Tandem Free Operation Simulator for Wireless Communications

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Abstract

Speech coding is used as an effective method to achieve bandwidth efficiency. The disadvantage of using speech compression is that it introduces signal distortion, which becomes more severe if a signal is passed through a series of coder/decoder operations. There are encoders and decoders (or transcoders) present in the mobile handsets as well as in the base stations. The transcoders in the base stations provide a considerable gain in system capacity but degrade the speech quality. Any call originating at a mobile is first converted into a compressed digital bit stream at the base station, then decoded to a 64 kbps digital signal for transmission over the terrestrial network. If the call destination is another mobile, another coding from 64 kbps to the compressed digital bit stream must take place, degrading the speech signal a second time. The speech quality may be improved if the compressed signal is not decoded at the terrestrial interface, but rather is transmitted as a data signal to the destination mobile, avoiding one of the coding steps.

This approach has recently been standardized as the Tandem Free Operation (TFO) protocol. TFO *bypasses* the decoder if a call is destined to another mobile telephone. The motivation behind this is that by removing the transcoding performed in the base stations, better end-to-end speech quality is realized.

This report studies the behavior of the TFO protocol standard. TFO is applicable only if the transmitting and destination mobiles use the same speech coding algorithms. The standard describes two different state machines that perform the same TFO functionality. The difference being that one state machine has additional states to handle hand-offs and the other does not. The main goal of this report is to investigate the need for the extra states. In this study, a high-level language is used to simulate the TFO protocol. Specific tests are performed, such as, for local and distant hand-offs. The results reveal that the additional hand-off information does not contribute significantly to its performance.

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Abbreviations and Acronyms

ACELP	Algebraic Code Excited Linear Prediction (TIA/EIA-136-410)
AMR	Adaptive Multi-Rate
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver System
CDMA	Code Division Multiple Access
Codec	Coder/Decoder
CON	Contact state
COR	Continuous_Retry state
CRC	Cyclic Redundancy Check
DCME	Digital Circuit Multiplication Equipment
EVRC	Enhanced Variable Rate Codec (TIA/EIA/IS-127-1)
EFRC	Enhanced Full-Rate Codec
EIA	Electronic Industries Association
ETSI	European Telecommunications Standards Institute
FAC	Fast_Contact state (only in state machine A)
FAI	Failure state (only in state machine A)
FAT	Fast_Try state (only in state machine A)
GSM	Global System for Mobile Communications
HO	Hard Handoff in the case of TIA/EIA-95; Handover with TRAU change involved in the case of TIA/EIA-136
IPE	In Path Equipment
KON	Konnect state
LSB	Least Significant Bit
MIS	Codec Mismatch state
MON	Monitor state
MS	Mobile Station
MSC	Mobile Switching Center
NAC	Not_Active state

NSS	Network and Switching Subsystem
OMC	Operating Maintenance Center
OPE	Operation state
OSS	Operating Support Subsystem
PCM	Pulse Coded Modulation
PER	Periodic_Retry state
PSTN	Public Switched Telephone Network
Q8	Speech Codec Service Option 1 for TIA/EIA-95 at 8 kbps (TIA/EIA-96-C)
Q13	Speech Codec Service Option 17 for TIA/EIA-95 at 13.3 kbps (TIA/EIA/IS-733-1)
REK	Re_Konnect state (only in state machine A)
SCCP	Signalling Correction Control Part
SMG	Special Mobile Group
SOS	Sync_Lost state (only in state machine A)
SS7	Signalling System number 7
TAN	Tandem state (only in state machine B)
TCME	TFO Circuit Multiplication Equipment
TDMA	Time Division Multiple Access
TFO_ACK	TFO Acknowledgement Message
TFO_ACK_L	TFO Acknowledgement Message during a codec mismatch
T_Bits	Time Alignment Bits
TFO	Tandem Free Operation
TFO_DUP	TFO Distant Handoff message
TFO_FILL	TFO Fill Message
TFO_TRANS	TFO Transparent Mode Message
TFO_NORMAL	TFO Normal Mode Message
TFO_REQ	TFO Request Message
TFO_REQ_L	TFO Request Message during codec mismatch
TFO_SYL	TFO Sync Lost Message
TIA	Telecommunications Industry Association
TRAU	Transcoder and Rate Adapter Unit - this unit performs speech encoding and decoding on the network side of the communications system according to the codec standard selected
TRX	Radio transceiver station
TTL	TRAU-TRX-Link
UI	User Interface
US1	US 1 Codec (TIA/EIA - 136 - 430)

Vocoder	Voice coder/decoder
VSELP	Vector Sum Excited Linear Predictive Coding (TIA/EIA–136–420)
WAK	Wakeup state

Chapter 1

Introduction

Mobile communications has advanced rapidly in the recent years. The capability to offer wireless communications to an entire population was not even conceived (by Bell Laboratories) until the 1960s and 1970s [6-8]. The beginning of the wireless communications era is attributed to the development of solid-state radio frequency hardware in the 1970s. The recent exponential growth in personal communications and cellular radio can be accredited to the new technologies of the 1970s, which have rapidly evolved. The future growth of wireless communications will be tied closely to radio spectrum allocations and regulatory decisions, which support or inhibit extended services. Customer requirements and technological advances in signal processing, access and network areas also contribute to the future advancement of mobile communications. It is necessary to provide the user with the best speech quality available, so that the customer is satisfied and continues to use wireless technology.

Bandwidth is a very scarce resource in wireless systems. Bandwidth efficient modulation and speech compression techniques are employed to achieve high system capacity. A generic mobile-to-mobile telecommunication system is shown in Figure 1. In order to transmit a speech signal digitally, it is necessary to pass the analog speech signal through an analog-to-digital converter and compress the data rate of the resulting digital signal. At the receiver, the analog signal is recovered from the compressed digital signal via a speech decoder and a digital-to-analog converter. The device that performs this task is called a speech coder/decoder or vocoder (voice code/decoder). A speech codec transforms the speech signal into a digital stream of data that is suitable for transmission over the radio interface and conversely regenerates audible speech from the received data [2]. The speech codecs are located in the Mobile Stations (MS) and the Base Stations (BS).

As voice enters the mobile handset (or Mobile Station (MS)), the codec in the handset converts the analog speech into a compressed digital information stream (e.g. at 8 kbps by CDMA Enhanced Variable Rate Codec (EVRC) [11]). The decoder in the base stations typically converts the compressed speech signal into a 64 kbps digital information stream so that it can be sent over the Public Switched Telephone Network (PSTN) using standard Pulse Code Modulation (PCM) techniques. The signal is then routed through the PSTN to the destination base station, where the digital signal is re-encoded to the compressed format (e.g. 8 kbps) and transmitted to the destination mobile.

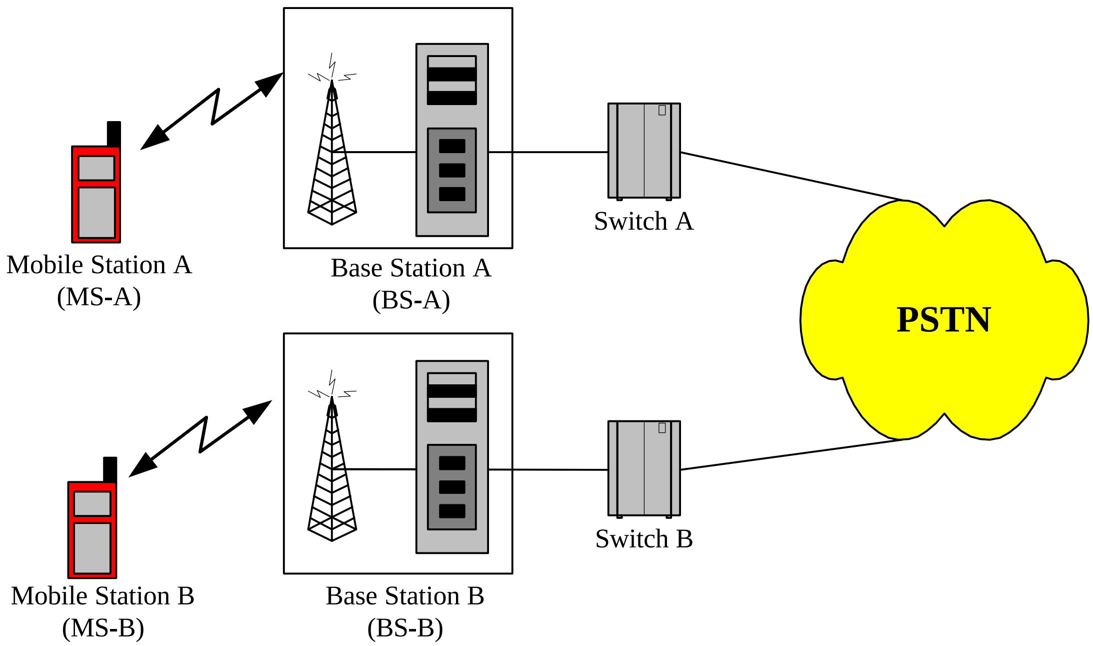

Figure 1 Generic wireless telecommunications system [2]

By reducing the rate for transmission of the speech signal (i.e. from 64 kbps) over the air interface, the bandwidth requirements could decrease by several factors and the system capacity increases by the same factor. But, the disadvantage of using speech compression is that it introduces signal distortion, which, of course, reduces speech quality. The distortion becomes more severe if a signal is passed through a series of codec operations. The noise introduced by the additional encoder deteriorates the speech parameters that are used to decode the speech signal. This makes it more difficult for the decoder to reconstruct the speech signal. In addition, as service providers deploy an ever-wider cross-section of technologies, involving increased conversion between different protocols carrying voice services, the problem intensifies. Initiatives to address these problems include the development of new codec standards, such as the Enhanced Full Rate (EFR) [12] and the Adaptive Multi-Rate (AMR) codecs [13], which are designed to optimize system performance with improved speech quality with substantial bandwidth economy.

Thus, the decoding and then encoding processes at the base stations provide a considerable gain in system capacity but can potentially degrade the speech quality. In Figure 1, it is clear that any call originating at a mobile is first converted to a compressed digital signal (e.g. 8 kbps) at a base station, then to a 64 kbps digital signal for transmission over the PSTN network. If the call destination is another mobile, another coding from 64 kbps to the compressed speech signal must take place, degrading the speech signal a second time. The speech quality may be improved if the compressed speech signal is not coded at the PSTN interface, but rather is transmitted as a data signal to the destination mobile, avoiding the transcoding step. This approach is feasible only if the transmitting and destination mobiles use the same speech coding algorithms. The European Telecommunications Standards Institute (ETSI) as Global System for Mobile Communications (GSM) and separately by the Telecommunications Industry Association (TIA) [1] has standardized the Tandem Free Operation (TFO) protocol recently. The protocol can be used to raise the quality and performance of the wireless transmission environment for the case of like codecs.

The negotiation and establishment of TFO protocol is taken care of by TFO messages and frames. The messages and frames are transmitted using a technique called *in-band signalling*. In-band signalling is where TFO signalling information is communicated together with the traffic signal on the 64 kbps link without using additional bandwidth. The details of this approach are described in Section 2.3.

There are several advantages of the TFO protocol standard. The benefits of TFO are:

- Enhanced speech quality in a mobile-to-mobile call,
- Decreased delay due the elimination of the transcoding in the base stations
- Savings of bandwidth on the terrestrial network

But, there are limitations to the TFO protocol, such as:

- Communicating between different speech coding standards is not supported
- Multi-party calling is not supported
- Digital transparency cannot be guaranteed in all configurations of mobile-to-mobile calls, such as when there are In-Path Equipments (IPEs) that do not support TFO

The TFO protocol standard is new and not widely deployed. The design of the protocol is based on the state machine concept. The TFO standard [1] describes two different state machines for TDMA and CDMA. They perform the same functions except one of them (i.e. state machine A for TDMA only) contains explicit states and messages to handle handoffs[1] and the other (i.e. state machine B for CDMA only) does not. In state machine B, TFO is re-negotiated and established after a hard handoff. But, for the purposes of this project, hard handoff is only simulated.

In order to benefit from the advantages of this recent technology, it is helpful to implement a high-level language simulation of the standard before using valuable resources to build a Digital Signal Processor (DSP) model. Also, a simulation system assists in understanding, testing and examining implementation issues of the TFO protocol standard. For example, with a simulator it is easy to change the functionality of the protocol or verify specific scenarios, which may reveal problems with the standard or implementation. One of the goals of the simulation tool is to find problems and/or issues in the standard and try to resolve them before spending the time and effort in implementing a prototype.

The main objective of this project is to find out if state machine B is a sufficient model for the TFO protocol without limiting the performance of the standard. One way of doing this is to use the high-level language (i.e. C) simulator and test specific scenarios that may eliminate certain states that are redundant. Elimination of states and messages reduces the complexity and decreases errors, such as deadlocks and/or race conditions. In addition, verifying the correctness of the TFO protocol is made easier once the number of states and messages is reduced. Since, only *specific* functionality of the TFO protocol is

[1] The act of transferring communication with a subscriber station from one base station to another. Hard handoff is described by the temporary disconnection of the traffic channel. Soft handoff is characterized by simultaneous communication with a subscriber by more than one base station.

tested, the simulation package does not have to implement all of the aspects of the TFO protocol standard.

The TFO protocol algorithms described in [1] have been implemented and verified. A general study of the protocol was conducted and it was found that the simplification or optimization of the standard protocol requires further testing and modifications to the existing design. A performance analysis has been carried out in order to observe how the TFO protocol behaves in specific situations, such as local and distant handoffs. These will be described in detail in Chapter 3.

A variety of scenarios have been tested including:

- Basic functionality of the TFO protocol
    - Basic operation of TFO (i.e. negotiation and establishment phases of the protocol)
    - Loop-back tests
    - Bit Error Rate (BER) (i.e. injecting specific amount of errors into the message stream) and other basic tests
- Specific functionality of the TFO protocol
    - Local handoffs
    - Distant handoffs

The organization of the report is as follows. First, in chapter 2, a brief description of the architecture of a typical wireless is presented followed by an overview of the TFO protocol followed by a more detailed explanation of elements of the standard such as in-band signalling, TFO messaging, TFO frames and TFO state machines. Chapter 3 presents the design of the simulator package followed by a performance analysis. Finally, Chapter 4 concludes the report by providing a short review of the results.

Chapter 2

Tandem Free Operation (TFO)

2.1 Background: Wireless System Architecture

In order to understand tandem free operation, it is essential to explain the architecture of a wireless system. These concepts form the foundation for the information contained in the subsequent chapters. There are three major second generation (2G) wireless systems:

- Global System for Mobile (GSM)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

For the purposes of this project, the details of these systems will not be discussed and are not important. Without loss of generality an overview of the Global System for Mobile (GSM) system will be presented. A diagram of the various interfaces used in GSM is shown in Figure 2.

The GSM architecture is made up of three main interconnected sub-systems that interact between themselves and with the users through network interfaces. The subsystems are the Base Station Subsystem (BSS), Network and Switching Subsystem (NSS) and the Operating Support Subsystem (OSS).

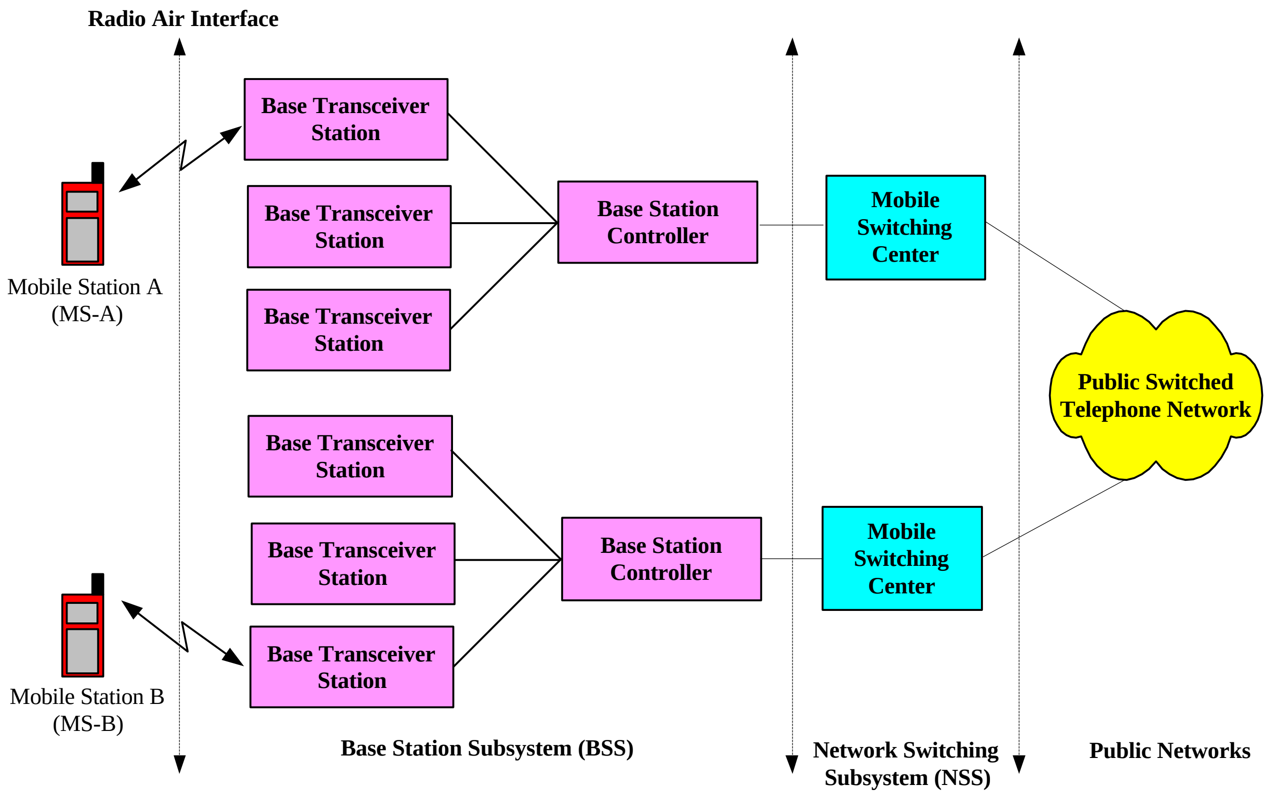

Figure 2 GSM system architecture [3]

The systems that are important to the TFO protocol are the base station and switching subsystems. The base station (also known as the radio subsystem) contains the infrastructure machines that are specific to the radio cellular aspects of the radio access technology. It is in direct contact with mobile stations through the radio interface. As such, the base station manages the radio interface between the mobile stations and all the other subsystems of GSM. The base station is also in contact with the mobile switching center as shown in Figure 2.

The Base Station Subsystem (or base station) contains two types of equipment: the Base Transceiver Station (BTS) and the Base Station Controller (BSC). The base station subsystem consists of many controllers, each connecting to a mobile switch, and each controller normally controls up to several hundred transceiver stations. The transceiver stations are in contact with the mobiles stations through the radio interface, and the controller is in contact with the switches of the switching subsystem as shown in Figure 2. The transceiver stations are the transmission equipment and the base station controller is the managing equipment. An important component of the base station is the Transcoder/Rate Adapter Unit (TRAU or speech codec unit). This unit supports the multiplexing (or decoding/encoding) of speech data to and from the interface between the controller and the transceiver station as well as the rate adaptation in the case of data. This interface is standardized and carries maintenance and traffic data.

The speech codec unit can be situated away from the transceiver stations and can be placed between the controller and the Mobile Switching Center (MSC). The mobile switching center is the basic switching functionality within the switching subsystem, whose main purpose is to coordinate and set-up calls between the users. The remote position of the speech codec unit allows for more compressed transmission between the transceiver station and the speech codec unit.

The base station controller is responsible for the radio interface management through the remote control of the base transceiver station and the Mobile Station (MS) (i.e. cellular phone). These responsibilities include the handover management and the allocation and release of radio channels. The controller is a small switch with substantial computational capability. The controller is connected to several transceiver stations on one side and the switching subsystem on the other side.

The interface between a mobile switching center and a controller uses the Signalling System number 7 (SS7) [10] protocol called the Signalling Correction Control Part (SCCP), which supports communication between the mobile switching center and the base station, as well as network messages between subscriber and the mobile switching center. This interface permits the service provider to use base stations and switching equipment that are vendor independent.

The network and switching subsystem, consists of the main switching functions of GSM, as well as the databases required for subscriber data and mobility management. It is sometimes called the switching subsystem. The main objective of the switching subsystem is to coordinate the communications between the wireless system users and other telecommunication users.

The Operation Support Subsystem (OSS) supports several (or possibly one) Operation Maintenance Center(s) (OMC), which are used to monitor and preserve the performance of each mobile station, base station, base station controller, and mobile switching center within the wireless system. The support subsystem has three main functions:

1. Maintain all telecommunications hardware and network operations
2. Oversee all payment procedures
3. Manage all mobile equipment in the system

An operation maintenance center is devoted to each of these tasks and has provisions for changing all base station parameters and billing procedures as well as offering system operators with the ability to determine the performance and integrity of each piece of subscriber equipment in the system [3].

2.2 Overview of the Tandem Free Operation Protocol

The objective of TFO protocol is to bypass the intermediate stages of encoding and decoding (i.e. transcoding) in the base stations in a mobile-to-mobile call to leave only the coding processes on the terminal equipments. This bypass would alleviate the tandem codec effect, thus resulting in less degradation due to speech coding.

A diagram of the GSM speech transcoding architecture is shown in Figure 3. For the following explanation, MS-A is the source mobile and MS-B is the destination mobile. As mentioned earlier, since the switches typically work in the 64 kbps domain, the call has to be decoded to 64 kbps (at TRAU A) and then back to 16 kbps at the far-end encoder (TRAU B). The 16 kbps channel in Figure 3 is specifically for the GSM coding architecture and refers to the bandwidth of the link or pipe between the base station transceiver and base station controller. The rate of the compressed digital information stream transmitted on the air interface varies according to the codec used in the wireless systems (e.g. CDMA EVRC produces a 8 kbps digital information stream or GSM EFR that produces a 12.2 kbps digital information stream).

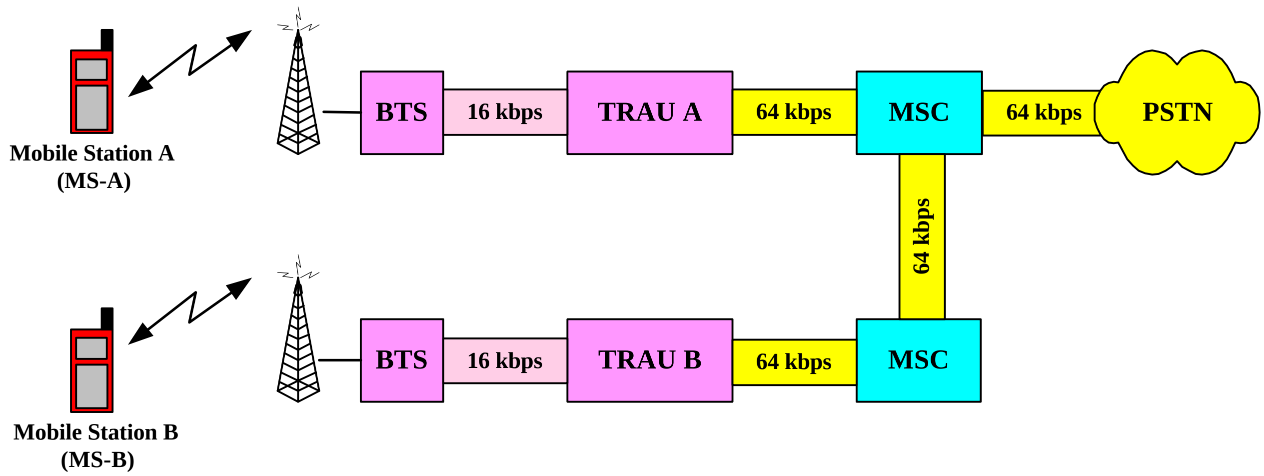

Figure 3 GSM Transcoding Architecture [2]

In *tandem* operation, the speech signal in a mobile-to-mobile call signal is encoded within the first mobile station to transmit over the air, and decoded within the associated first speech codec unit (i.e. TRAU A). The PCM samples are then transported within the fixed part of the network to the second speech codec unit (i.e. TRAU B) using 64 kbps traffic links. This second unit compresses the speech signal for transmission on the second air interface, and the associated second mobile station decodes this signal to analog voice for the human ear. The Decoder-Encoder pair in TRAU A and TRAU B respectively is in tandem operation. The TFO protocol allows the speech samples to bypass the encoder/decoder pair in the TRAUs for mobile-to-mobile calls. A possible configuration of two speech codec units is shown in Figure 4, which is to be used as a reference model. There are two possible paths in Figure 4, one from Mobile A to Mobile B and another from Mobile B to Mobile A. These paths are identical. There are several components between the two mobiles that assist the speech signal in reaching its destination. The following explanation will provide a detailed description of the path between the source MS (i.e. Mobile A) and the destination MS (i.e. Mobile B).

As mentioned earlier each of the mobile stations contains a coder/decoder pair. This transcoder is responsible for encoding analog voice to a compressed digital information stream. Once the encoding has been performed, the digital bit stream travels through the air interface to the speech codec unit (i.e. TRAU A). The speech codec unit is responsible for decoding the compressed bit stream to a 64 kbps signal for the digital network. TRAU A also contains the TFO_Protocol block, which contains the TFO protocol functionality and controls the switch that decides between bypassing the decoder or not. If the TFO protocol conditions are satisfied, the signal will bypass the decoder and the 16 kbps signal will be transmitted using a technique called in-band signalling.

The digital network is made up of several different components, some of which are the In Path Equipment (IPE), such as echo cancellors, Digital Circuit Multiplication Equipments (DCMEs), etc. The TFO Protocol also has to ensure that the path between the speech codec units is clear. This is carried out during the TFO negotiation process with TRAU B. Once this and the other requirements of TFO are ensured, the compressed traffic signal is transmitted to TRAU B, where it performs the reverse process of TRAU A and passes the digital bit stream to Mobile B so that it may be decoded for human perception.

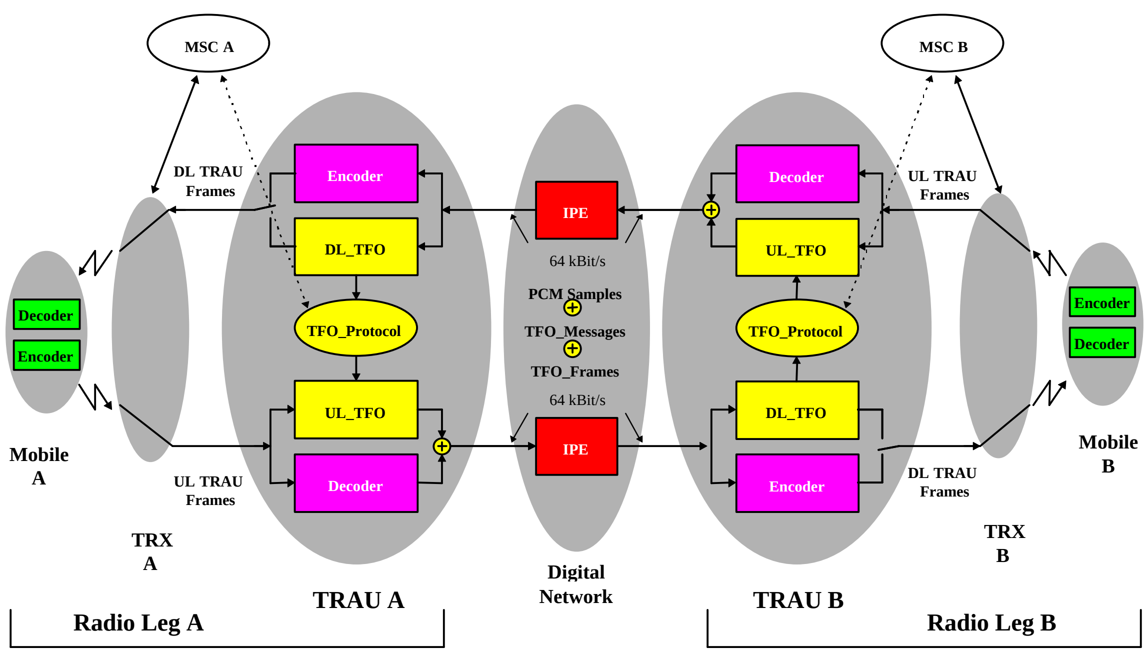

Figure 4 Functional Entities for Handling of TFO [1]

2.3 Limitations of the Tandem Free Operation Protocol

There are two major steps in order to communicate using the TFO protocol; negotiation and establishment (or operation). *TFO messages* are used in order to negotiate a TFO connection. After negotiation has succeeded, *TFO frames* are exchanged so that TFO can be established (or operational). TFO negotiation and operation are based on in-band signalling. The objective of TFO negotiation is to check if the:

- Call is mobile-to-mobile;
- Both TRAUs contain TFO functionality;
- Wireless coding standards match (i.e. a mobile using a GSM coding standard communicates with another mobile using the GSM coding standard)
- Codecs match
- Path between the speech codec units (i.e. TRAUs) are digitally transparent (or clear)

First, it is necessary to ensure that the call is mobile-to-mobile. If this is not the case and the call is mobile-to-land (or land-to-mobile) then the conversion to 64 kbps is necessary. In addition to the previous requirement, the TRAUs must identify each other as TFO capable.

In the case of call transfers, the new call route is evaluated and TFO is applied if possible, otherwise normal operation applies. In addition, for multiparty calls, TFO is not applicable. As a result, when a two-party TFO call is extended to multi-party TFO negotiation will fail, all the links are reverted to normal operation automatically.

Another important issue during negotiation is the compatibility between the different wireless coding standards. The TFO protocol does not support different wireless coding standards communicating with each other. If, for example, MS-A was using the CDMA coding standard IS-127 EVRC and MS-B was using the TDMA coding standard IS-641 EFRC, the extra transcoding will be performed since TFO is not supported in this situation. In this case, the quality of speech is degraded. In addition, during the negotiation phase, the codecs at each of the base stations are also checked. If the codecs in the radio legs do not match, TFO will not be established.

A final and important issue in establishing TFO is the need for digital transparency. Digital transparency means that the digital content transmitted by a speech codec unit is not modified during transmission. In other words, the user traffic and TFO signalling information are transmitted as a digital data stream on the PSTN interface, unaffected by the in-path equipment. When digital lines are used, the distortion to the signal is mainly due to the use of in path equipment. The in path equipment must therefore be disabled or configured in such a way that the information (signalling and speech) required for TFO is not altered. The TFO messages follow a generic structure, which allows identifying and bypassing them by the equipment, without detailed knowledge of the protocol served. As part of the TFO establishment, if TFO can be successfully established (i.e. both stations contain the same codec type etc.) then each speech codec unit sends TFO negotiation messages (i.e. Go transparent commands) which indicate to the In Path Equipment (IPE) along the base station subsystem the type of IPE transparency mode. The main limitation of the TFO in-band signalling technique is that the digital transparency of the PSTN interface behind the mobile switching centers cannot be guaranteed in all the configurations of mobile-to-mobile calls.

The in-band signalling technique for TFO negotiation consists of replacing the Lowest Significant Bit (LSB) of every 16th consecutive PCM sample with one bit of the TFO message, which is transferred on 64 kbps links as shown in Figure 5. This provides for a channel (0.5 kbits/s) where the degradation on speech quality due to the bit stealing is inaudible. This in-band signalling approach is reliable and ensures high throughput signalling. A diagram of the PCM sample (or byte) format with the embedded frame and message is shown in Figure 6.

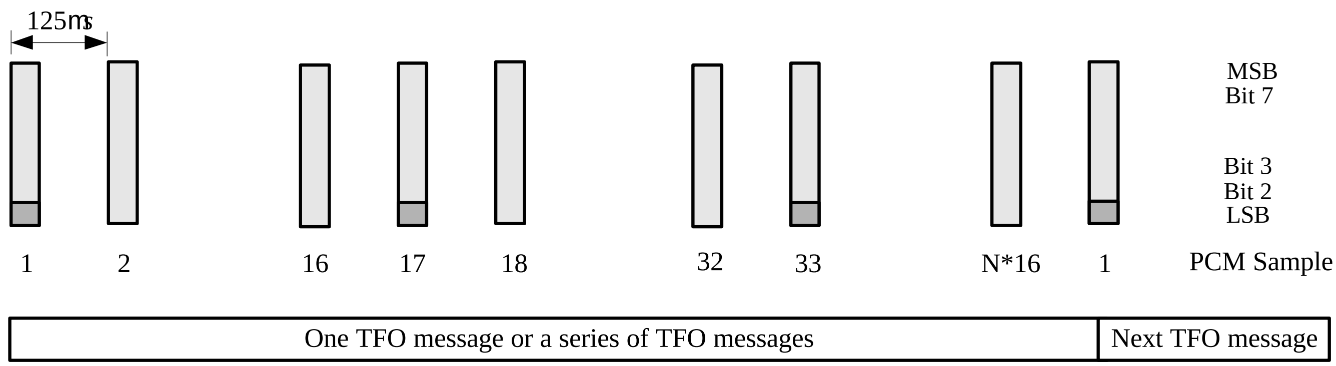

Figure 5 In-band signalling structure for TFO message [1]

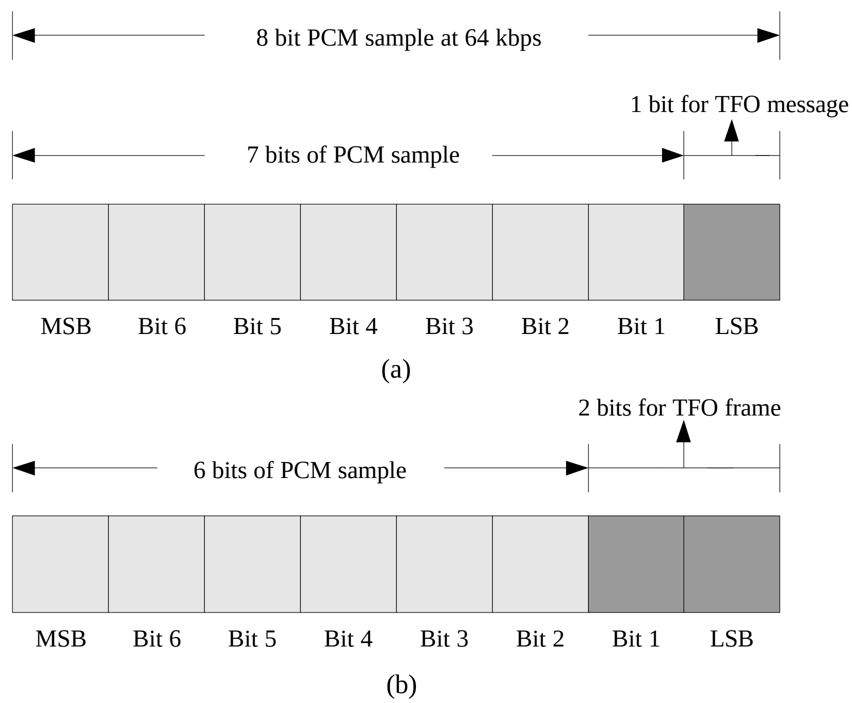

Figure 6 PCM sample format with (a) TFO message and (b) TFO Frame

During Tandem Free Operation, TFO Frames are also transmitted using in-band signalling. But, the difference between the TFO message and the TFO frame is that the TFO frame has a fixed size of 320 bits (length is 20 ms) and is transmitted in the two least significant bits of the PCM samples, which is shown in Figure 7. TFO messages are sent prior and in parallel to these TFO Frames on the PSTN interface.

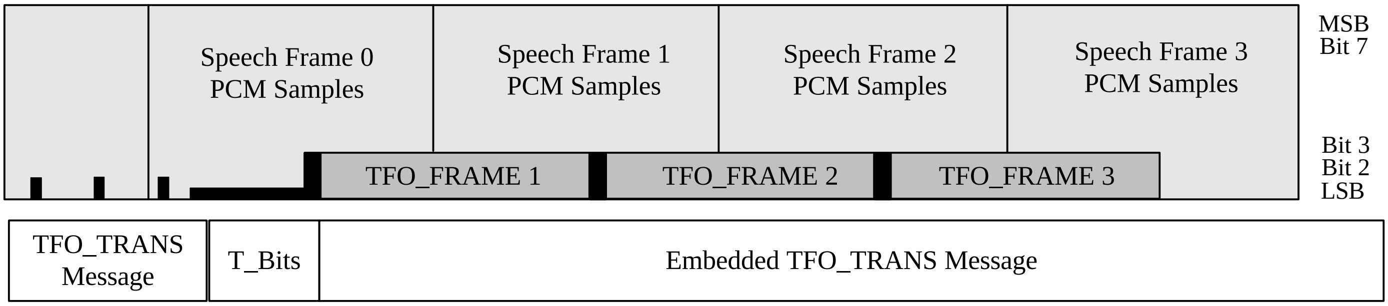

Figure 7 In-band signalling structure for TFO Frame [1]

2.4 Definition of the Tandem Free Operation Messages and Frames

TFO messages are used for negotiation and throughout tandem free operation as a means for communication. The TFO messages are made up of three fields, including:

- Header
- Command (i.e. REQ, ACK, DUP, SYL etc.)
- Extensions

Figure 8 shows the construction of one of the TFO messages. The header is a fixed pattern made up of 20 bits and is used to signal the beginning of a TFO message. The command field consists of 10 bits and is used to differentiate the types of messages sent and is described in Table 1. There are 0, 1 or 2 extension(s) after the command field and the length of this field is 20 bits. It contains sub-fields that consist of: the signature (which is an 8 bit random number to facilitate the detection of circuit loop back conditions and to identify the message sources), a CRC field, codec list and synchronization bits. For example, the TFO_REQ message consisting of a Header field, a REQ field, a System_Identication field, and a TFO_Req_Extension field takes 140 ms for transmission as shown in Figure 8.

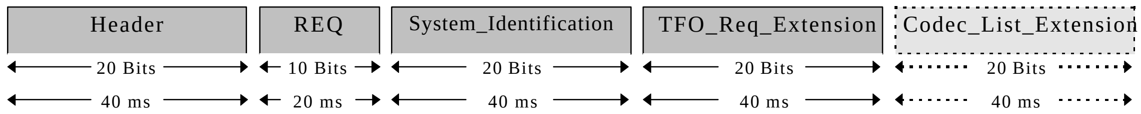

Figure 8 Construction of the TFO_REQ Messages [1]

Table 1 briefly describes the TFO messages transmitted after a specific action. Once TFO has been established, TFO frames are exchanged as well as (in some circumstances) TFO messages that are embedded in the TFO frames. Embedded messages are useful when signalling a change in the codec type during TFO, for example. The details of the TFO messages can be found in [1].

Once the negotiation (or the handshaking) is complete, TFO frames are transported as shown in Figure 6. An example of the TFO frame structure is shown in Table A 1 in Appendix A. The TFO frame covers 160 8-bit octets and spans a period of 20 ms. The TFO frame contains information on synchronization, codec type, system identification (i.e. GSM, TDMA or CDMA), absence or presence of embedded TFO message, traffic data (that is protected by Cyclic Redundancy Checks (CRC) against data corruption during transmission) and other important information (that can be seen in Table A 1).

Table 1 Description of TFO messages

Transmitted TFO Message	Description
TFO Request message (TFO_REQ)	Request to a distant partner for TFO
TFO Acknowledgement Message (TFO_ACK)	TFO acknowledge to distant partner if a TFO_REQ message was received.
TFO Transparent Mode Message (TFO_TRANS)	Forces the IPEs to go transparent. May serve as alternative TFO_ACK in some cases.
TFO Normal Mode Message (TFO_NORMAL)	Command the IPEs to go to normal operation when not in TFO mode.
TFO Sync Lost Message (TFO_SYL)	Once contact was made, suddenly fails to receive any more TFO frames from the distant partner (only in state machine A). Distant Handoff (HO)
TFO_DUP	Local partner has changed (only in state machine A). Distant Handoff (HO).
TFO_REQ_L	Used in Mismatch, Operation and Periodic_Retry to inform about alternative Codecs supported locally
TFO_ACK_L	Response only to TFO_REQ_L.

2.5 Description of the Tandem Free Operation State Machine(s)

The design of the TFO protocol is based on the state machine concept. A state machine is a model consisting of a set of states, a start state, an input event, and a transition (or next) event that maps input symbols and current states to next events. Operation begins in the start state with an input string. It changes to new states depending on the transition event. A transition event is an action that takes place as a result of the input event. The input events, in this specific case include the current state and/or message, the local and distant codecs, the TFO message received and/or the signature in the message.

The TFO state machine consists of a maximum of 15 states and uses a maximum 10 different types of TFO messages. The state machine is designed as a table that contains a set of states, a start state, an input event, and a transition event (or action). The transition event is decided by cross-referencing the input events with the current state.

The TFO protocol describes two state machines; these state machines are shown in Figure 9 and Figure 10. The *only* difference between the two state machines is the reaction to local and distant handoffs. Local handoff is when mobile station changes base stations and the TRAU (in that base station) suddenly starts receiving TFO frames. On the other hand, distant handoff is when the near-end TRAU suddenly stops receiving TFO frames or when TFO frame synchronization is lost. State machine A contains additional states and messages to handle these handoffs, while state machine B does not. These states and messages intend to decrease the amount of time to re-acquire TFO after a handoff. But, additional states could also increase the likelihood of errors such as race conditions and deadlocks, which are difficult to test and require complex test cases. Recall, the main goal of this simulation is to investigate if state machine B is sufficient for the TFO protocol without significantly affecting the overall performance.

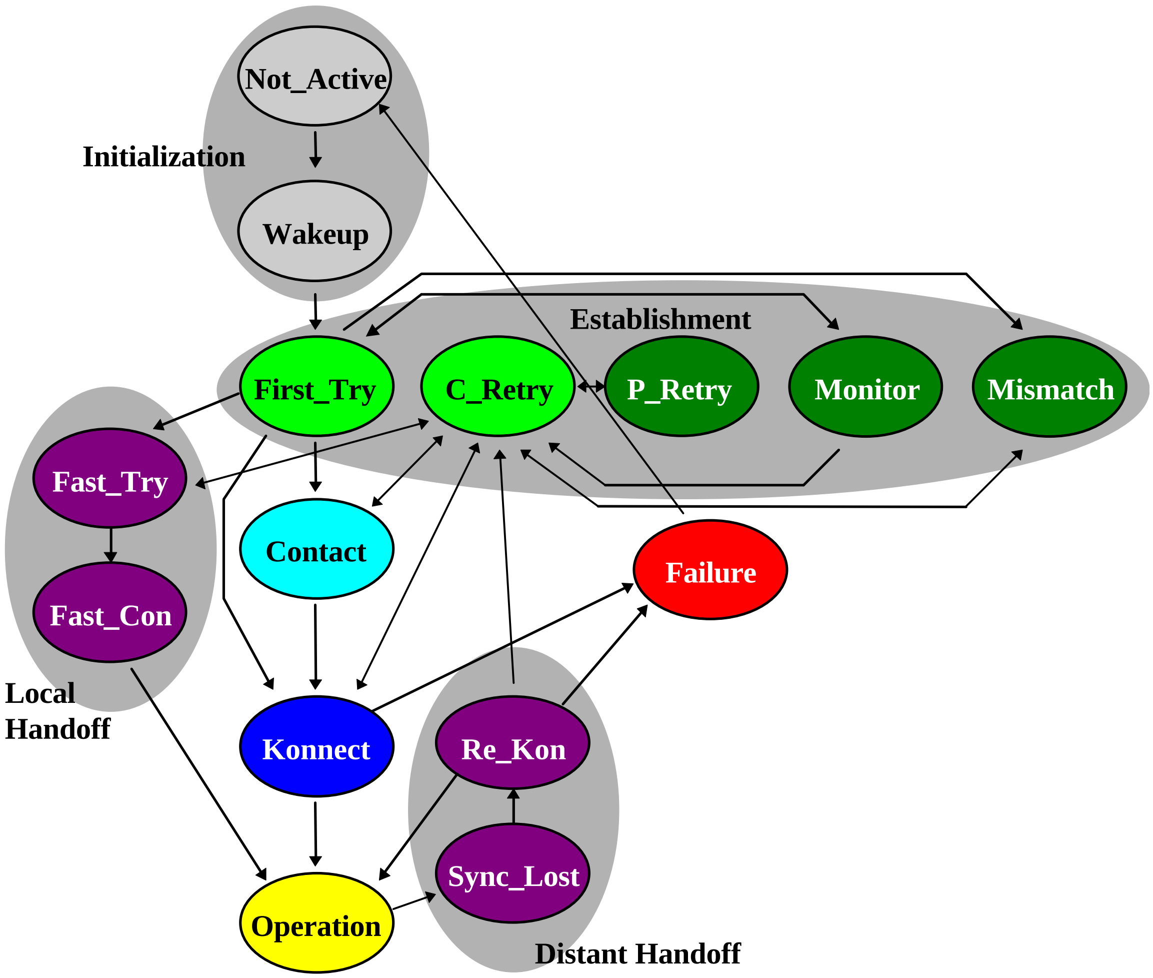

Figure 9 A diagram of state machine A [1].

Note this state machine has additional states, (i.e. Fast_Try, Fast_Con, Re_Kon and Sync_Lost) that explicitly handle local and distant handoffs. Also, the Failure state replaces the Tandem state of state machine B.

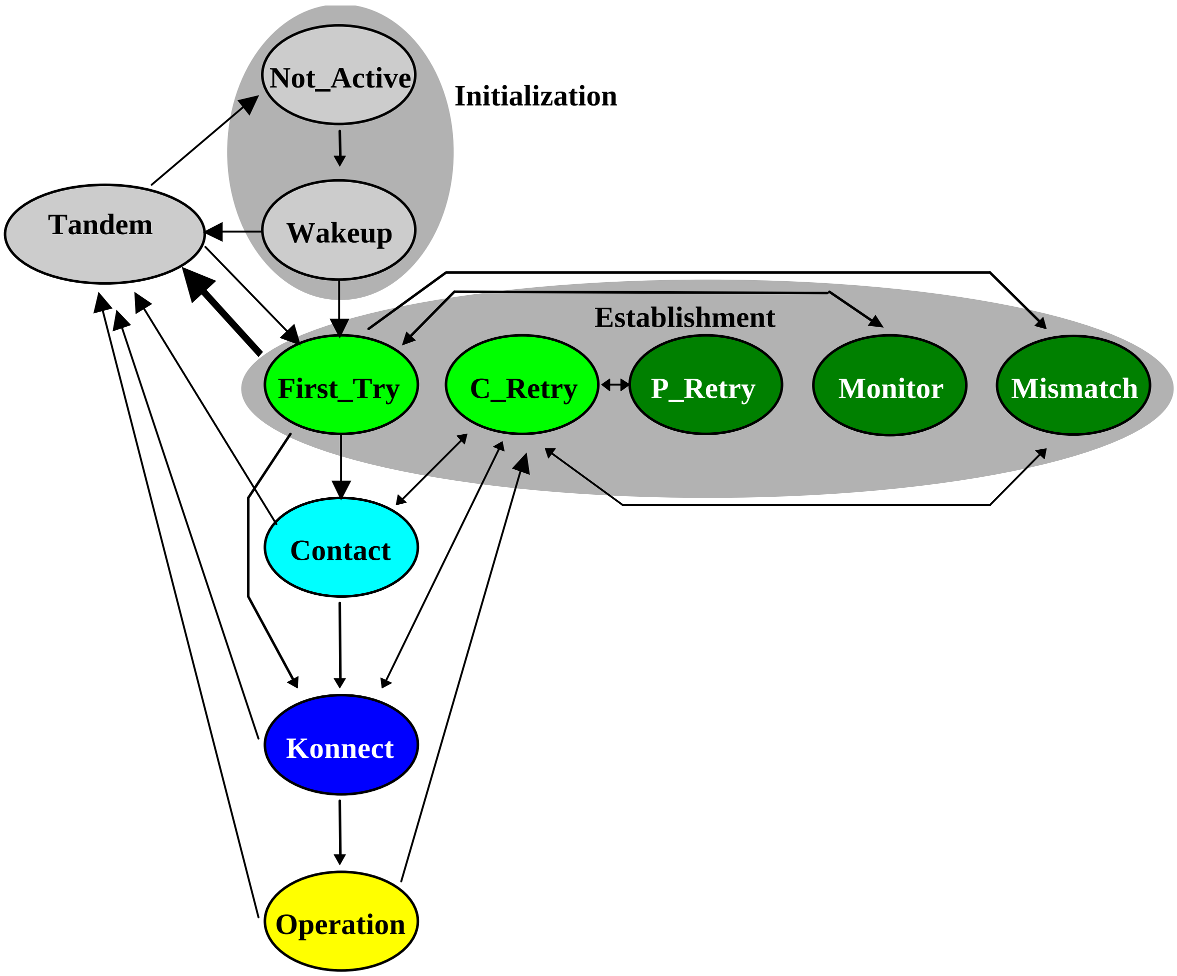

Figure 10 A diagram of state machine B [1]

Descriptions of the states in the state machines are given below and are taken from [1].

1. Not_Active State (NAC)

The TRAU does not perform speech coding, in other words it is turned off.

2. Wakeup State (WAK)

This state is entered when the TRAU is being activated by the appropriate event (i.e. activation by a MSC message). TFO operation begins in the Wakeup State and transitions to the First_Try state when speech processing is performed.

3. First_Try State (FIT)

Regular request (TFO_REQ) messages are sent onto the PSTN interface for a certain maximum period of time. If there is no response, a Runout of TFO messages is reported and the protocol goes into Monitor state.

4. Continuous_Retry State (COR)

TFO Contact had existed, but was interrupted and synchronization of the messages and or frames was lost. The TRAU sends a maximum number of regular request (TFO_REQ) messages continuously to test if TFO could be re-established. If transmitter reports a Runout of TFO messages, the system enters the Periodic_Retry State.

5. Periodic_Retry State (PER)

Entered from the Continuous_Retry state, the protocol periodically sends a single request (TFO_REQ_L) message to determine if TFO could be re-established.

6. Monitor State (MON)

The TRAU monitors the PSTN 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) has been received, it transits into the Continuous_Retry state.

7. Mismatch State (MIS)

A distant TFO Partner exists, but the Codecs do not match. It tries to resolve the mismatch by sending the mismatch request (TFO_REQ_L) message, which contains a list of other codecs that can be used. Once TFO_REQ_L messages are received, the MSC tried to resolve the mismatch with a handoff, for example. If it is still not resolved and needs the far-end TRAU to change codecs, it sends a TFO_ACK_L message. If, after this negotiation the codec mismatch has not been resolved, the protocol transits to the Failure state or Tandem state depending on the state machine.

8. Contact State (CON)

Request (TFO_REQ) messages have been received from a distant TFO Partner. The Codecs do match. An acknowledgment (TFO_ACK) message will be sent to check the digital transparency of the link to the distant partner. As soon as a TFO_ACK message from a distant partner has been received, the TRAU knows that the links in both directions are digitally transparent. The TRAU sends TFO_TRANS message to bypass the IPEs and starts sending TFO Frames. It transits into Konnect State.

9. Konnect State (KON)

The TRAU sends TFO Frames as long as it receives correct TFO messages. The first received TFO Frame causes the transition into the Operation State. If no TFO Frames are received within a certain period, the TRAU transits to the Failure (or Tandem) State.

10. Operation State (OPE)

This is the main state of the TFO Protocol. In this state, the TRAU sends and receives TFO frames and the TFO connection is fully operational.

The states described below are only present in state machine A (as shown in Figure 9) [1].

1. Fast_Try State (FAT)

When the TRAU in the First_Try state and suddenly receives TFO Frames and the Codecs do match, then there is a high probability that a local Hand-Off (HO) has been initialized from an existing TFO connection and a fast TFO establishment is likely. The TFO_Protocol has to still check, whether the link to the distant TFO Partner is (already) transparent. Sending the TFO_DUP message does this.

2. Fast_Contact State (FAC)

This state is entered from First_Try via Fast_Try, if TFO Frames and then loss of synchronization (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. Then the TRAU transits directly to Operation state.

3. Sync_Lost State (SOS)

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

4. Re_Konnect State (REK)

This state is entered from Operation state via the Sync_Lost state, if distant HO (TFO_DUP) messages are received. The TRAU starts to send TFO Frames again. The TRAU transits back to Operation State, as soon as TFO Frames are received, again.

5. Failure State (FAI) (state machine A) or Tandem State (TAN) (state machine B)

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

In order to help understand some of the states and transitions in the TFO state machine(s) presented earlier, a diagram of a messaging sequence to reach Tandem Free Operation (TFO) is shown in Figure 11, as an example of the TFO negotiation and establishment procedure. The state transitions are shown in the Base Station 1 and 2 blocks. The blue (or dotted) and red (or solid) arrows show the transmission of a TFO messages for station 1 and 2, respectively.

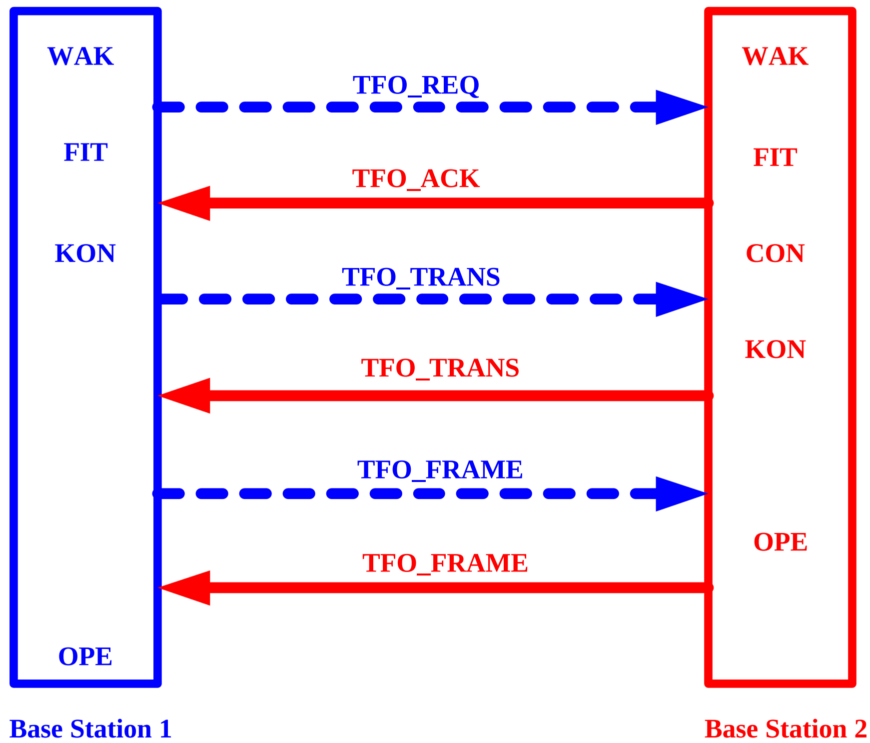

Figure 11 The TFO Messaging sequence to reach TFO operation

In Figure 11, Base Station 1 initiates the negotiation phase by sending a request (i.e. TFO_REQ) message. Base Station 1 then transits into the First_Try (FIT) state and waits for a response. As soon as the request message is received by Base Station 2, it transits from the Wakeup state to the FIT state and sends an acknowledgement message (i.e. TFO_ACK) to Base Station 1. After sending the TFO_ACK, it transits into the Contact state and the station is ready for TFO. After Base Station 1 receives the acknowledgment message it knows that Base Station 2 is ready for TFO and transits into the Konnect state and sends a transparent-check message (i.e. TFO_TRANS) to make sure the path is clear, followed by a TFO frame. Once Base Station 2 receives the transparent-check message, it also transits to the KON state and sends a transparent-check message followed by a TFO frame. As soon as one base station receives a TFO frame, that side transits into the Operation state. It is now in TFO mode and TFO frames are exchanged.

Chapter 3

Tandem Free Operation (TFO) Protocol Simulator

This section describes the development and implementation of the simulation algorithm for the TFO protocol. The standard is given in [1]. The first section will briefly explain the main aspects of the TFO protocol as well as algorithms that were designed to implement the protocol. This protocol has been completely simulated but not all of the functionality has been tested. Recall that the purpose of this simulator is to verify only *specific* scenarios of the TFO protocol standard. The conditions tested mainly concentrate on decreasing the complexity of the TFO protocol standard.

3.1 Design of the TFO Protocol Simulator

The TFO protocol simulator is functionally separated into three main processes; the transmitter, the receiver and the TFO protocol. A diagram of the TFO processes is shown in Figure 12. The TFO protocol standard [1] does not provide any specific details on the design of the three different modules. Some of the detailed algorithms of these modules have been left to the designer and are described briefly in the following sub-sections. The designs of the three modules consider the whole protocol and follow the specifications presented in [1].

The transmitter (Tx_TFO) and the receiver (Rx_TFO) that are on different base stations communicate with each other through the TFO_Protocol (as can be seen in Figure 12). The Tx_Queue is the TFO message and control buffer between the TFO_Protocol and the transmitter. Once a complete TFO message has been received by Rx_TFO, the message is passed to the TFO_protocol, which is an event driven state machine design. The functionality of the TFO state machine resides in the TFO_Protocol module. The state machine is represented by a table that contains the next action(s) to be processed in response to different TFO messages received. The TFO_Protocol module references the table(s) to find the next state and/or message and sends this action to the transmitter so that an appropriate message can be created and transmitted by the Tx_TFO to the distant TFO partner.

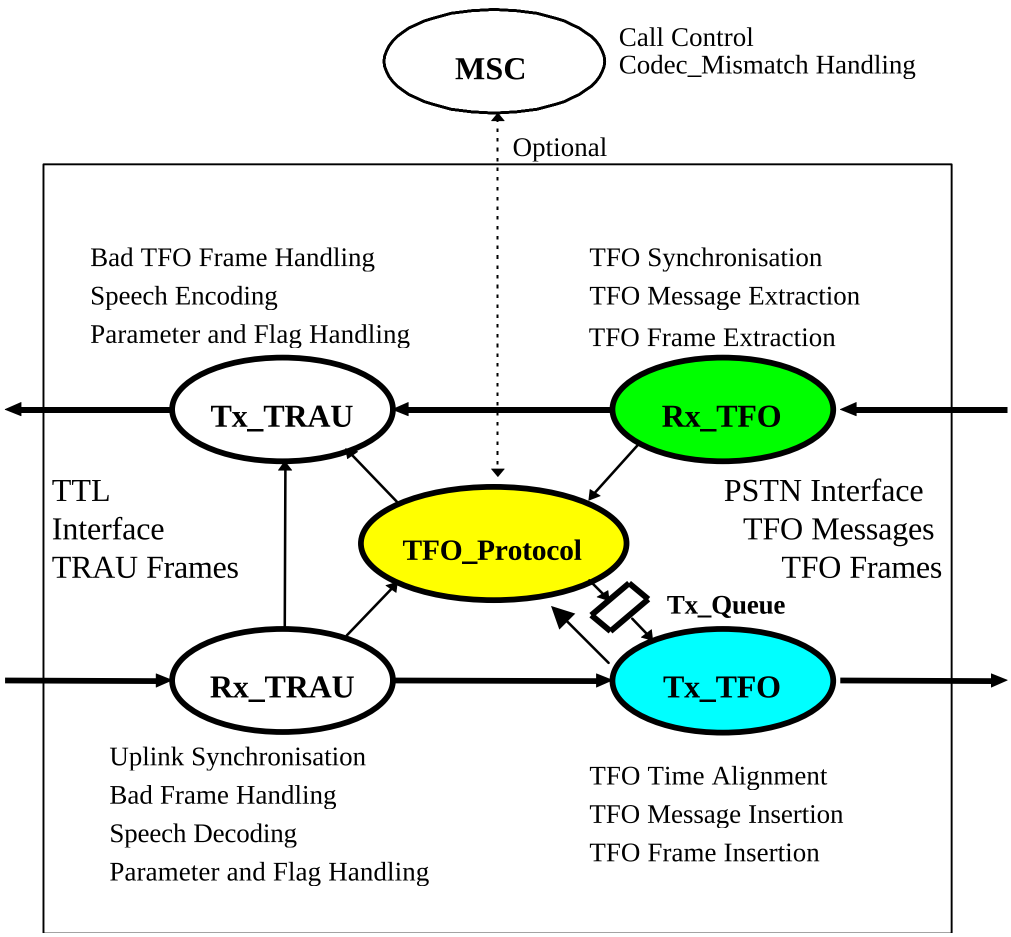

Figure 12 The Tandem Free Operation Processes [1]

The Tx TRAU and the Rx TRAU processes shown in Figure 12 are responsible for actual user traffic encoding and decoding. Their designs are outside the scope of the TFO protocol and have not been implemented. The functionality TRAU is present at a higher level than the TFO processes (i.e. transmitter, receiver and TFO protocol) and does not require to be tested for the purposes of this project.

The main function of the TFO protocol simulator is shown in Figure 13. The simulator consists of a menu that is displayed so that the user can enter the type of test that should be conducted, such as, loop back, mismatch test, local handoff etc. This is followed by the initialization procedure for the queues, buffers, etc. The three main modules are called until the test is complete or until the user wants to end the testing procedure.

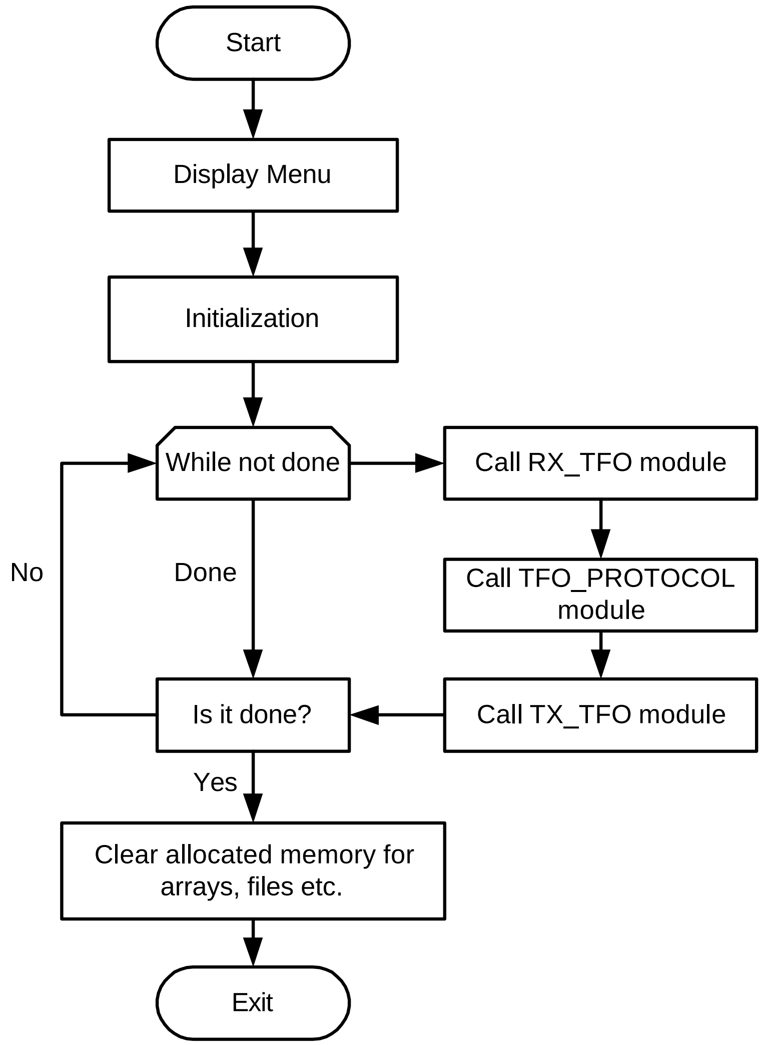

Figure 13 Flowchart of the main module

3.1.1 Design of the Transmitter

The main purpose of the transmitter is to receive commands from a queue (i.e. Tx_Queue, that receives commands from the TFO protocol as shown in Figure 12) and transmit the appropriate TFO messages and/or TFO frames to the network. The next event and/or command is determined by the state machine (which is implemented in the TFO protocol module) and placed in the queue. The transmitter reads the next command from the queue and inserts the next TFO event (message or frame) into the user traffic information speech sample as mentioned in Chapter 2 and as shown in Figure 6. A flow chart of the transmitter is shown in Figure 14.

Each TFO message (frame) has to be transmitted completely before the Tx_TFO can transmit a different TFO message (frame). The transmitter first checks if it is in the process of sending anything, if it is not then it will take the next event from the queue. Once the transmitter receives an event and TFO is operational (which means that the system is in the Operation state of the TFO protocol) then the transmitter creates and transmits a TFO frame. If on the other hand, TFO is not operational then either, a PCM sample is sent or a PCM sample with an embedded bit from a TFO message is transmitted.

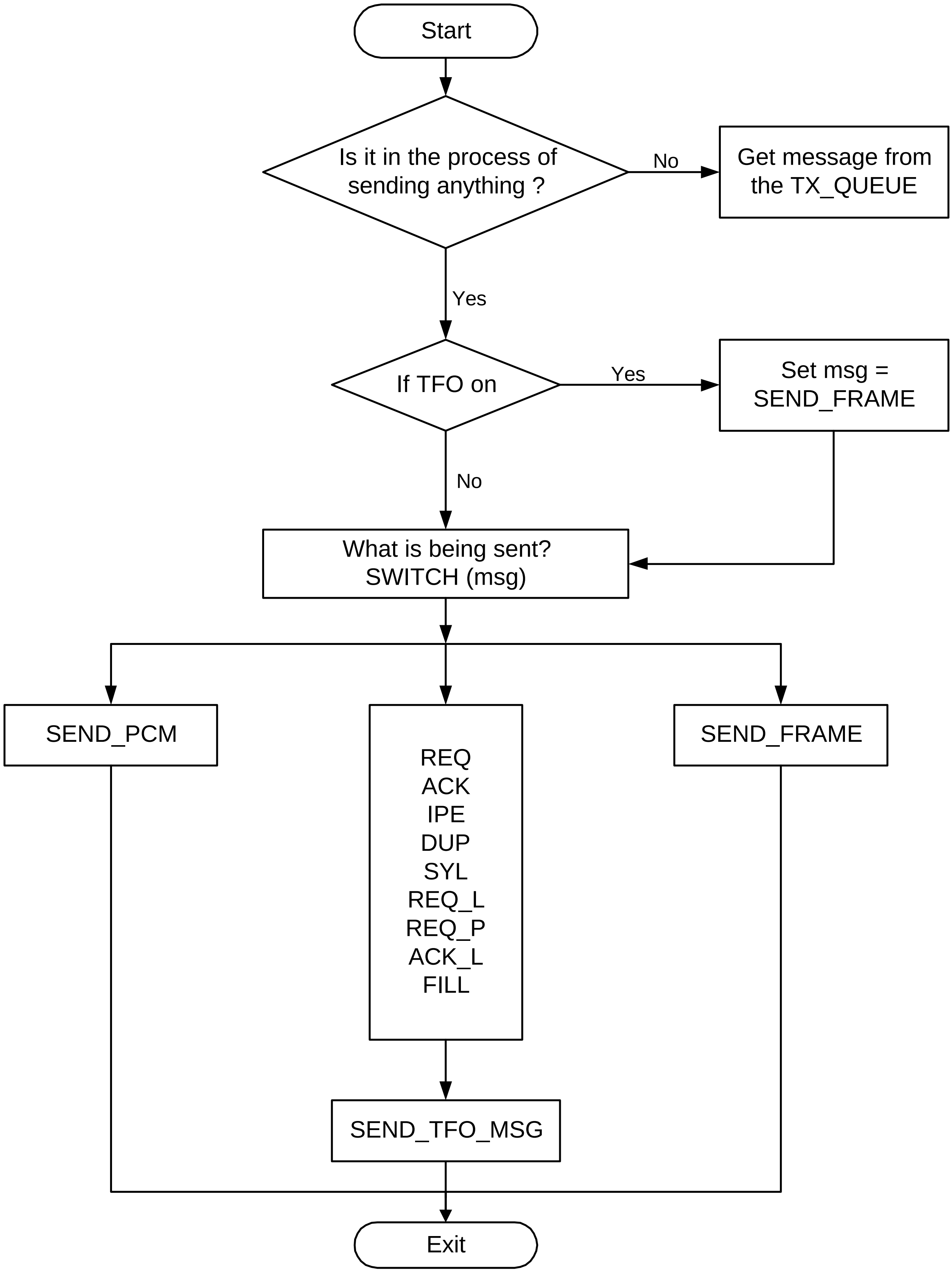

Figure 14 Flowchart of the TFO transmitter

3.1.2 Design of the Receiver

The receiver is responsible for receiving data (TFO message and/or TFO frames) and synchronizing to them. The monitoring of the TFO frame or TFO message synchronization is a continuous process. Typically, TFO messages and frames follow each other with a well-defined phase relation. Insertion of Time Alignment bits (T_Bits) or octet slips may, however, occasionally alter that regular phase relation and should be taken into account. In all error cases, the receiver should investigate, if the synchronization has been lost due to octet slip, phase adjustment, or other events and should try to resynchronize as fast as possible. The receiver locks on to Synchronization (Sync) bits in order to synchronize to the incoming TFO data (TFO messages and/or TFO frames). Sync bits are zeros placed at every 160 PCM bytes.

After the receiver obtains the TFO data, it passes all the PCM samples and TFO frames to the Tx_TRAU for supplementary processing. The receiver also removes the control bits and TFO signalling information and sends the information to the TFO Protocol module. The Rx_TFO process is a complex module since there are many concurrent tasks that it is responsible for. These tasks are such as:

- Searching for the TFO message, or
- Searching for the TFO frame and embedded message, or
- Searching for the TFO frame
- Checking the TFO frame or message for errors
- Time alignment of the TFO frame
- Synchronizing to the incoming data (i.e. TFO frame and/or TFO message)

A flowchart of the receiver process is shown in Figure 15. The first TFO message and/or frame have to be error-free so that the receiver can lock onto the Sync bits. If the first TFO message has errors, it will be ignored and the receiver will continue to search for an error-free message. All the subsequent messages after an error-free message can either have errors (i.e. bit flip) or a byte slip (which is considered a bit error). The specific rules for errors in TFO messages and frames can be found in [1]. Once the receiver has acquired the complete message and/or frame, it checks if there are any errors by using the Cyclic Redundancy Check (CRC) field in the TFO data. If synchronization is lost then the receiver searches for an error-free message and/or frame as it did in the negotiation phase.

The receiver module is responsible for many tasks. There were some issues when creating this module, such as:

- Receiving incoming bits
- Searching for a TFO message
- Searching for a TFO frame
- Synchronizing problems

Since the TFO message is sent every 16^{th} PCM sample in the LSB, it is necessary to build a receiver that would be able to efficiently retrieve the data. In order to receive all the incoming bits and search for a message, an array to store all these bits is required. It is also important to use a minimal amount of memory. Therefore, buffer space is limited and in turn, search time is also reduced. Also, if a DSP implementation is taken into account, there are limits to the size of buffers, such as tables, arrays, etc.

The receiver is designed to handle error checking, and synchronization issues. In order to ensure that the bits are received correctly, a CRC field in the TFO message and frame is used. Also, in the case of loss of synchronization due to a handoff or any other interrupt; the receiver tries to re-synchronize to the incoming message using the synchronization bits in the incoming messages or frames. Most of the aspects of the receiver have been implemented in the TFO protocol simulator package.

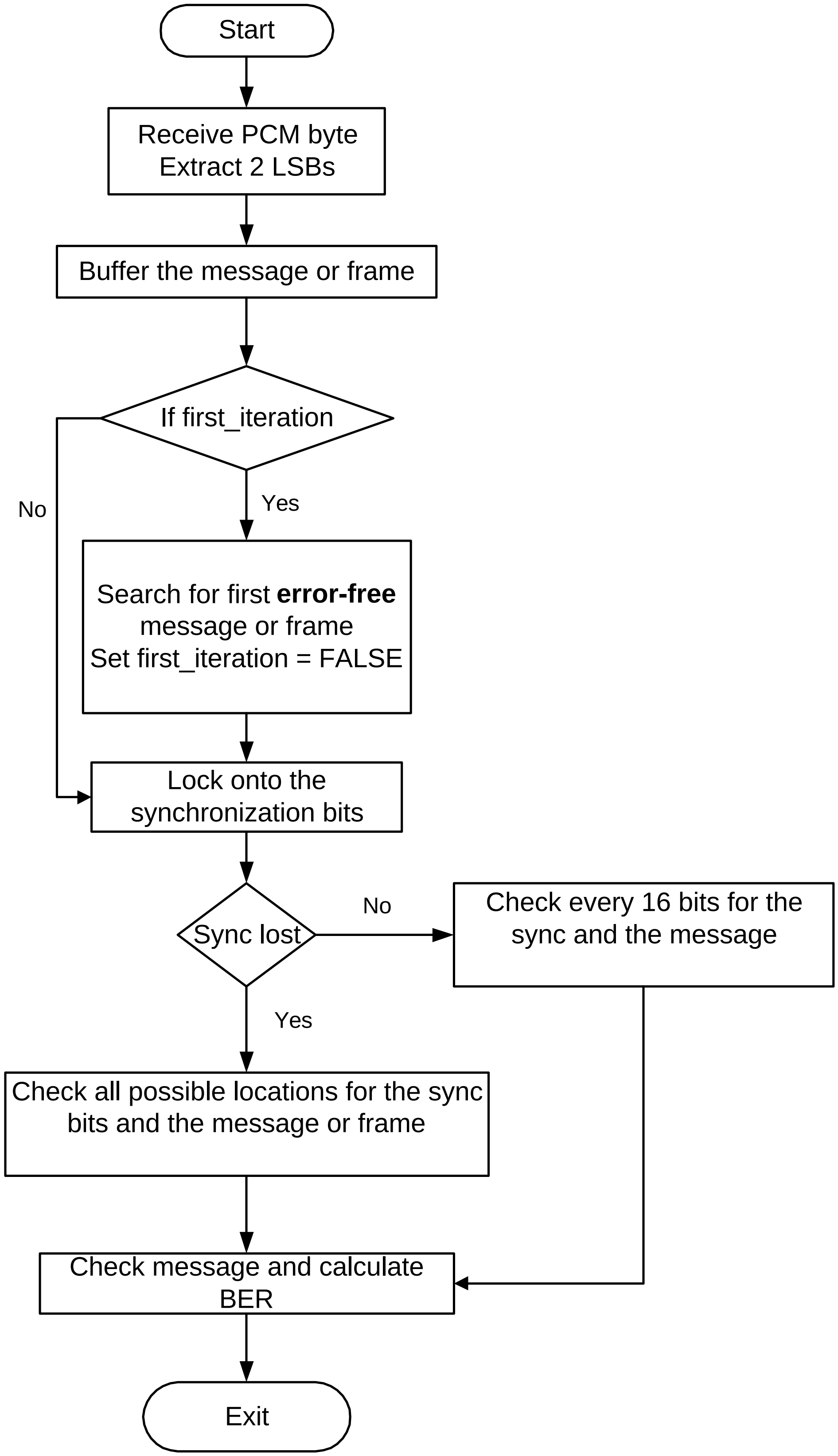

Figure 15 Flowchart of the TFO receiver

3.1.3 Design of the State Machine(s)

The state machine is in the form of a table that contains the conditions and actions for all possible next events. The tables that represent the state machines reside in the TFO protocol module. A flowchart for the TFO protocol module is shown in Figure 16. The TFO protocol waits for a message to be passed to it from the receiver. Once a message has been received and confirmed, specific conditions (i.e. local and distant signatures, codecs, etc.) are checked with the table and the next event is chosen accordingly. After the next event has been selected, it is passed to the transmitter and the corresponding message and/or frame is created accordingly and transmitted.

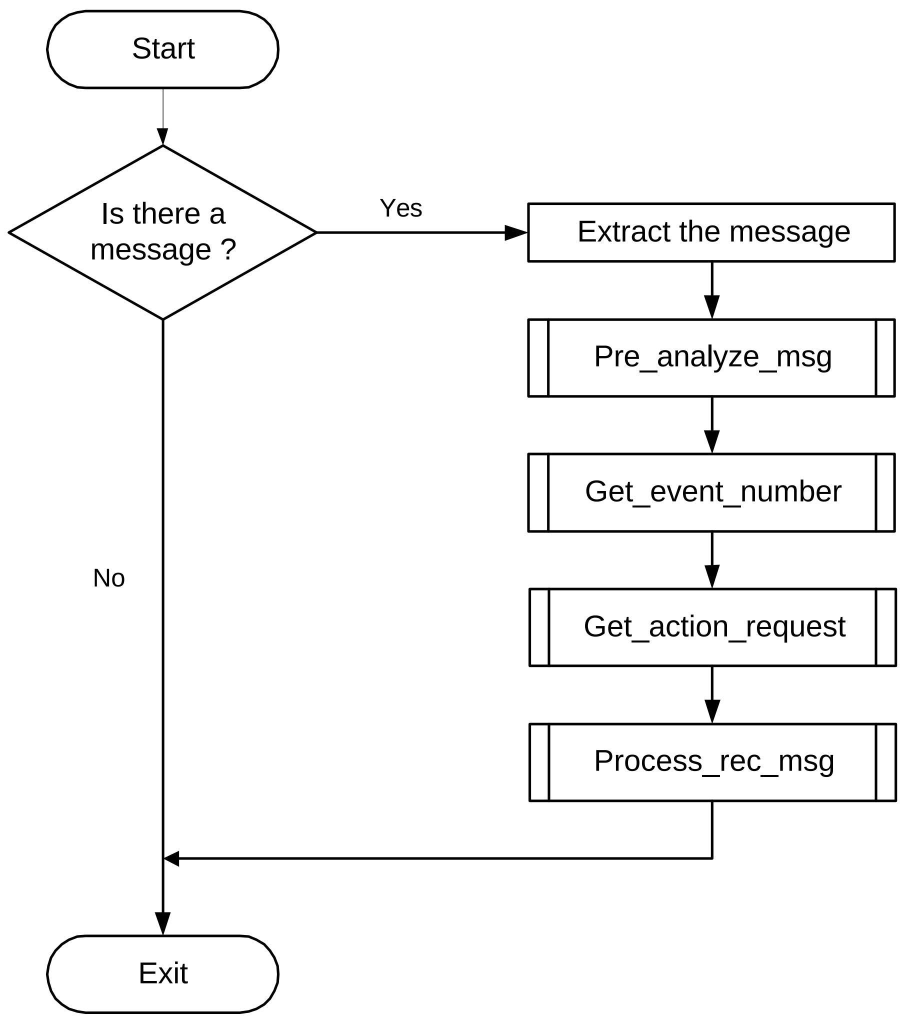

Figure 16 Flowchart of the TFO protocol module

3.2 Performance Analysis

This section presents the results of specific tests that were conducted using the TFO simulator. In order to conduct tests on the TFO simulator, it was necessary to create a User Interface (UI) to facilitate the verification of different scenarios. At the moment, the UI can be set-up to test most of the TFO protocol standard. It can also be upgraded to incorporate test cases that are more specific. An example of the interface is shown in Appendix B. All of the following tests were conducted using this user interface.

Other tests were conducted for more specific cases, but due to the large amount of data obtained, only tests results deemed important are shown. These tests are:

- Amount of time to reach operation (or TFO mode)
- Amount of time to resolve mismatch
- Verification of the loop-back functionality in TFO
- Reaction to errors (i.e. increasing Bit Error Rate (BER))
- Reaction to phase misalignment (i.e. byte slip)
- Reaction to certain types of interruptions (i.e. local and distant handoff)
- Reaction of the state machine B when receiving irregular messages

The scenarios listed above not only assist in testing the correctness of the simulator but also aid in possibly eliminating states that may not be essential. The first five tests verify the basic behavior of the TFO protocol. They are necessary in order to advance to the next level of testing, which incorporates the rest of the tests listed above. Each of the test cases listed above was simulated twenty times and an average of the results was recorded which can be found in Table 2 and Table 3.

The average time to reach operation is the same in both state machines since they use the same messaging sequence. This ideal messaging sequence to reach TFO mode was shown earlier in Figure 11. The amount of time it takes to reach operation is less than one second, which makes the negotiation phase of TFO is relatively transparent to the user. The amount of time it takes for negotiation or to re-acquire TFO after an interruption (e.g. handoffs) is crucial since the user will be in the process of a call and these actions have to be transparent to the user. If the interruption or negotiation takes more than 2–3 seconds, the customer could discern a quality difference.

Table 2 Results for basic functions of the TFO protocol simulator

Type of test	Type of state machine	
	A	B
Average amount of time to reach operation	869 ms	869 ms
Average amount of time to resolve mismatch	458 ms	N/A
Loop-back test	PASS	PASS
BER	PASS	PASS
Phase Misalignment	PASS	PASS

The average time to resolves a mismatch depends on the codecs that are present in the local codec list. The time shown is an average of all the possible scenarios of codec mismatch. The loop-back functionality in the TFO simulator was tested. It was found that the loop-back functionality performed according to the requirements given in the standard.

In the case of the BER test, errors were injected into the TFO messages as they were transmitted to the far-end. In this test, random bits were flipped depending on the percentage of errors entered by the user. Varying rates of BER were introduced and the receiver was tested to check if it could decipher the TFO message that was originally sent. The test results revealed that this aspect of the TFO simulator is functional.

Phase alignment and/or synchronization of the receiver were important issues when designing this simulator. This simulator was able to successfully handle a byte slip and other misalignment tests (i.e. testing with time alignment bits).

Since the basic functionality of the TFO simulator was successfully verified, tests that are more specific were conducted. These tests address the goal of this project, which was to find an approach to simplifying the TFO protocol standard. In order to do this the necessity of the additional states for handoffs was investigated. Since a complete investigation would require more time and resources, a partial study was conducted. This study will contribute to creating more detailed test cases for further verification. The results of local and distant handoff for both of the state machines are shown in Table 3.

Table 3 Results for local and distant handoff

Type of test	Type of state machine	
	A	B
Average amount of time to reach operation after local handoff	1221 ms	1547 ms
Average amount of time to reach operation after distant handoff	1300 ms	1347 ms

Recall that the state machine B was not equipped with the additional messages and states to handle a local handoff. This was the reason that it took 326 ms longer (for local handoff) to reach operation using state machine B than using state machine A. But, the total time required to reach operation was still less than 2 seconds and state machine B was able to successfully reach TFO mode without using additional messages. Also, there was no major difference (47 ms) between the results of the state machines for distant handoff. This was an important result and supported the hypothesis that the extra messages may not be required and did not significantly hinder the performance of the TFO protocol.

Further tests were conducted to observe the reaction to state machine B to receiving unusual messages, such as the additional ones present in state machine A. Preliminary results revealed that for all the previous tests discussed (i.e. such as the tests in Table 2 and Table 3) state machine B was able to communicate effectively. This also suggested that the smaller state machine (i.e. B) might be able to handle certain abnormal conditions, such as, receiving unfamiliar messages, which may be found in scenarios where different versions of the standards are implemented in the two TRAUs.

Since state machine B was able to handle handoffs effectively (as shown in Table 3), this suggests that the extra states (i.e. in state machine A) may not be necessary and could be removed. But, it is recommended that further tests be organized and investigated to rigorously verify all possible scenarios to support the minimization of the TFO protocol.

Chapter 4

Summary and Conclusions

A simulator for the TFO protocol, a new standard designed to improve the speech transmission quality of mobile-to-mobile telephone calls in wireless networks was implemented. The protocol is effective in situations where both mobiles are matched, i.e. employ compatible speech coding algorithms. The simulator was used to study the performance of the protocol in a variety of areas including the following:

- Time required to enable bypassing the transcoder stage in the base stations
- Time required to determine if mobiles are matched
- Impact of transmission errors (i.e. increasing Bit Error Rate (BER))
- Impact of phase misalignment (i.e. byte slip)
- Loop-back functionality

The TFO protocol describes two different state machines that perform similar functions except one of them (say, state machine A) contains explicit states and messages to handle handoffs and the other (say, state machine B) does not. This study showed that the protocol could operate satisfactorily with state machine B, i.e. showed that the additional hand-off provisions do not contribute significantly to its performance. Thus, a state machine with fewer states, thereby reducing potential errors due to race conditions, deadlocks, etc, can model the protocol adequately. It was also shown that the two state machines were able to effectively communicate with each other, which imply that state machine B is robust, and can handle new or undefined but valid messages reliably.

The results of this study should be viewed as preliminary and further rigorous testing should be carried out to substantiate them. Also, although the simulator modeled the entire protocol, this study did not fully test the correctness of all of its aspects, but only those pertinent to our basic objective. Nonetheless, the information that was obtained by the testing of the TFO protocol standard is beneficial and the tests can be improved in order to verify other possible scenarios in future enhancements of wireless architecture.

Appendix A: TFO Frame Structure

Table A 1: TFO Frame Structure for TDMA VSELP speech codec [1]

Octet no.			**Bit number (m)**					
(n)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0	**0**	S1	**0**	S2	**0**	S3	**0**	S4
1	**0**	S5	**0**	S6	**0**	S7	**0**	S8
2	**1**	C1	**C2**	C3	**C4**	C5	**C6**	C7
3	**C8**	C9	**C10**	C11	**C12**	C13	**C14**	C15
4	**1**	D1	**D2**	D3	**D4**	D5	**D6**	D7
5								
6	**1**							
7								
8	**1**							
9								
10	**1**							
11								
12	**1**							
13								
14	**1**		**Other D bits**					
15								
16	**1**							
17								
18	**1**							
19								
20	**1**							
21								
22	**1**							
23								
24	**1**							
25	**D158**	D159	**D160**	D161	**D162**	D163	**D164**	D165
26	**1**	D166	**D167**	D168	**D169**	D170	**D171**	C16
27	**C17**	C18	**C19**	C20	**C21**	C22	**C23**	C24
28	**1**							
29								
30	**1**							
31								
32	**1**		**Other C bits**					
33								
34	**1**							
35								
36	**1**							
37								
38	**1**	C100	**C101**	C102	**C103**	C104	**C105**	C106
39	**C107**	C108	**C109**	C110	**T1**	T2	**T3**	T4

S1...S8: System identifier

C1...C4: Codec type
C5: Embedded TFO message indicator bit
C6...C11: Reserved.
C12: Bad Frame Indicator (BFI). Set if the speech frame has a CRC failure during the over the air uplink transmission. Cleared for valid frame.
C13...C15: Reserved.

C16: Error concealment indicator. Set if the frame underwent error concealment treatment in the local decoder. Cleared otherwise.

C17...C110: Reserved.

D1...D72: R0, LPC and subframe 1-information bits

D73...D75: CRC over R0, LPC and subframe 1 information bits

D76...D104: Subframe 2 information bits

D105...D107: CRC over subframe 2 information bits

D108...D136: Subframe 3 information bits

D137...D139: CRC over subframe 3 information bits

D140...D168: Subframe 4 information bits

D169...D171: CRC over subframe 4 information bits

Notes: VSELP encoded parameters are transmitted in the order specified in TIA/EIA-136-420 with the most significant bits transmitted first.

Appendix B: User Interface

```
                 TFO Simulator
===================================

Main Menu
----------------------------------
1. Read options from default file
2. Choose options from menu
3. Run Simulator
0. Quit
1
Enter File Name: opt.dat
===================================
                 TFO Simulator
===================================

Main Menu
----------------------------------
1. Read options from default file
2. Choose options from menu
3. Run Simulator
0. Quit
2


              STATION 1 (0)                                    STATION 2 (1)

===================================              =================================

1.  State Machine (A or B)              = A          16. State Machine (A or B)            = A
2.  Test Loop Back  ST1                 = 1
3.  Set Current State ST1               = 13         17. Set Current State ST2             = 2
4.  Codec List ST1               Used   = 2          18. Codec List ST2             Used   = 0
                                 Sup_A  = 1                                         Sup_A  = 2
                                 Sup_B  = 1                                         Sup_B  = 0
5.  Byte Slip ST1                       = 0          19. Byte Slip ST2                     = 0
6.  Time Alignment Bits                 = 0          20. Time Alignment Bits               = 0
= TFO_FRAME   21. Message to Send       = PCM_SAMPLE
8.  Number of Times to send             = 3          22. Number of Times to send           = 0
9.  Signature  ST1                      = 12         23. Signature  ST2                    = 0
10. Frame Sync Lost ST1                 = 0          24. Frame Sync Lost ST2               = 0
11. Msg Sync Lost ST1                   = 0          25. Msg Sync Lost ST2                 = 0
12. Inhibit TFO ST1                     = 0          26. Inhibit TFO ST2                   = 0
13. Allow TFO ST1                       = 0          27. Allow TFO ST2                     = 0
14. Initialize Station ST1              = 0          28. Initialize Station ST2            = 0
15. Set Read/Write Q1              = 1 5 10          29. Set Read/Write Q2            = 0 45 56


Other Options (For both stations)
===================================

30. Test BER                    = 0
31. Set BER Value Ground        = 0.000000
```

32. Set BER Value Air = 0.000000
33. Station to Start = 0

==================================

Enter Choice (from 1-33) **--------------**> 0

References

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