	C;F;LA;B;
Monitor	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	.	.
MIS:	C;S;L;T2;B;	C;L;T2;B;	C;L;T2;B;	C;S;LA;B;	C;LA;B;	C;LA;B;
Mismatch	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	**terminate prot.**	**Terminate prot.**
CON:	C;S;L;T2;B;	C;L;T2;B;	C;L;T2;B;	C;S;LA;B;	C;LA;B;	C;LA;B;
Contact	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	.	.
FAT:	C;S;L;T2;B;	C;L;T2;B;	C;L;T2;B;	C;S;LA;B;	C;LA;B;	C;LA;B;
Fast	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
Try	.	.	.	.	.	.
FAC:	C;S;L;T2;B;	C;L;T2;B;	C;L;T2;B;	C;S;LA;B;	C;LA;B;	C;LA;B;
Fast	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
Contact	.	.	.	.	.	.
KON:	C;DT;S;L;T2;B;	C;DT;L;T2;B;	C;DT;L;T2;B;	C;DT;S;LA;B;	C;DT;LA;B;	C;DT;LA;B;
Konnect	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	.	.
REK:	C;DT;S;L;T2;IT;B;	C;DT;L;T2;IT;B;	C;DT;L;T2;IT;B;	C;DT;S;LA;IT;B;	C;DT;LA;IT;B;	C;DT;LA;IT;B;
Re_Konnect	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	.	.
SOS:	C;S;L;T2;IT;B;	C;L;T2;IT;B;	C;L;T2;IT;B;	C;S;LA;IT;B;	C;LA;IT;B;	C;LA;IT;B;
Sync_Lost	MIS;	MIS;	MIS;	MIS;	MIS;	MIS;
.	.	.	.	.	**In_Call_Mod.**	.
OPE:	----------	----------	----------	NoAc;	NoAc;	----------
Operation	----------	----------	----------	OPE;	OPE;	----------
.	.	.	.	trans. Error?	Trans. Error?	.
FAI:	NoAc;	NoAc;	NoAc;	NoAc;	NoAc;	NoAc;
Failure	FAI;	FAI;	FAI;	FAI;	FAI;	FAI;

Table 30: Mismatching TFO_TRANS and TFO Frames

Event:	**TFO_TRANS**	**TFO_FRAME**	**TFO_FRAME**
	.	.	.
Number:	21	22	23
Condition:	DCh!=LCh	Duc!=Luc	Duc!=Luc
&	.	n==1	n>1
Comment:	Mismatch	Mismatch	Mismatch
.	of channel type	for one	for at least
State:	.	TFO Frames	two TFO Frames
NAC:	----------	----------	----------
Not_Active	----------	----------	----------
.	.	.	.
WAK:	----------	----------	----------
Wakeup	----------	----------	----------
.	.	.	.
FIT:	C;U;L;T2;B;	NoAc;	C;U;L;T2;B;
First_Try	MIS;	FIT;	MIS;
.	HO?	HO? be tolerant	**typical in HO**
COR:	C;U;L;T2;B;	NoAc;	C;U;L;T2;B;
Continuous	MIS;	COR;	MIS;
Retry	.	Call Forw.?	.
PER:	C;F;L;T2;B;	NoAc;	C;F;L;T2;B;
Periodic	MIS;	PER;	MIS;
Retry	.	Call Forw.?	.
MON:	C;F;L;T2;B;	NoAc;	C;F;L;T2;B;
Monitor	MIS;	MON	MIS;
.	.	Call Forw.?	.
MIS:	C;L;T2;B;	NoAc;	C;L;T2;B;
Mismatch	MIS;	MIS;	MIS;
.	.	Call Forw.?	.
CON:	C;L;T2;B;	NoAc;	C;L;T2;B;
Contact	MIS;	CON;	MIS;
.	.	.	.
FAT:	C;L;T2;B;	NoAc;	C;L;T2;B;
Fast	MIS;	FAT;	MIS;
Try	.	.	.
FAC:	C;L;T2;B;	NoAc;	C;L;T2;B;
Fast	MIS;	FAC;	MIS;
Contact	.	.	.
KON:	C;DT;L;T2;B;	NoAc;	C;DT;L;T2;B;
Konnect	MIS;	KON;	MIS;
.	.	.	.
REK:	C;DT;L;T2;IT;B;	NoAc;	C;DT;L;T2;IT;B;
Re_Konnect	MIS;	REK;	MIS;
.	.	.	.
SOS:	C;L;T2;IT;B;	NoAc;	C;L;T2;IT;B;
Sync_Lost	MIS;	SOS;	MIS;
.	.	.	.
OPE:	NoAc;	NoAc;	C;DT;L;T2;IT;B;
Operation	OPE;	OPE;	MIS;
.	ignore?	Hard HO?	hard HO into TFO
FAI:	NoAc;	NoAc;	NoAc;
Failure	FAI;	FAI;	FAI;

Table 31: Local Events, Call Termination

Event:	**New_L_Codec_List**	**Data_Call**	**TRAU_Idle**	**TFO_FILL**	**TFO_NORMAL**
	.	.	.	.	.
Number:	30	27	28	37	33
Condition:	.	.	.	.	.
&	.	.	.	.	.
Comment:	from BSS	in Call Modif.	Command from	ignore	ignore
.		.	BTS or BSC	is just	alternative:
State:	.	stop TFO	to Reset TRAU	Filler	Soft Resert
NAC:	NoAc;	NoAc;	NoAc;	----------	----------
Not_Active	NAC;	NAC;	NAC;	----------	----------
.	.	.	.	.	.
WAK:	NoAc;	NoAc;	NoAc;	----------	----------
Wakeup	WAK;	NAC;	NAC;	----------	----------
.	.	.	.	.	.
FIT:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
First_Try	FIT;	NAC;	NAC;	FIT;	FIT;
.	update loc. Par.	.	.	.	.
COR:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Continuous	COR;	NAC;	NAC;	COR;	COR;
Retry	.	.	.	.	.
PER:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Periodic	PER;	NAC;	NAC;	PER;	PER;
Retry	.	.	.	.	.
MON:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Monitor	MON	NAC;	NAC;	MON	MON
.	.	.	.	.	.
MIS:	C;L;T2;	C;N;	C;N;	NoAc;	NoAc;
Mismatch	MIS;	NAC;	NAC;	MIS;	MIS;
.	**direct info**	.	.	.	.
CON:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Contact	CON;	NAC;	NAC;	CON;	CON;
.	.	.	.	.	.
FAT:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Fast	FAT;	NAC;	NAC;	FAT;	FAT;
Try	.	.	.	.	.
FAC:	NoAc;	C;N;	C;N;	NoAc;	NoAc;
Fast	FAC;	NAC;	NAC;	FAC;	FAC;
Contact	.	.	.	.	.
KON:	NoAc;	C;DT;N;	C;DT;N;	NoAc;	NoAc;
Konnect	KON;	NAC;	NAC;	KON;	KON;
.	.	.	.	.	.
REK:	NoAc;	C;DT;IT;N;	C;DT;IT;N;	NoAc;	NoAc;
Re_Konnect	REK;	NAC;	NAC;	REK;	REK;
.	.	.	.	.	.
SOS:	NoAc;	C;IT;N;	C;IT;N;	NoAc;	NoAc;
Sync_Lost	SOS;	NAC;	NAC;	SOS;	SOS;
.	.	.	.	.	.
OPE:	L;T2;	C;DT;IT;N;	C;DT;IT;N;	NoAc;	NoAc;
Operation	OPE;	NAC;	NAC;	OPE;	OPE;
.	**direct info**	.	.	.	.
FAI:	NoAc;	C;	C;	NoAc;	NoAc;
Failure	FAI;	NAC;	NAC;	FAI;	FAI;
.	.	**exit from FAI**	**exit from FAI**	.	.

Table 32: Special Events, Timeouts

Event:	**Runout**	**T==0**	**Frame_Sync_Lost**	**Frame_Sync_Lost**	**Mes_Sync_Lost**
	.	.	.	.	.
Number:	31	32	34	35	36
Condition:	.	.	n<3	n>2	.
&	.	.	.	.	.
Comment:	IPEs may become	Time-Out	start to send	Stop TFO Frames	.
.	unsynchronised	.	SYL already	if 3 Frames missing	.
State:	.	.	.	.	.
NAC:	----------	----------	----------	----------	----------
Not_Active	----------	----------	----------	----------	----------
.	.	.	.	.	.
WAK:	----------	----------	----------	----------	----------
Wakeup	----------	----------	----------	----------	----------
.	.	.	.	.	.
FIT:	U;N;	----------	----------	----------	NoAc;
First_Try	MON	----------	----------	----------	FIT;
.	**PSTN Call**	.	.	.	.
COR:	U;L1;T5;	C;N;REQ;	----------	----------	NoAc;
Continuous	PER;	COR;	----------	----------	COR;
Retry	**at end of COR**	Reset IPEs	.	.	.
PER:	NoAc;	L1;T5;	----------	----------	NoAc;
Periodic	PER;	PER;	----------	----------	PER;
Retry	.	**Periodic Test**	.	.	.
MON:	----------	----------	----------	----------	----------
Monitor	----------	----------	----------	----------	----------
.	.	.	.	.	.
MIS:	NoAc;	N;B;	NoAc;	NoAc;	NoAc;
Mismatch	MIS;	MIS;	MIS;	MIS;	MIS;
.	**typ. Final state**	List not Ack_ed!	.	.	.
CON:	REQ;	----------	----------	----------	C;REQ;
Contact	COR;	----------	----------	----------	COR;
.	can this occur?	.	.	.	.
FAT:	REQ;	----------	NoAc;	NoAc;	C;REQ;
Fast	COR;	----------	FAT;	FAT;	COR;
Try	fast HO failed	.	typical in HO	typical in HO	fast HO failed
FAC:	REQ;	----------	NoAc;	NoAc;	C;REQ;
Fast	COR;	----------	FAC;	FAC;	COR;
Contact	fast HO failed	.	typical in HO	typical in HO	fast HO failed
KON:	NoAc;	C;DT;N;	----------	----------	C;DT;REQ;T1;
Konnect	KON;	FAI;	----------	----------	COR;
.	may happen	Misbehaviour!	.	.	after Timeout: N
REK:	NoAc;	C;DT;N;IT;B;	----------	----------	C;DT;REQ;IT;B;T1;
Re_Konnect	REK;	FAI;	----------	----------	COR;
.	may happen	Misbehaviour!	.	.	after Timeout: N
SOS:	REQ;IT;B;T1;	----------	----------	NoAc;	C;REQ;IT;B;T1;
Sync_Lost	COR;	----------	----------	SOS;	COR;
.	after Timeout: N	.	.	wait for Runout	after Timeout: N
OPE:	NoAc;	B;	SYL1;	C;DT;SYL;	NoAc;
Operation	OPE;	OPE;	OPE;	SOS;	OPE;
.	**typ. Final event**	List not Ack_ed!	**1: Alarm, go on**	**2: Alarm, stop!**	**Typ. Final event**
FAI:	NoAc;	----------	----------	----------	NoAc;
Failure	FAI;	----------	----------	----------	FAI;
.	typical	.	.	.	don´t trust!

Codec Mismatch Resolution and Codec Optimization

11.1 General

It is not mandatory for a BSS to support the Resolution of Codec Mismatch or the Codec Optimization. In that case the Local_Codec_List shall include only the Local_Used_Codec. However, in the optional case, if a BSS sends a Local_Codec_List that includes more than the Local_Used_Codec, then it is mandatory for that BSS to support the Resolution of Codec Mismatch or the Codec Optimisation, considering the reported Codec_Types.

Similar, in case of AMR, the Resolution of an ACS mismatch or the ACS Optimisation is not mandatory. If, however, a BSS sends a Supported_Codec_Set that contains more Codec_Modes than the Active_Codec_Set, then is it mandatory for that BSS to support the Resolution of an ACS mismatch and the ACS Optimisation.

The determination of the Local_Codec_List (i.e. the list of all Codecs supported by the local radio leg, consisting of the local MS, the local BSS and the local radio resources) and in case of AMR the determination of the Local_Supported_Codec_Set (LSCS) is outside the scope of this specification. The communication of the TRAU with the local BSS, is a BSS specific matter for the FR,

HR and EFR and is also outside the scope of this specification. The communication means for the AMR between the TRAU, BTS and BSC are described in the clause 8 and in GSM 08.58, see also GSM 08.60 and 08.61.
Only Codec_Types that are real alternatives, considering all resources, shall be reported within the Local_Codec_List. Similarly, only Codec_Modes that are really to be considered shall be indicated within the LSCS.

The Local_Codec_List shall be updated and resent as soon as these local resource conditions have changed, if the BSS wants a have these new conditions considered within the Codec Mismatch Resolution or Codec Optimisation.
Similar a new LSCS shall be sent, if new conditions shall be considered.

Whenever a new Distant_Codec_List or a new Local_Codec_List becomes available, then the BSS shall attempt to resolve the Codec_Mismatch or optimize the Codec_Type as soon as possible by following the rules outlined below and shall perform a subsequent intra cell handover to the new Local_Used_Codec.

Whenever a new SCS becomes available, then the BSS shall attempt to consider it as soon as possible.

If the AMR (FR and/or HR) is the Local_Used_Codec or is in the Local_Codec_List, then the determination of a possible common ACS as described in clause 12 shall be performed before the Resolution of a Codec Type Mismatch, respectively the Codec Type Optimisation. All AMR channel mode combinations, i.e. FR-FR, FR-HR, HR-FR and HR-HR, that have a common ACS, shall be considered for the Resolution of the CodecType Mismatch and the Codec Type Optimisation.

The default rule for the ICM determination (see GSM 05.09) shall apply, if an handover is required to change the codec type to AMR or to change the AMR channel mode.

11.2 Resolution of Codec_Type Mismatch and Optimisation

The Codec_Types, respectively their combinations, are ordered in term of speech quality in the so-called “Preference_List”:

1. AMR: FR-FR (AMR-FR in both legs)
2. EFR-EFR (EFR in both legs)
3. AMR: FR-HR / HR-FR (FR in one leg and HR in the other leg, whichever is selected, see below)
4. AMR: HR-HR (AMR-HR in both legs)
5. FR-FR (FR in both legs)
6. HR-HR (HR in both legs)

Number 1 is the best and number 6 the worst.

The Preference_List given above contains all the possible TFO combination. If a combination does not exist for the call, it shall be removed from the Preference_List. This Preference_List shall be up-dated if a new Local_Codec_List or Distant_Codec_List is received. Similarly in case of AMR the Preference_List shall be up-dated if the local or distant SCS is modified.

The Resolution of a Codec_Type Mismatch and/or Optimization shall be performed by taking the best available combination of the Preference_List. If the Preference_List is empty, then TFO is not possible.

The two AMR channel modes, FR and HR, lead to four combinations that need to be considered:
AMR (local) – AMR (distant): FR-FR, FR-HR, HR-FR and HR-HR (FR means AMR with TCH/F and HR AMR with TCH/H).

If the two combinations FR-HR and HR-FR have the same common ACS (CACS), then they are considered equivalent in terms of speech quality. At the same time it is obvious that a combination FR-FR exists with at least the same Codec_Modes. The FR-FR combination gets preference according to the Preference_List.

If the two combinations FR-HR and HR-FR have two different CACSs, then they shall be ranked by the following additional rule:

1. ***The combination with the highest number of modes in the CACS shall be selected;***
2. ***If they have the same number of modes, then the combination with the widest spread shall be selected. The spread is the difference between the highest and lowest mode indexes.***
3. ***If the spreads are identical, then the combination with the highest mode among the two common ACS shall be selected.***

11.3 Preferred Codec

The Preferred_Codec_Type is intended to be used (e.g. by TCMEs) for optimizing the transmission saving, without loss in speech quality, after thatTFO has already been set up.

If the Preferred_Codec_Type is included in the Local_Codec_List, then it shall be used as the new Used_Codec_Type. If it is not, the Preferred_Codec_Type shall be ignored. The Codec_List estension block of the TFO_REQ_P (see sub-clause 6.1) message provides the other preferred codecs. The best combination according to the Preference_List shall be retained.

It is assumed that all TCMEs support the full set of eight different AMR Codec_Modes, including DTX and 8 and 16 kbit/s TFO frame formats. For this reason a common ACS will always exist between any TRAU and any TCME.

12 AMR Common and Optimal Common Active Codec Set for TFO

12.1 Determination of the Common ACS for Immediate TFO setup

When AMR is used on both sides, TFO shall be established immediatly if ACSs verify some rule. The Common ACS shall be updated each time a new local ACS or a new distant ACS is available.

The common ACS shall be built from the local ACS, reported in Ul TRAU frames and distant ACS, reported in TFO_REQ respectively in TFO_ACK. The CACS is common modes of these two ACSs if they verify the rules given in sub-clause 12.5.3 or else CACS is empty.

If the common ACS is empty then immediate TFO setup is impossible. Mismatch and optimisation handling has then to be applied (see clause 11) after the full set of TFO parameters has been exchanged with TFO_REQ_L, respectively TFO_ACK_L. The Optimized OACS shall then be calculated.

If the Common ACS is not empty, one or both BSS may have to change ACS. This happens when one (or both) ACS is not equal to Common ACS but verifies the contiguity rule (see subclause 12.5.3). As soon as both BSS have changed their ACS, TFO_ICM shall be immediately applied. The TFO_ICM for that shall be defined by the default ICM determination rule, provided in GSM 05.09, on the common ACS. Further optimization shall be done according to clause 11 after TFO setup and when the full set of TFO parameters has been exchanged, either with TFO_REQ_L, respectively TFO_ACK_L or with Con_Req.

12.2 General principles for AMR TFO optimization

AMR TFO Optimization shall happen in two situations:

- After immediate TFO setup has taken place, when TFO is then ongoing.
- When Immediate TFO setup is impossible, TRAU waits for the complete remote configuration and send it to the BSS in the TRAU frames (with configuration protocol), which applies the following rules to find OACS.

The determination of the optimal common AMR ACS is performed for all different possible combinations of AMR channel modes, i.e. FR/FR, FR/ HR, or HR/ HR, and HR/FR.

When it is not possible to find a common ACS (CACS) for one of the combinations, then it shall not be considered in the Preference_List (see sub-clause 11.4.).

The first step is to determine the Common SCS (see sub-clause 12.3), next to determine the common MACS (see sub-clause 12.4) and eventually to determine the optimal common ACS, if any, to use in both radio legs (see sub-clause 12.5).

Additional criterions are taken into account to eventually determine the Optimal common ACS for TFO (see sub-clause 12.5.3).

12.3 Determination of the Common Supported Codec Set

The common SCS (CSCS) is built from the local and distant SCSs. Only modes, which are present in both SCSs, are part of the CSCS.

If the CSCS is empty then the corresponding AMR combination shall not be considered.

12.4 Determination of the Common MACS

The common MACS (CMACS) shall be determined by taking the minimum of both MACS local and distant.

12.5 Determination of the Optimal Common Active Codec Set

12.5.1 Preliminary rule

If the CMACS is bigger than the number of modes in the CSCS all the modes of the CSCS are retained otherwise the rules of the next sub-clauses apply.

12.5.2 Clustering of the AMR modes

The AMR modes are clustered according to the speech quality, which can be achieved and depending on the traffic channels, which are used, i.e. TCH/F or TCH/H.

12.5.2.1 AMR-FR/AMR-FR

The AMR modes in TCH/F are ranked as described in the following table :

Table 32: Clustering of the AMR FR modes

A	B	C	D	E
12,2 10,2	7,95	7,4 6,7	5,9	5,15 4,75

The C SCS is then described according to this table. For example if the CSCS is 12,2 7,95 7,4 6,7 and 4,75 it becomes ABCCE.

12.5.2.2 AMR-FR/AMR-HR & AMR-HR/AMR-HR

This sub-clause is also valid for AMR-HR/AMR-FR. The AMR modes are ranked as given the following table:

Table 33: Clustering of the AMR HR modes

A	B	C	D	E
7,95 7,4	6,7	5,9	5,15	4,75

12.5.2.3 Optimal Common Active Codec Set (OACS)

In the following the procedure to follow to build the OACS is described. When a mode is retained it is incorporated in the OACS. When a mode is removed from the CSCS it is meant that this mode shall not be consider for the determination of the following modes of the OACS.

The order of consideration of the modes is expressed in term of cluster name. When there are two modes of a same cluster as in the example given in sub-clause 12.5.2.1 both shall be considered. An additional rule is given to determine which one of the two must be retained for the OACS.

The rules given in the following apply to all AMR combinations.

CMACS equals 1:

The selected mode is determined by going through the CSCS in the following order CBDEA. When there are two modes in one cluster the one with the lowest rate is retained. It stops as soon as a mode is available.

CMACS equals 2:

The first mode is determined by going through the CSCS in the following order DECBA. When there are two modes the one with the lowest rate shall be retained. It stops as soon as a mode is available .The retained mode is removed from the CSCS.

The second mode is determined by going through the CSCS in the following order BACDE. When there are two modes of one cluster the one with the highest rate shall be retained. It stops as soon as a mode is available.

CMACS equals 3:

The first mode is determined by going through the CSCS in the following order ABCD. When there are two modes the one with the highest rate shall be retained. It stops as soon as a mode is available. The retained mode is removed from the CSCS.

The second mode is determined by going through the CSCS in the following order EDCB. When there are two modes the one with the lowest rate shall be retained. It stops as soon as a mode is available. The retained mode is removed from the CSCS.

The third mode is determined by going through the CSCS in the following order CBDEA. When there are two modes available for a cluster the one with the lowest rate is retained.

CMACS equals 4:

The first mode is determined by going through the CSCS in the following order ABC. When there are two modes the one with the highest rate shall be retained. It stops as soon as a mode is available. The retained mode is removed from the CSCS.

The second mode is determined by going through the CSCS in the following order EDC. When there are two modes the one with the lowest rate shall be retained. It stops as soon as a mode is available. The retained mode is removed from the CSCS.

The third mode is determined by going through the CSCS in the following order CBDEA. When there are two modes available for a cluster the one with the lowest rate is retained. The retained mode is removed from the CSCS.

The fourth mode is determined by going through the CSCS in the following order DBCAE. When there are two modes available for a cluster the one with the lowest rate is retained.

12.5.3 Acceptability of the Common or Optimized Active Codec Set

The OACS selected by previous subclause and any CACS shall verify the following acceptability rule:

Acceptability Rule:
The different clusters are assigned to different weights: A 1, B 2, C 3, D 4 and E 5.

The different modes of the LACS, DACS and CACSare weighted according to the cluster they belong to.

The folowing means are computed:

$$M_L = \frac{1}{LMACS}\sum_{i=0}^{LMACS-1} LACS(i),\ M_D = \frac{1}{DMACS}\sum_{i=0}^{LMACS-1} DACS(i),\ M_C = \frac{1}{CMACS}\sum_{i=0}^{CMACS-1} CACS(i)$$

LMACS is the number of codec modes flaged in the Local ACS (LACS). DMACS is the number of codec modes flaged in the Distant ACS. CMACS is the number of codec modes flaged in the Common ACS (CACS).

LACS(i) is the weight of the ith codec mode flaged in the Local Active Codec Set; respectively DACS(i) and CACS(i) are the weigths of the ith codecs flaged in the Distant ACS and the Common ACS.

In consequence M_L, M_D and M_C are weighted average modes for the Local, Distant and Common ACS.

The Acceptability rule is applied using the Local and Distant AMR configurations. Consequently both Local and Distant BSS process the Acceptability rule using the same inputs.

The acceptability rule consists of:

If CMACS equals 1 then

If $M_C \neq Min(\lceil M_D \rceil, \lceil M_L \rceil)$ then the CACS is not accepted.

Else

If $Min(CACS) > Min(\lfloor M_D \rfloor, \lfloor M_L \rfloor)$ then the CACS is not accepted.

If $Max(CACS) < Min(\lceil M_D \rceil, \lceil M_L \rceil)$ then the CACS is not accepted.

Else the CACS is accepted.

End

$\lceil X \rceil$ stands for the greatest integer smaller than or equal to X.

$\lfloor X \rfloor$ stands for the smallest integer greater than or equal to X.

It is assumed that CMACS is never nul. In case it is there's no CACS.

Furthermore, to establish immediate TFO setup, CACS shall verify the contiguity rule:

Contiguity Rule:

All modes of CACS shall be contiguous within (local) ACS.

Example A: Rule of contiguity is fulfilled

(Local)	ACS	12.2	10.2	7.95	4.75
	CACS		10.2	7.95	

Example B: Rule of contiguity is not fulfilled

(Local)	ACS	12.2	10.2	7.95	4.75
	CACS		10.2		4.75

It can happen that CACS for Immediate TFO setup does not verify the contiguity rule but a subset of this CACS does. In that case, CACS is restricted to this subset to establish immediate TFO setup. If several subset verify the rule, the one with the most number of modes is chosen. If several could be chosen, the subset with the lowest mode will be chosen.

NOTE 1: This rule is directly related to the link-adaptation, which does not allow a jump in the codec list.

NOTE 2: The codec numbering on the Abis is absolute on the Abis link but not on the radio. BTS shall take care of this and change the codec numbering at the same time it change ACS (into CACS) on the Abis link. The MS is not aware of the change, it does not see anymore CMC outside the CACS. RATSCCH need not to be used.

12.6 Location of the determination of the Common and Optimized Active Codec Set

12.6.1 Locations for the immediate TFO Setup

The determination of the CACS for immediate TFO_Setup shall be in the BTS and in the TRAU. The BTS shall not change the MS ACS. The BTS shall restrict the adaptation within the CACS, which is actually a sub-set of the MS ACS. When this change of ACS is completed this is signalled to the TRAU by modifying the ACS field of the TFO parameters conveyed by the UL TRAU frames. The TRAU has previously determined what shall be the CACS for TFO_Setup. When the CACS as determined by the TRAU is also present in the ACS field previously mentioned then the TRAU shall enter in the Konnect State.

12.6.2 Locations for the AMR TFO optimization

The AMR TFO optimization as described in sub-clauses 12.2 to 12.5 shall be located for Codec Mismatch and optimization in the BSC.

The AMR TFO optimization for the current AMR combination can be furthermore located in the BTS.

If this is delegated to the BTS by the BSC (see GSM 08.58) the AMR_TFO optimization shall be in the BTS.

13 Overall Procedure for TFO

13.1 AMR Configuration mismatch and Optimization

The resolution of the AMR_Configuration Mismatch is based on similar principles as the Codec_Type Mismatch resolution (chapter 11) . The rules defined in chapter 12 may result in a common ACS (CACS) on both BSSs, based on the ACSs, respectively in a optimal ACS (OACS) based on the SCSs. These rules shall always be mandatory in the TRAU, then optional also in the BTS and finally optional in the BSC, or all three.

Definition: Optimisation Mode (transmitted in TFO_REQ and TFO_ACK):

a) 00: No change of ACS supported by BTS or BSC
b) 01: Change of ACS is supported, but in a slow way, either by handover or BSC_initiated RATSCCH
c) 10: fast RATSCCH modification is authorised to BTS.

This gives 3*3=9 possible cases for the **first TFO "contact":**
At reception of TFO_REQ (TFO_ACK) with AMR and the Optimisation_Mode in the ACS Extension.

1) **Both sides do not support change of ACS:**
Then the CACS == OACS and the acceptability and contiguity can be checked immediately and the decision, whether to go to TFO or not can be done immediately.

a) Easy case, TRAU only:
If the CACS is identical to the ACSs on both sides (perfect match), then the TRAUs shall immediately go into TFO as for any other Codec Type. This is the simplest and fastest TFO setup.
It should work well within one operators network.

Immediate TFO Setup is also possible, if the CACS is acceptable and is a contiguous subset of the ACSs, including the lowest modes of both ACSs. In that case the TRAU shall sent no CMR downlink higher than the highest mode of the CACS. The TRAUs can restrict the maximum rate to the CACS. This case is for example important for TFO between FR_AMR and HR_AMR and may as well result immediately in the optimal ACS. Also this should work well within one operators network.

b) Easy case, BTS support needed:
If the CACS is acceptable and is a contiguous subset of both ACSs, but not including the lowest mode of one of the ACSs, then the BTSs are able to control the link adaptation without reconfiguring the MS. Thus fast TFO setup is possible, after the BTS has sent the CACS back to the TRAU. This TFO setup is still fast and optimal. No distant SCS needs to be exchanged, it should be identical to the ACS.

Note 1: TFO is permanently run with a lower Codec Mode in the ACS of the MS that is not allowed in the CACS. But the MS does not know about it! Typically the BTSs can control this, except in case of transmission errors. Then the CMI in uplink may go down to this forbidden Codec Mode for a short while, resulting in muting for that short period (40ms). An "intelligent" MS implementation could learn this over time by observing the CMCs.

Note 2: The TCMEs in this case may try to lower the CMR on the path to the forbidden Codec Mode, but the BTSs shall not accept this and shall set the CMC to the lowest allowed mode in the CACS. In fact this is similar handled like a transmission error in TFO or TRAU Frames, resulting in a forbidden Codec Mode.

2) **Both sides support BTS authorised RATSCCH:**
Whenever at least one common codec mode exists, immediate TFO Setup shall be done with the CACS. Then exchange SCS by fast TFO Configuration frames, define the optimal OACS and do a RATSCCH based optimisation on both air interfaces and on TRAU and TFO interfaces (to be described still, e.g. by inventing a

"Ratscch_Req" in addition to the Con_Req), within TFO, finally release the adaptation.

3) **All the other cases (slow mode change at least at one side or no change at one side)**
Here we do not know the SCS from the beginning and therefore the OACS is not known. On the other hand we could not prevent a later change. Therefore it is not recommendable to go quickly into TFO, because a change of the ACS in TFO would mean loss of speech communication. So first the SCS shall be exchanged and based on that the OACS can be determined. The change of the ACSs can be made independently. The TFO setup is performed. No fast TFO Setup is possible, but TFO is likely after optimisation.

In all cases the BSC is finally informed about TFO and the active configuration and the distant configuration parameters.

The configuration of the AMR codec is changed using one of the three methods listed in the sub-clause 8.3.2.1. This solves the point ② of the list provided in the sub-clause 8.3.2.

Annex A (Normative): Inband Signalling Protocol: Generic Structure

Scope

Inband Signalling Messages (IS Messages) can be used to construct a specific IS Protocol for the communication between telecommunication entities for various purposes. The original purpose is to establish tandem free operation of mobile-to-mobile calls in GSM networks. The IS Messages provide communication channels inside the speech signal paths between the speech transcoders.

In addition IS Messages allow the control of equipment within the speech signal paths between these telecommunication entities (e.g. speech transcoders). These equipments are termed "In Path Equipments" (IPEs).

Annex A defines the generic structure of these IS Messages and rules for the IS_Sender.

Annex B defines the generic rules with respect to these IS Messages for the IPEs.

Annex A is mandatory for TFO_TRAU Equipment and informative for IPEs.

Annex B is informative for TFO_TRAU Equipment.

Annex B shall be followed by IPEs, which want to be compatible to IS Messages.

A.1 Generic Structure of Inband Signalling Messages

All IS Messages follow a set of design rules, or a generic structure, which allow to identify and bypass them by IPEs without detailed knowledge of the IS Protocol served. The principle of the IS Protocol shall in that sense be future proof: it can be enhanced and extended to other applications without modifying the IPEs.

The IS Messages replace some of the LSBs of the PCM samples of the Speech, Audio or Modem signal.

By construction the introduced signal distortion is practically inaudible in case of Speech signals.

Modem signals will in most cases not be affected with respect to their data transmission performance.

A.1.1 Frequency and Order of Bit Transmission

IS Messages are transferred within the Least Significant Bit (LSB) of PCM samples on 64 kbit/s links, by replacing the LSB of every 16th consecutive PCM sample with one bit of the IS Message (16_PCM_Sample_Grid).

This is equivalent to an average bit rate of 10 bit per 20 ms or 500 bits per second. See Figure 14:

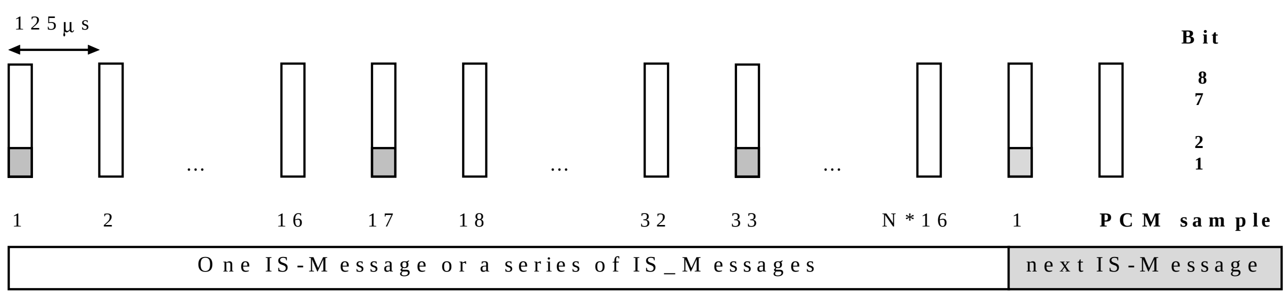


Figure 14: Inband Signalling Structure

A vertical bar denotes an 8-bit PCM sample, the shadowed box in bit 1 (LSB) represents an inserted bit of the IS-Message.

By definition each IS Message "occupies" an integer multiple of 16 PCM samples. Especially the 15 PCM samples after the last inserted bit of an IS Message "belong" still to that IS Message.

All IS Messages, whichever type, have by construction “0”-Bits at every 10^{th} position, starting with position 1, 11, 21 and so on. This “0”-Bits occur therefor regularly every 20 ms and may be used for synchronization purposes.

Each IS Message consists of an IS_Header followed by an IS_Command_Block. Most IS Messages have a number of further IS_Extension_Blocks. Figure 15 shows an example with two IS_Extension_Blocks.

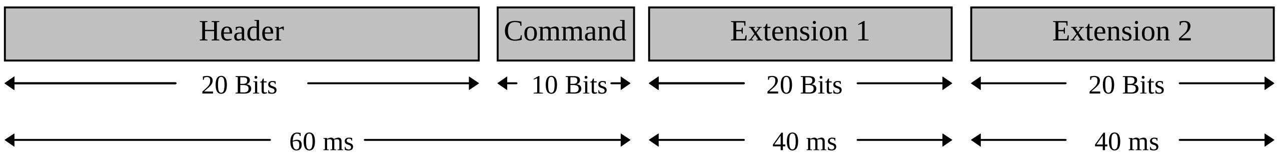


Figure 15: Example for IS Message with two IS_Extension_Blocks

The MSB of each constituent field is transmitted first. The IS_Header is transmitted first, followed by the IS_Command_Block and - if applicable - any further IS_Extension_Block(s).

By construction all IS Messages do have lengths of integer multiples of 10 bits, thus occupying integer multiples of 160 PCM samples, thus lasting integer multiples of 20 ms. The shortest IS Message has a length of 60 ms.

A.1.2 IS_Header

The IS_Header consists of a 20-Bit long sequence, as defined in Figure 16:

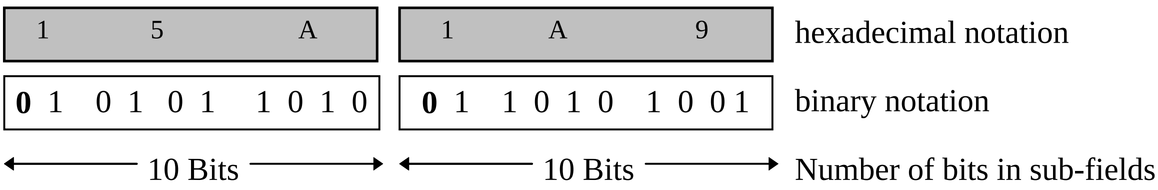


Figure 16: Structure of the 20 bit IS_Header

A.1.3 IS_Command_Block

The IS_Command identifies the IS Message and/or serves for the control of IPEs. The names of the IS_Commands and their codes in hexadecimal notation in the IS_Command_Block are given in the Table 34.

Table 34: Defined IS_Commands

Index	Command	Code	Meaning / Action
		hexadecimal Nibble 1-3	
0	reserved	0x000	no extension
1	**REQ**	0x05D	Denotes an IS_REQ Message, with extension
2	**ACK**	0x0BA	Denotes an IS_ACK Message, with extension
3	**IPE**	0x0E7	Denotes an IS_IPE Message, with extension, i.e. an IS_TRANS or the IS_NORMAL Message
4	**FILL**	0x129	Denotes the IS_FILL Message, no extension
5	**DUP**	0x174	Denotes the IS_DUP Message, no extension
6	**SYL**	0x193	Denotes the IS_SYL Message, no extension
7	reserved	0x1CE	no extension

All other values are reserved for future use.

Each IS_Command is protected by the binary, systematic (9,3) block code with generator polynomial $g(x) = x^6 + x^4 + x^3 + x^2 + 1$. The minimum Hamming distance of this code is dmin = 4, which allows the correction of up to one bit error within each code word of length 9 bits.

The first bit (MSB) of the IS_Command_Block is defined to be "0", for synchronisation purposes, see Figure 17.

Table 20 gives the hexadecimal notation of the complete IS_Command_Block.

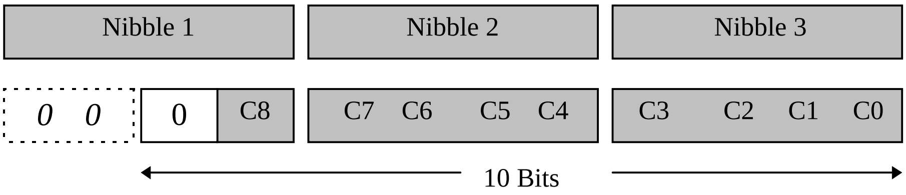


Figure 17: General Construction of an IS_Command_Block

A.1.4 IS_Extension_Block(s)

Most IS Messages have one or more IS_Extension_Block(s). Each IS_Extension_Block is 20 bits long and shall consist of two "0"-Synchronization_Bits at position 1 (MSB) and 11, a 16-bit Information_Field (split into two fields of 9 and 7 bits, respectively) and a 2-bit Extension_Field (EX), see Figure 18:

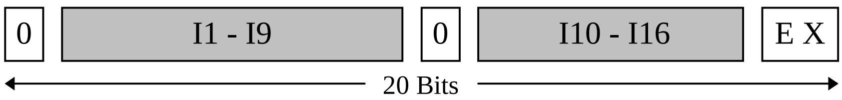


Figure 18: General Construction of an IS_Extension_Block

The Extension_Field indicates if an other IS_Extension_Block is following (EX :="1.1") or not (EX := "0.0").

All other codes are reserved. This may be used to detect transmission errors within the Extension_Field.

A.2 Detailed Specification of IS Messages

A.2.1 IS_REQ Message

With the IS_REQ Message an IS_Sender can test, if there is an IS Partner and indicates that it is willing to negotiate.

IS_REQ is used to initiate the IS Protocol or to indicate changes in the configuration, etc.

IS_REQ has at least one IS_Extension_Block, containing the IS_System_Identification. (see A.5).

Other IS_Extension_Blocks may follow, see Figure 19.

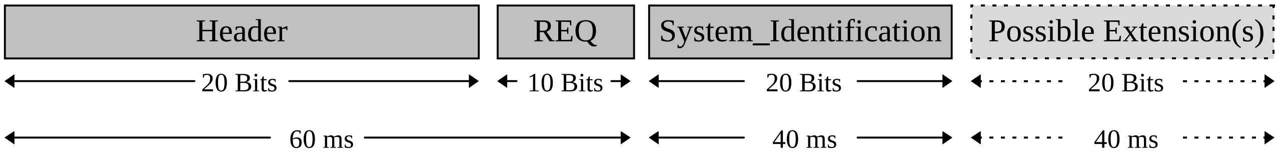


Figure 19: General Construction of an IS_REQ Message

In general an IS_REQ Message shall be as short as possible. Special care must be taken in the design of the IS_Extension_Blocks to avoid audible effects, since sometimes an IS_REQ Message may be transmitted for quite some time (several seconds).

A.2.2 IS_ACK Message

With the IS_ACK Message an IS Partner typically answers an IS_REQ Message or an IS_ACK Message. It can also be used to submit further information to the other IS Partner. IS_REQ and IS_ACK are the main message types between IS Partners.

The IS_ACK has at least an IS_Extension_Block containing the IS_System_Identification (see A.5).

Other IS_Extension_Blocks may follow, see Figure 20.

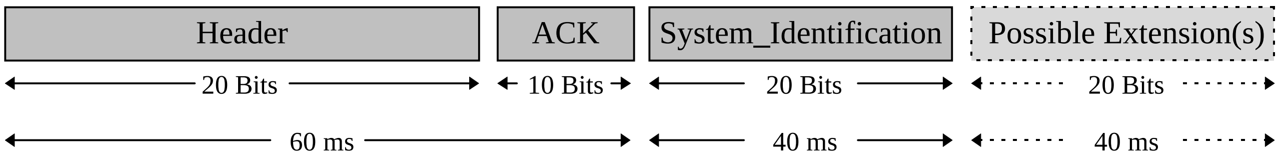


Figure 20: General Construction of an IS_ACK Message

No specific design constraints with respect to audibility exist, since IS_ACK is typically not sent very often.

A.2.3 IS_IPE, IS_TRANS and IS_NORMAL Messages

The IPE command denotes IS_IPE Messages. An IPE shall always look for this type of message and follow the instruction. An IS_Sender shall use this IS_IPE Message to command all IPEs into a specific mode of "Bit Transparency".

This Message has one IS_Extension_Block, indicating the requested IPE_Mode. See Figure 21.

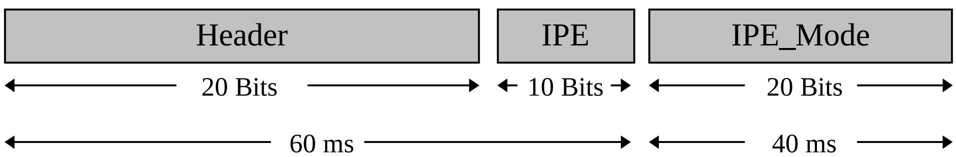


Figure 21: General Construction of an IS_IPE Message

No specific design constraints with respect to audibility exist, since IS_IPE is typically not sent very often.

Table 35 defines 16 out of 32 possible IPE_Commands. The other codes are reserved for future extensions.

Table 35: Defined IPE_Modes

Index	IPE_Mode	Code	MEANING / ACTION
		hexadecimal Nibble 1 - 5	
0	Normal	0x00000	Normal Operation
1	Trans_1_u	0x044DC	pass 1 LSB; 7 upper Bits are used
2	Trans_2_u	0x089B8	pass 2 LSBs; 6 upper Bits are used
3	Trans_3_u	0x0CD64	pass 3 LSBs; 5 upper Bits are used
4	Trans_4_u	0x11570	pass 4 LSBs; 4 upper Bits are used
5	Trans_5_u	0x151AC	pass 5 LSBs; 3 upper Bits are used
6	Trans_6_u	0x19CC8	pass 6 LSBs; 2 upper Bits are used
7	Trans_7_u	0x1D814	pass 7 LSBs; 1 upper Bit is used
8	Transparent	0x22CE0	Full Transparent Mode for all eight bits
9	Trans_1	0x2683C	pass 1 LSB; 7 upper Bits are free and unused
10	Trans_2	0x2A558	pass 2 LSBs; 6 upper Bits are free and unused
11	Trans_3	0x2E184	pass 3 LSBs; 5 upper Bits are free and unused
12	Trans_4	0x33990	pass 4 LSBs; 4 upper Bits are free and unused
13	Trans_5	0x37D4C	pass 5 LSBs; 3 upper Bits are free and unused
14	Trans_6	0x3B028	pass 6 LSBs; 2 upper Bits are free and unused
15	Trans_7	0x3F4F4	pass 7 LSBs; 1 upper Bit is free and unused
16	reserved	0x41D1C	reserved
17..31	reserved	reserved	reserved

The IPE_Mode is protected by the binary, systematic (16,5) block code with generator polynomial
g(x) = x^11 + x^7 + x^5 + x^4 + x^2 + x + 1. The minimum Hamming distance of this code is dmin=7, which allows the correction of up to 3 bit errors within each code word of length 16 bits.

Bits 1 (MSB) and 11 are the synchronisation bits and set to "0", see Figure 22. The EX field is set to "0.0" in all currently defined IPE_Modes, i.e. no further IS_Extension_Block is following.

Table 35 defines the coding in hexadecimal notation for the complete IPE_Mode_Extension_Block, with EX := 00.

Nibble 1	Nibble 2	Nibble 3	Nibble 4	Nibble 5
0 T_{15} T_{14} T_{13}	T_{12} T_{11} T_{10} T_9	T_8 T_7 0 T_6	T_5 T_4 T_3 T_2	T_1 T_0 E X

← **20 Bits** →

Figure 22: IPE_Mode_Extension_Block for the IS_IPE Message

An IS_ IPE Message containing the NORMAL command is termed **IS_NORMAL Message**.

An IS_ IPE Message containing a TRANS_x command is termed **IS_TRANS_x Message**.

An IS_ IPE Message containing a TRANS_x**_u** command is termed **IS_TRANS_x_u Message.**

The latter two are sometimes also termed **IS_TRANS Message**, if the details are not important.

The behaviour of IPEs, when receiving such commands, is described in Annex B.

The first IS Message in a series is often "swallowed" by IPEs (see Annex B). An IS_IPE Message must therefor never be the first message of a series of IS Messages, i.e. it shall be sent as an isolated IS Message or after a (sufficiently long) uninterrupted IS Protocol.

A.2.4 IS_FILL Message

The IS_FILL Message has no IS_Extension_Block and no specific meaning. An IS_ Sender can use the IS_FILL Message to fill a temporary gap in the protocol flow. This may be important to keep all IPEs in synchronization and open for further IS Messages. See Figure 23. An IS_FILL Message shall also be used by the IS_Sender to resynchronize all IPEs in case of a phase shift of the Keep_Open_Indication.

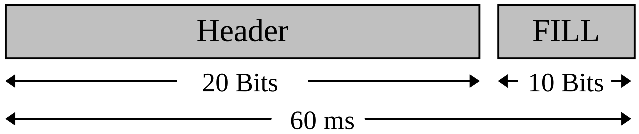


Figure 23: Construction of the IS_FILL Message

IS_FILL is designed in a way that multiple repetitions cause minimal audible effects.

A.2.5 IS_DUP Message

The IS_DUP Message may be used between IS Partners to indicate an half duplex mode. It may be especially important in Handover situations. The IS_DUP Message has no IS_Extension_Block, see Figure 24.

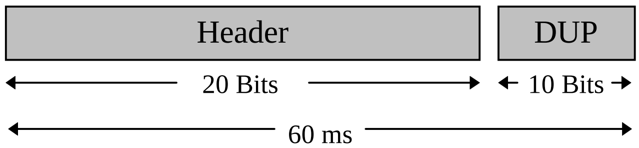


Figure 24: Construction of the IS_DUP Message

A.2.6 IS_SYL Message

The IS_SYL Message may be used between IS Partners to indicate the loss of synchronisation. It may be especially important in Handover situations. The IS_SYL Message has no IS_Extension_Block, see Figure 25.

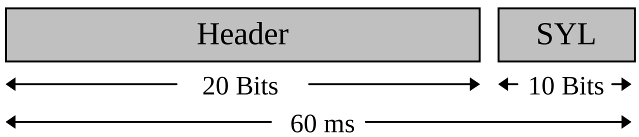


Figure 25: Construction of the IS_SYL Message

A.3 Keep_Open_Indication

In Transparent_Mode, i.e. after properly receiving an IS_TRANS Message, all IPEs shall monitor the bypassing bit stream for the Keep_Open_Indication (definition see below). If this Keep_Open_Indication is not seen for some time, then the IPEs shall fall automatically back into normal operation, i.e. the mode of operation before the IS_TRANS Message.

This automatic fall back shall have the same effect as the IS_NORMAL Message would have.

By definition the Keep_Open_Indication is a continuous bit stream of one "0"-Bit in the LSB of every 160^{th} PCM sample, i.e. every 20 ms. At least one "1"-Bit must be present within the LSBs of the other 159 PCM samples. See Figure 26.

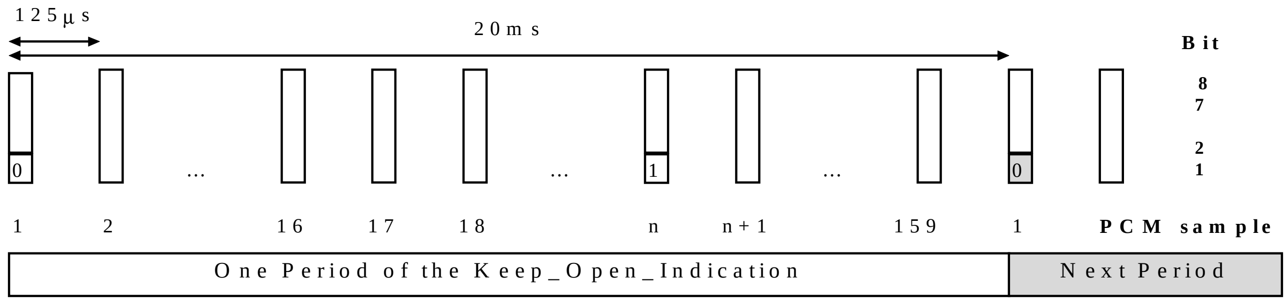


Figure 26: Keep_Open_Indication

The "0"-Bit stream of the Keep_Open_Indication shall always be present as long as the IPEs need to be in Transparent_Mode.

The Keep_Open_Indication shall be in phase with the preceding IS Messages., i.e. the first bit of the Keep_Open_Indication shall be in the position of the first bit of the (hypothetical) next IS Message. In fact, the IS Messages themselves contain this Keep_Open_Indication by definition.

In case of a known phase shift of the Keep_Open_Indication, the IS_Sender has to send at least one IS Message, which defines the new phase position of the Keep_Open_Indication. If no other IS Message is to be sent, then the IS_FILL Message shall be used. If an IS Message longer than 160 ms is scheduled for transmission, then an IS_FILL Message should be inserted before, to guarantee fast resynchronization of the IPEs.

A.4 Rules for Sending of IS Messages

IS Messages replace some bits of the PCM samples and therefor cause a minimal signal distortion. Therefore IS Messages shall be used with care and not longer than necessary. The IS Protocol is kept to a minimum to avoid unnecessary complexity. One basic assumption is that only one IS Protocol is active at a time between two IS Partners.

Only specific telecommunication entities shall be allowed to initiate IS Protocols. They are called **IS_Active** or active IS Partners. In principle these shall only be terminal devices or their "representatives" within the network. Examples are ISDN-Terminals, Speech-Servers, TRAUs (in GSM as representatives of the MSs).

Other telecommunication entities shall only react on IS Protocols. They are called **IS_Passive**. Most IPEs are of this type. They bypass the IS Messages, they obey the IS_IPE Messages, but they never initiate IS Messages.

Other telecommunication entities are IS_Passive by default. But if they receive IS Protocols that they can understand, then they may become IS_Active and start to initiate IS Protocols. They thus become active IS Partners and shall take care that only one IS Protocol is active on both of their sides. They are called **IS_Responsive.** Examples are TCMEs.

Active IS Partners shall send

either continuous sequences of IS Messages without interruption of the 16_PCM_Sample_Grid:

- or isolated IS Messages with same message lengths;
- or isolated IS Messages with sufficient distance between them, if shorter IS Messages follow longer IS Messages.

The latter case is important, because shorter isolated IS Messages travel faster through IPEs than longer ones, see annex B.

As said above, after initialization of an IS Message sequence, no interruption of the 16_PCM_Sample_Grid shall occur within the sequence. Adjustments of the phase position of the Keep_Open_Indication shall be done only after the IS_TRANS Message by inserting the necessary number n (with $0 < n < 160$) of "1" Bits (termed "T_Bits") into the LSBs of the PCM samples that have to be skipped. The first PCM sample for this insertion of T_Bits is the one where the next regular IS Message or next regular Keep_Open_Indication would begin. At the new phase position the next IS Message or the IS_FILL Message shall be sent, to allow IPEs to resynchronize fast. See Figure 27.

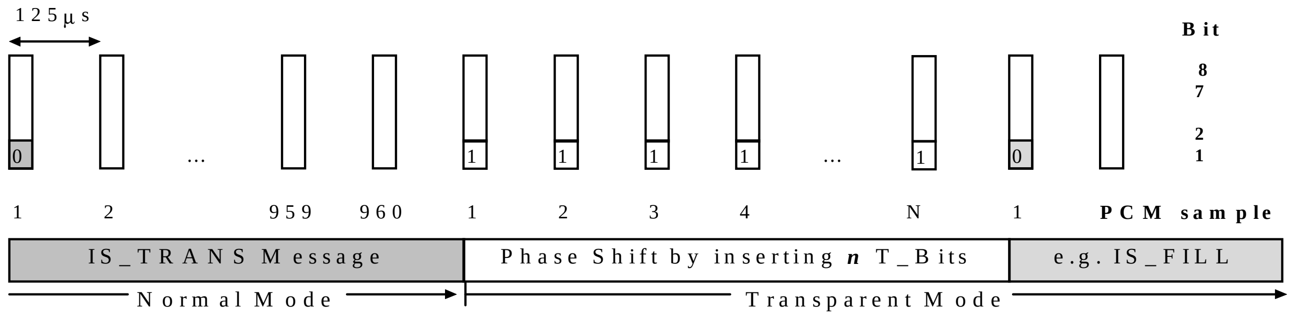


Figure 27: Phase Shift of the 16_PCM_Sample_Grid by inserting T_Bits

Similarly, the adjustment of the phase between two Keep_Open_Indications shall be done by inserting the necessary number of T_Bits and by sending an IS Message - preferably, but not necessarily - the IS_FILL.

Finally a "negative" phase adjustment between two Keep_Open_Indications shall be allowed by shortening the cycle by a maximum of 2 PCM samples and sending an IS Message (see above) at the new phase position.

A.5 IS_System_Identification_Block

The IS_System_Identification_Block is a mandatory IS_Extension_Block for the IS_ACK and IS_REQ messages with the 16-bit Information_Field containing the IS_System_Identification. It identifies the system within which the message is generated. Table 22 shows the defined IS_System_Identification codes.

Table 36: Defined IS_System_Identification Codes

System	Code (in hex)
GSM	either 0x53948, if EX == "0.0" or 0x5394B, if EX == "1.1"
	reserved

The only defined code so far is GSM_Identification, see also Figure 28.

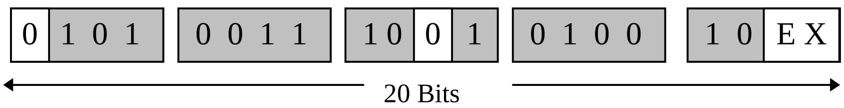


Figure 28: IS_System_Identification for GSM

All other codes are reserved. Further IS_System_Identification Codes for other systems shall be defined in a way that the audibility is minimal and the hamming distance to the already defined once is maximal.

The IS_System_Identification is protected by the binary, systematic (16,8) block code with generator polynomial g(x) = x^8 + x^7 + x^6 + x^4 + x^2 + x + 1. The minimum Hamming distance of this code is dmin=5, which allows the correction of up to 2 bit errors within each code word of length 16 bits.

Code word 0x0000 is per definition used for GSM.

The resulting 16 bits are placed into the IS_System_Extension_Block as shown in Figure 28 and then the whole 20 bit word is additionally EXORed with the fixed code word 0x53948 to minimise audible effects.

Annex B (Informative): In Path Equipment: Generic Rules and Guidelines

Scope

Inband Signalling Messages (IS Messages) can be used to construct a specific IS Protocol for the communication between telecommunication entities for various purposes. The original purpose is to establish tandem free operation of mobile-to-mobile calls in GSM networks. The IS Messages provide communication channels inside the speech signal paths between the speech transcoders.

In addition IS Messages allow the control of equipment within the speech signal paths between these telecommunication entities (e.g. speech transcoders). These equipments are termed „In Path Equipments" (IPEs).

Annex A defines the generic structure of these IS Messages and rules for the IS_Sender.

Annex B defines the generic rules with respect to these IS Messages for the IPEs.

Annex A is mandatory for TFO_TRAU Equipment and **informative for IPEs**.

Annex B is informative for TFO_TRAU Equipment.

It shall be followed by IPEs, which want to be compatible to IS Messages.

B.1 Types of In Path Equipment

The term "In Path Equipment" (IPE) is used for any telecommunication equipment within the (64 kbit/s) transmission path for the speech signal between two entities, which want to communicate via IS Messages, i.e. the IS Partners.

In modern telecommunication networks most of these IPEs are digitally transparent for the complete 64 kbit/s data stream all the time after call establishment until call release. These IPEs are optimal and need no consideration here.

Some IPEs are most of the time digitally transparent, but disturb the link every now and then. Examples are:

- switches, which interrupt the link during Handover;
- switches, which insert a kind of conference bridge for a short while during Handover;
- links, which do octet deletions or insertions (octet slips);
- DTMF generators, which insert DTMF tones sometimes for a short while; and more.

- Other IPEs are digitally transparent in one direction, but not in the other. Examples are:
  - DTMF generators (again), which insert the DTMF tones only in one direction;
  - Network Echo Cancellers (NEC), which let the signal pass unaltered towards the PSTN, but cancel the echo; and more.

Other IPEs are semi-transparent, i.e. let most or some of the bits pass, but not all. Examples are:

- A/μ_Law converters;
- μ/A_Law converters; and
- especially the tandem connection of A/μ_Law and μ/A_Law converters, or vice versa.

links, which insert inband signalling by bit stealing (T1 links); and more.

Other IPEs are not transparent at all to the digital bit stream, although the speech signal pass more or less unaltered. Examples:

- level shifters, which adjust the signal levels, e.g. between national networks;
- DCMEs (Digital Circuit Multiplication Equipment), which compress the bit stream by encoding/decoding the speech signal for cost efficient transmission; and more.

Many of these IPEs - for some time - will be not compliant with the IS Message principle described above. The IS Messages will not pass these non-compliant IPEs or not in both directions, or not always. Care must be taken to identify situations where IPEs are part-time-transparent or semi-transparent, when applying IS Messages. Other IPEs - at some point in time in the future - will be compliant to the IS Message principle. The rules they have to fulfil are described below.

B.2 IS_Compliant IPEs

B.2.1 Typical IPEs are IS_Passive

General: An IPE shall ***never*** actively initiate the exchange of IS Messages. The active initiation is only done by terminals or their "representatives". This avoids uncontrolled and unnecessary fluctuation of IS Messages within the network.

Most IPEs shall never actively respond to IS Messages by sending other IS Messages. They are called ***IS_Passive***.

They need not and do not understand the IS Protocol, but let it just pass unaltered and obey the relevant IS_IPE Messages.

Some IPEs may, however, respond on received IS Messages, modify these and/or respond with own IS Messages, ***if*** they understand the IS Protocol and can take or bring advantage to the overall system performance or system quality. These IPEs are called ***IS_Responsive***. Examples are GSM-specific Digital Circuit Multiplication Equipments (TCMEs), which reduce transmission costs without degrading the speech quality. These IPEs may be able to step into the IS Protocol, interpret and respond to it and modify the speech signal in an system_compliant way. Thus they become ***IS_Active*** Partners themselves.

B.2.2 IS Message_Transparency

When commanded into a Transparent Mode, the IPEs are fully transparent at least for the LSBs in all PCM samples. Therefore the following rules are needed only and only do apply for the IPEs, when in Normal_Mode:

IPEs shall let the IS Messages bypass, respectively re-insert them, from their input to their respective output.

They shall not alter them, nor do any kind of error correction. Exceptions are the IS_Responsive IPEs.

B.2.2.1 First IS Message

During its **Normal_Mode** an IS_Compliant IPE shall always monitor the incoming PCM data stream for the occurrence of the IS_Header sequence. If the IS_Header is detected after a period without IS Messages, the IPE shall store the following IS_Command and IS_Extension_Block(s). During reception of this first IS Message, the normal operation of the IPE is maintained with the consequence that the first IS Message may not appear at the output of the IPE.

B.2.2.2 IS Messages within a Sequence

All further IS Messages which follow directly after the first detected IS Message in the same phase position shall be passed unaltered to the output of the IPE with exactly that delay the IPE would later introduce when commanded into Transparent_Mode by one of the IS_TRANS commands, see Figure 29.

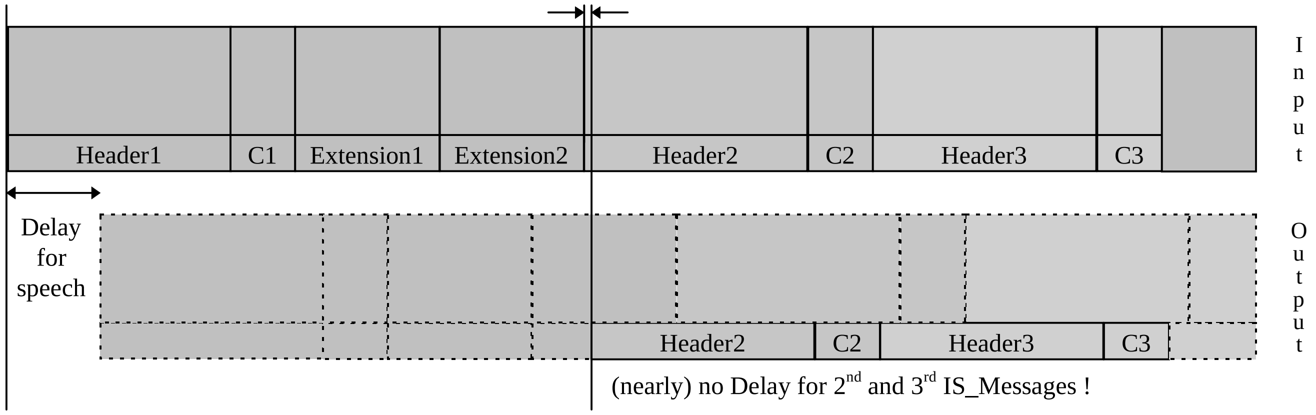


Figure 29: Transparency and Delay for first and following IS Messages

The upper row symbolizes the speech signal at the input of the IPE, with the PCM samples drawn vertically and the IS Messages inserted into the LSBs. The lower row symbolizes the speech signal at the output of the IPE. The vertical lines denote the boundaries of the IS Message elements.

Figure 29 shows an example where the first IS Message is detected, but not passed through. The distortion caused by the first IS Message is still "somehow" there (indicated by the empty dashed boxes in the LSB), but the message is destroyed. The second and third IS Messages are passed through unaltered. Note, however, that the delay of the speech signal is (in this example) substantially higher than the delay of the IS Messages. They travel faster than the speech signal through this IPE.

B.2.2.3 Isolated IS Message

In cases where the first detected IS Message is not immediately followed by further IS Messages, the IPE shall insert this first IS Message (which the IPE has stored) into its output PCM bit stream, with exactly the delay and phase position a second IS Message would have, see Figure 30, which shows an example where an isolated IS Message is travelling through an IPE.

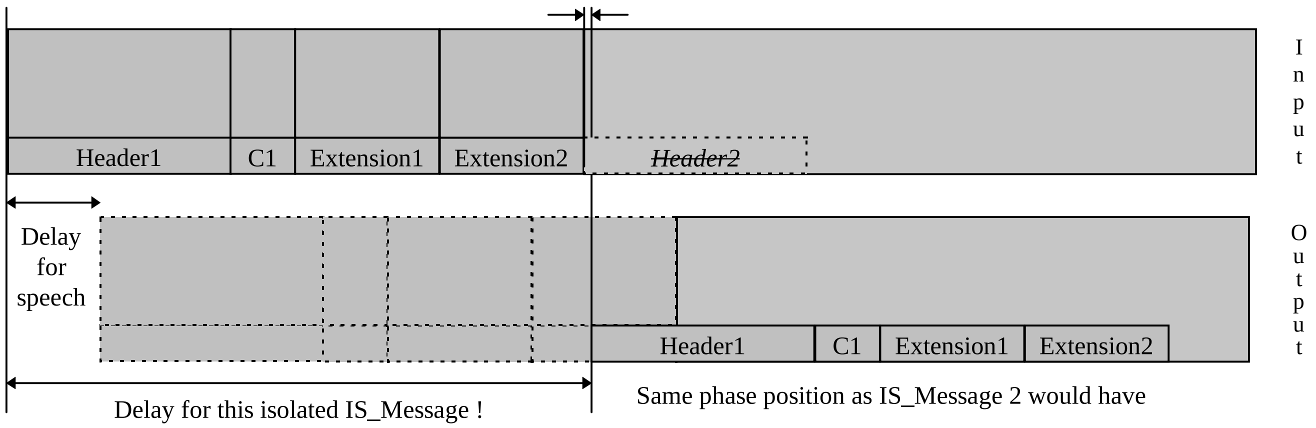


Figure 30: Transparency and Delay for an isolated IS Message

Note that the delay of an isolated IS Message is depending on its own length! Longer IS Messages will have more delay, shorter less. It could - in principle - happen that a second, shorter isolated IS Message would "bypass" the first longer IS Message - with the consequence that the first one would be destroyed. This is especially important when there are several IPEs in the path, since the delay effects accumulate. Therefore it is not allowed to send shorter isolated IS Messages too close after longer IS Messages. IS Messages with same length have no restriction.

In summary: the first IS Message in a series of IS Messages is "swallowed" by an IPE, while all the following IS Messages pass unaltered and with minimal delay. If an IS Message occurs isolated, then it is not swallowed, but delayed by exactly its own length. The latter mechanism ensures that isolated IS Messages can pass through an unlimited number of IPEs.

B.2.2.4 Check if IS Message is following

The checking, whether an other IS Message is following or not is done "on the fly", i.e. bit by bit. This is possible due to the fact that all messages begin with exactly the same IS_Header. The decision, whether an IS Message is an isolated message or the first message in a series, can be done latest after the last bit of the (next) IS_Header. See Figure 28.

Consequently: after detection of the first IS Message, the IS_Header is in any case inserted at the output in the correct position, regardless, whether a second message follows or not.

B.3 IPE State Representation

Concerning the IS Protocol, an IPE can be described with five major States in two main Modes, where the States describe the IPE with respect to the IS Protocol and the Modes describe the IPE with respect to the operation on PCM data. Figure 31 shows a graphical representation of the State diagram of an IPE.

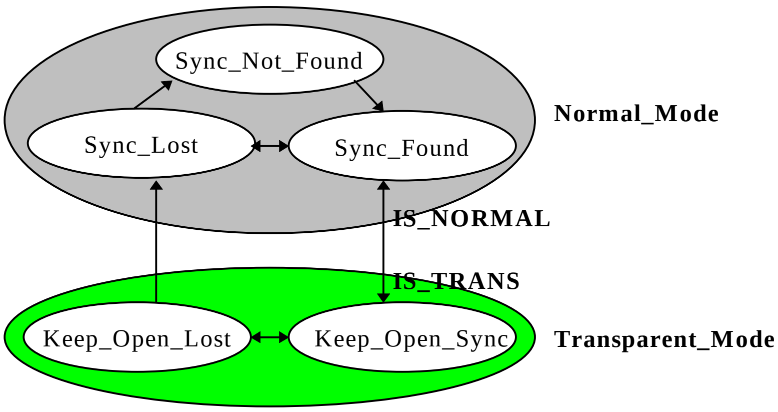


Figure 31: Principle of a State Diagram of an IPE

Some Definitions:

An IS Message shall be recognized as "*error-free*", if no error can be detected, neither within the IS_Header, nor in the IS_Command nor in any IS_Extension_Block.

An IS Message shall be recognized as "*single-error*", if no more than one bit position differs in the IS_Header or the IS_Command_Block or the IPE_Mode_Block or one EX-field or one Sync bit.

An IS Message shall be recognized as "*correctable*", if the phase position is as in preceeding IS Messages and:

- no more than 2 bit position differs in the IS_Header; and
- no more than 1 error is detected within the IS_Command_Block; and
- no more than 3 errors are detected within the IPE_Mode_Block; and
- no more than 0 error is detected within the EX-field(s); and
- no more than 1 error is detected within the Sync-Bit(s); and
- the total number of detected errors is not higher than 3.

IS Messages, which are error-free, single-error or correctable are also called "*valid*" IS Messages.

An IS Message shall be recognized as "*present*", if the phase position is as in preceeding IS Messages and:

no more than 4 bit position differs in the IS_Header and

- no more than 2 errors are detected within the IS_Command_Block; and
- no more than 3 errors are detected within the IPE_Mode_Block; and
- no more than 1 error is detected within the EX-field(s); and
- no more than 2 errors are detected within the Sync-Bit(s); and
- the total number of detected errors is not higher than 4.

Sequences, which differ in more than "present" are not recognized as IS Messages at all ("not_present").

Note that the insertion of T_Bits may change the phase position of an IS Message. The IS Message shall in that case be classified after the removal of the T_Bits.

An octet slip may also change the phase position of an IS Message. If an error-free or a single-error IS Message can be found after considering a hypotetical octet slip (±1 sample), then it may be regarded as error-free or single-error and the new phase position shall be regarded as valid, if no valid or present IS Message can be found at the old phase position.

B.3.1 IPE in Sync_Not_Found

After start-up or after a long interruption of the IS Protocol an IPE is in Normal_Mode, performing its normal operation. IS Messages have not been found and consequently no bypassing of IS Messages is performed.

The algorithm for initial synchronization shall be able to detect each single IS Message, especially the first or an isolated one. An IPE shall always, during Normal_Mode and during Transparent_Mode, search for the IS_Header and consequently for complete IS Messages. When found, it can be assumed that with high probability the following IS Messages and the Keep_Open _Indication will stay within the found "grid"or "phase" of every 16^{th} PCM sample, the ***16_PCM_Sample_Grid***.

An IPE transits from Sync_Not_Found into Sync_Found, if and only if an error_free IS Message is detected. Then the IPE lets the following IS Messages bypass, as described above.

If the first IS Message is an error_free IS_TRANS Message, then the IPE transits directly into the Transparent_Mode.

B.3.2 IPE in Sync_Found

The IPE continues its normal operation, but opens an "***IS_Door***" every 16th LSB for the bypassing IS Messages.

An IPE shall regard sync as continued, i.e. stay in Sync_Found, if after each IS Message another valid IS Message follows within the same phase position, i.e. within the 16_PCM_Sample_Grid.

For any deviations from a valid IS Message, the IPE transits to Sync_Lost.

If an error_free or correctable IS_TRANS is received in Sync_Found, then the IPE transits into the Transparent_Mode.

B.3.3 IPE in Sync_Lost

In Sync_Lost, an IPE shall search for IS Messages on all positions as for initial synchronisation. In parallel, an IPE shall bypass not_valid, but present IS Messages at the found phase position for a maximum of one second. An IPE shall close the IS_Door after that, if no valid IS Message is following, i.e. transit into Sync_Not_Found.

A single valid IS Message brings the IPE back into Sync_Found.

As soon as the IPE detects in Sync_Found or in Sync_Lost a single or more deviations from an error_free IS Message, then the IPE may optionally open the IS_Door also at positions ±1 around the present (0) phase position for a maximum of one second] to allow other IPEs in the path for parallel re-synchronization. See Figure 32. The IPE may try to find a continuation of the disturbed IS Message at these 3 positions. If the IPE can detect an error-free or a single-error IS Message in this way, then it shall accept the new phase position, if no IS Message can be found at the old phase position anymore.

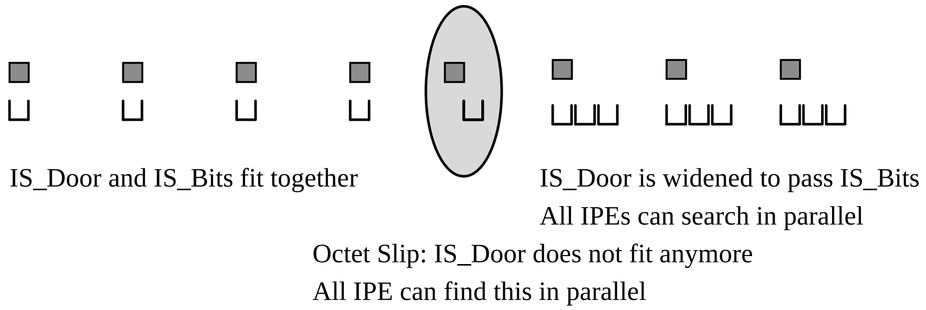


Figure 32: Handling of octet slip for fast and parallel re-synchronization of all IPEs (optional)

B.3.4 IPE in Keep_Open_Sync

The IPE enters this State by receiving a valid IS_TRANS Message. This is the main State of the Transparent_Mode.

It depends on the specific IPE, if this Transparent_Mode is active only for the commanded direction (that is the default assumption) or in both directions (because for a specific IPE it might be useless or impossible to maintain Normal_Mode in one direction and Transparent_Mode in the other one).

The IPE shall bypass the commanded LSBs and handle the upper bits accordingly (IPE specific).

The IPE shall search in parallel for IS_IPE Messages (IS_TRANS, IS_NORMAL) and

transit - if necessary - to Normal_Mode or an other Transparent_Modes (other number of transparent LSBs).

The IPE shall monitor the bypassing bit stream for the Keep_Open_Indication and accept the Keep_Open_Indication only at the phase position defined by the preceding IS Message.

If the Keep_Open_Indication is not seen anymore then the IPE transits into Keep_Open_Lost.

B.3.5 IPE in Keep_Open_Lost

The IPE shall continue its operation in Transparent_Mode and Keep_Open_Lost for a maximum of one second before it shall return to Normal_Mode.During that time the IPE shall try to resynchronize either by finding an IS Message or by finding the Keep_Open_Indication at positions ±1 and 0 around the present phase position (handle of Octet Slip).

The IPE may take advantage of the fact that T_Bits are inserted or deleted by the IS_Sender in case of an intentional phase adjustment.

An IS Message at any arbitrary phase position followed by a valid Keep_Open_Indication is accepted as re-defining the Keep_Open phase position, if and only if the Keep_Open_Indication is no longer present at the old phase position.
A Keep_Open_Indication at a phase position ±1 PCM sample interval around the old phase position is accepted as re-defining the Keep_Open phase position, if and only if the Keep_Open_Indication is no longer present at the old phase position.

The Keep_Open_Indication is ***valid***, as long as at least 40 "0"-Bits are seen at the correct positions within a sliding window of length of one second. At least one "1"-Bit must be seen in between each pair of the expected "0"-Bits.

B.4 IPE Error Handling

The **first** IS_Message shall only be accepted, if there is no detectable error.

For all following IS_Messages it shall apply:

Errors in IS Messages shall be passed unaltered through the IPEs. This shall hold for all IS Messages.

Only error-free or correctable IS_IPE Message shall be applied by the IPE to its own operation. Other IS_IPE Messages shall be ignored, but bypassed.

B.5 IPE Transmission Delay

The transmission delay introduced by an IPE for the speech, audio or modem signal is in general different in Normal_Mode and Transparent_Mode. Some IPEs may have several different Normal_Modes with possibly different signal delays. IS Messages are transmitted within the regular 16_PCM_Sample_Grid. It is important that this regularity is not disturbed. Therefor care must be taken at the transition between these modes.

The transmission delay of a specific IPE is in general lower for IS Messages than for speech, audio or modem signals.

B.5.1 IPE Transmission Delay in Normal_Mode

The delay for IS Messages in Normal_Mode shall be identical to the delay in that Transparent_Mode, that follows after the first IS_TRANS Message. If different Transparent_Modes with different delays could follow, then the shortest delay of all possible Transparent Modes shall be selected for IS Messages in Normal_Mode.

If an IPE in Normal_Mode has to change its transmission delay, then this shall not affect the delay of the IS Messages.

B.5.2 IPE Transmission Delay in Transparent_Mode

In the majority of all cases the IPE will keep the transmission delay for the IS Messages in Normal_Mode also in Transparent_Mode for the transmission of the commanded transparent LSBs. IPEs which do not understand the IS Protocol shall never modify the transparent bits, so they are also not allowed to change delay.

Some IPEs, which understand a specific IS Protocol, may have even different Transparent_Modes and also here the transmission delays may differ. Examples are TCMEs.

If an IPE has to change its transmission delay at the transition from Normal_Mode to Transparent_Mode, then the IPE shall readjust the phase of the Keep_Open_Indication after transition into the Transparent_Mode with higher delay by inserting the relevant number of T_Bits after the first IS_TRANS Message and before the next IS Message. If no other IS Message is following, then the IS_FILL shall be inserted, obeying all other relevant rules of the specific IS Protocol (e.g. EMBED bit C5 in TFO Frames).

If an IPE has to change from one Transparent_Mode to an other one with a different transmission delay, then the IPE shall readjust the phase of the Keep_Open_Indication after transition into the new Transparent_Mode by inserting the relevant number of T_Bits. If no other IS Message is following, then the IS_FILL shall be inserted at the new phase position to mark the new grid position of the 16_PCM_Sample_Grid and to allow other IPEs to resynchronize, obeying all other relevant rules of the specific IS Protocol (e.g. EMBED bit C5 in TFO Frames).

B.6 Compliance to IS Messages

An IS_Compliant IPE shall be capable of interpreting and obeying the IS_IPE Messages.

It depends on the intelligence and task of an IPE, how many and which of the other IS Messages it needs to understand.

The IPEs shall synchronise to all IS Messages, especially to find or refind the Keep_Open_Indication. All IPEs shall resynchronize, if they see an IS Message in a new phase position, and if the synchronization can not be found in the old phase position anymore.

B.6.1 Compliance to IS_REQ and IS_ACK Messages

Most IPEs need not and do not understand these messages. They just synchronise to them and let them pass unaltered.

Only IS_Responsive IPEs may take advantage. This is system specific and IPE specific.

B.6.2 Compliance to IS_NORMAL Message

The IPE shall act in response to the receipt of an IS_NORMAL Message such that:

The IPE shall synchronise to it. The message shall appear unchanged at the output of the IPE.

The IPE shall resume its Normal_Mode of operation for all data received subsequent to the IS_NORMAL Message, until a different command is received.

It depends on the type and operation of the specific IPE, whether the Normal_Mode is resumed in both directions, or only in the direction in which the IS_NORMAL Message flows. It must be assumed that in general only this one direction is affected.

B.6.3 Compliance to IS_TRANS_x Messages

The IPE shall act in response to the receipt of an IS_TRANS_x Message (x in the range 1 to 8) such that:

The IPE shall synchronise to it. The IS_TRANS_x Message shall appear unchanged at the output of the IPE.

The IPE shall be transparent in all x LSBs of all PCM samples received subsequent to the IS_TRANS Message.

The transparency shall persist as long as the Keep_Open_Indication persists, or until a different command is received.

The (8-x) upper bits of the PCM samples are not of interest and may be modified arbitrarily by the IPE.

It depends on the type and operation of the specific IPE, whether the Transparent_Mode is resumed in both directions, or only in the direction in which the IS_TRANS Message flows. It must be assumed that in general only this one direction is affected.

B.6.4 Compliance to IS_TRANS_x_u Messages

The IPE shall act in response to the receipt of an IS_TRANS_x_u Message (x in the range 1 to 7) such that:

The IPE shall synchronise to it. The messages shall appear unchanged at the output of the IPE.

The IPE shall be transparent in all x LSBs of all PCM samples received subsequent to the IS_TRANS Message.

The transparency shall persist as long as the Keep_Open_Indication persists, or until a different command is received.

The (8-x) upper bits of the PCM samples are important and in general shall not be modified by the IPE, but shall be bypassed transparently in exactly the same manner and delay as the x LSBs. It is important that this transparency for the upper bits is provided by IPEs that do not understand the specific IS Protocol (e.g. do not understand the IS_System_Identification or the protocol of the transmitted parameters).

Only IPEs which do ***exactly*** understand the specific IS Protocol shall take advantage of the opportunities given with the IS_TRANS_x_u Messages. An example is the TCME, which transmits internally only the coded speech parameters and re-generates the upper x bits at its output (termed here as "first solution"). The resulting delay in the upper 8-x bits shall be identical to the delay in the x LSBs.

If this transparency of the upper (8-x) bits or their re-generation can not be established, then the upper bits shall contain a constant pattern, giving the least output energy (PCM_Silence). This "second solution" may cause temporary interruptions of the speech signal in some transition cases (e.g. hand over in some tandem free GSM mobile-to-mobile calls). Therefore the first solution is the preferred one.

IPEs, which implements the second solution shall switch to the full transparent 64 kbit/s channel as soon as they loose synchronisation with the protocol of the transmitted parameters (e.g. the "TFO Frames" in GSM Systems). The full transparency shall be executed for both directions. The near side shall be fully transparent in less than 60 ms and the other side the one way delay of that IPE later.

It depends on the type and operation of the specific IPE, whether the Transparent_Mode is resumed in both directions, or only in the direction in which the IS_TRANS Message flows. It must be assumed that in general only this one direction is affected.

B.6.5 Compliance to IS_FILL Message

The IS_FILL Message has no specific meaning, but may serve for two purposes.

First of all, it can be used to close the gap in an IS Protocol to keep all IPEs synchronized. Otherwise - in case of an interruption - the ***n*** IPEs in the path would swallow the next ***n*** IS Messages again.

Second, an IS_FILL Message can be used to resynchronize all IPEs to a new grid position, if necessary.

B.6.6 Compliance to IS_DUP Messages

The IS_DUP Message is sent by an IS Partner to the distant IS Partner to inform about a specific Half_Duplex reception.

Most IPEs need not and do not understand this message. They just synchronize to it and let it pass unaltered.

Only IS_Responsive IPEs may take advantage. This is system specific and IPE specific.

B.6.7 Compliance to IS_SYL Messages

The IS_SYL Message is sent by an IS Partner to the distant IS Partner to inform about a specific Sync_Lost Situation.

Most IPEs need not and do not understand this message. They just synchronize to it and let it pass unaltered.

Only IS_Responsive IPEs may take advantage. This is system specific and IPE specific.

Annex C (Informative): The SDL model of the TFO protocol

The SDL model does not take the AMR into account.

This annex contains a few *selected* pages from the formal SDL model of the protocol for Tandem Free Operation described in the main body of this standard. The *complete* SDL specification, *which is fully simulateable*, is available in various electronic formats as described below.

The SDL model gives a precise description of the *logical* behaviour of the TFO protocol. It is not intended to imply a particular way of implementing the protocol nor does it intend to restrict an implementation only to what is specified in the SDL.

This is not a real-time model and critical timing requirements have not been included. These are fully described in the main text of this standard, for example clause 7. The purpose of this SDL specification is to give a clear and unambiguous understanding of the TFO protocol with respect to the temporal ordering and interchange of TFO messages over the A-interface.

The SDL specification models the TFO messages as described in clause 6, the TFO processes as described in clause 8 and the TFO protocol as described in clauses 9 and 10. Additionally, it illustrates the use of Table 19 (clause 11) for resolving codec mismatch. In the case of a conflict between the SDL model and clauses 9 and 10, clause 9 and 10 shall have precedence.

The SDL model is available in electronic format in the zip archive **TFO_SDL.zip**. This archive can be found on the ETSI CD-ROM together with the TFO standard.

TFO_SDL.zip contains the following files:

- **README.txt**

  how to install and use the simulateable model

- **TFO_PDF.pdf**

  the complete SDL specification in graphical format as a .pdf file

- **TFO_CIF.pr**

  the complete SDL specification in machine processable format as a .pr file

- **TFO_SDT**

  a directory containing all the SDT (version 3.2) source files

If you have any questions related to the SDL model please contact: *pex@etsi.fr*

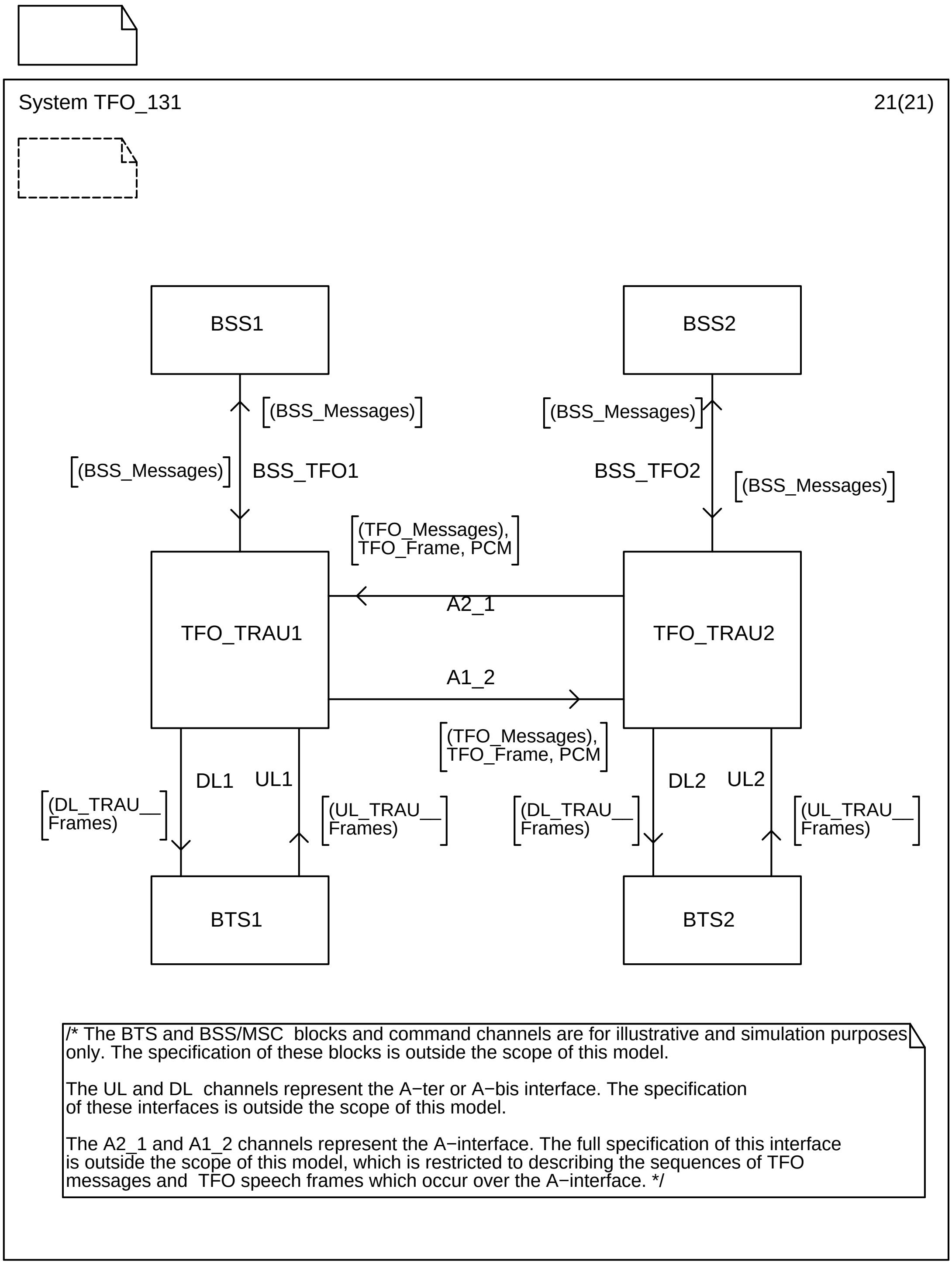


Figure 33: Overall SDL model structure

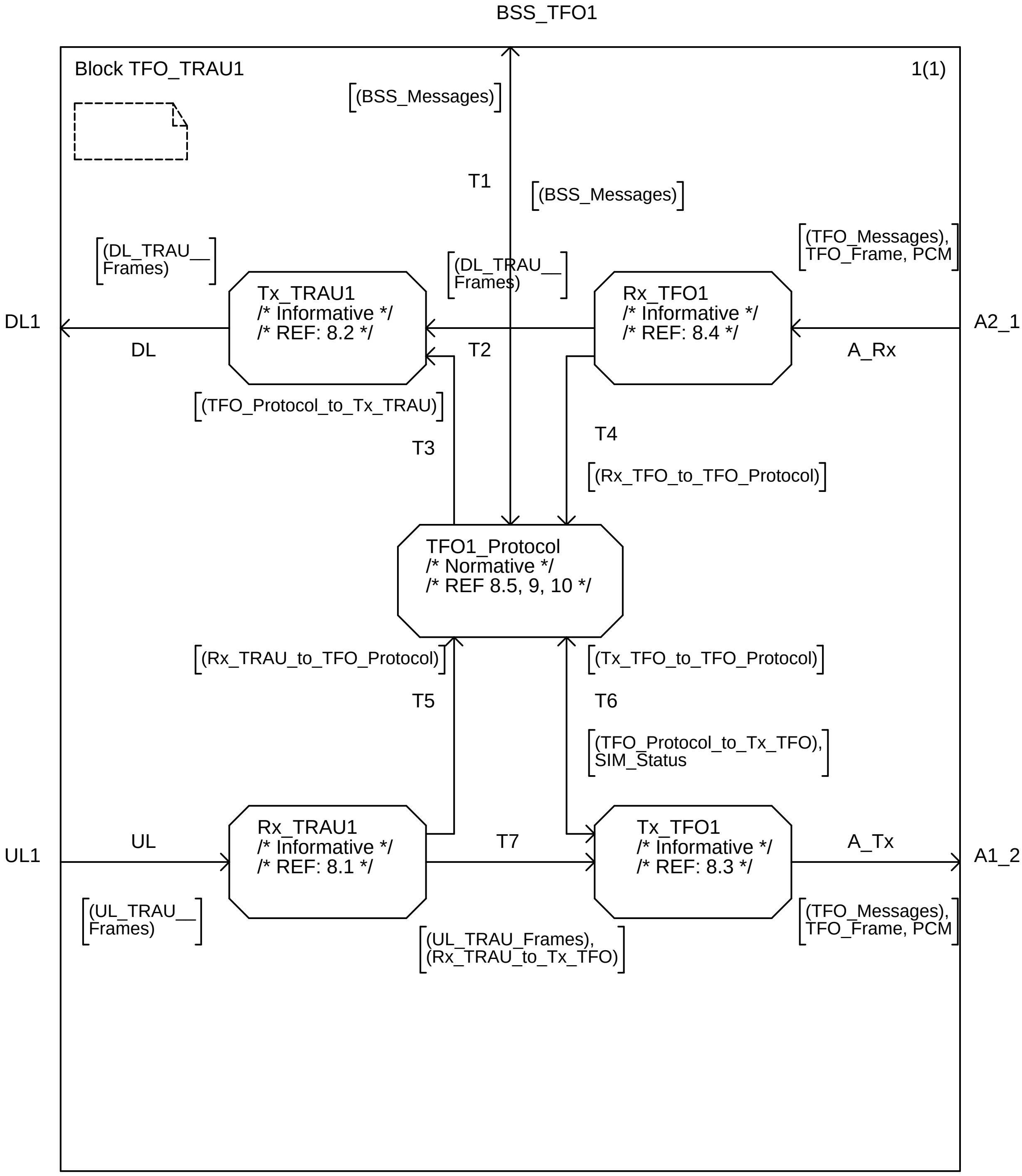


Figure 34: TFO/TRAU SDL process diagrams

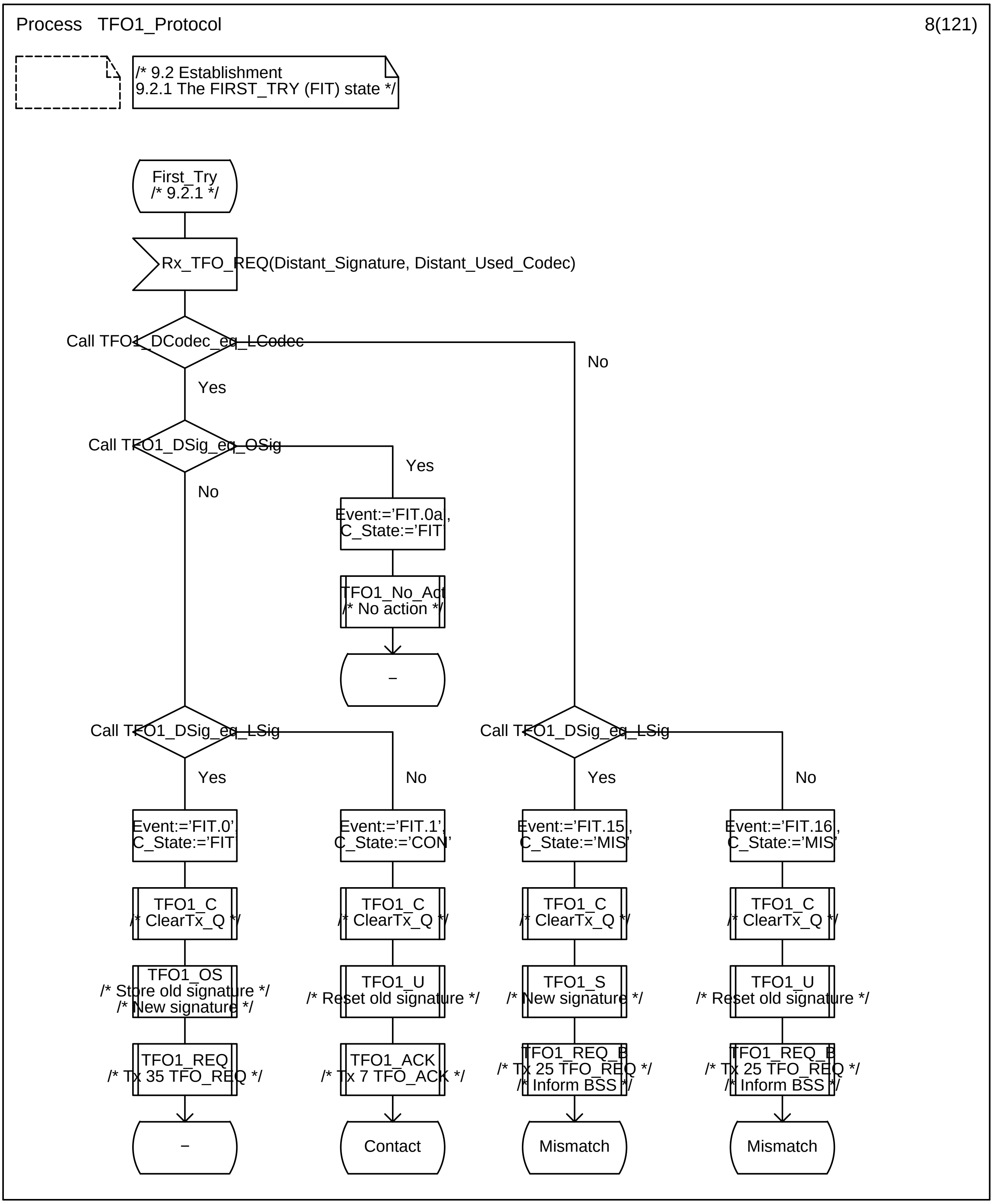


Figure 35: Partial TFO protocol transition (taken from the First_Try state)

The complete SDL for the TFO messages, TFO process and the TFO protocol transitions corresponding to the protocol matrix given in clause 10 can be found in the electronic SDL files.

History

Document history		
V2.0.0	February 1999	
V7.0.0	February 1999	
V7.1.0 (v1.0.)	September 1999	First draft of the CR, edited by Nortel Networks
V7.1.0 (v2.0)	October 1999	Support of AMR, edited by Nortel Networks
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