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Foreword

This ETSI Technical Report (ETR) has been produced by the Terrestrial Trunked Radio (TETRA) Project of the European Telecommunications Standards Institute (ETSI).

ETRs are informative documents resulting from ETSI studies which are not appropriate for European Telecommunication Standard (ETS) or Interim European Telecommunication Standard (I-ETS) status. An ETR may be used to publish material which is either of an informative nature, relating to the use or the application of ETSs or I-ETSs, or which is immature and not yet suitable for formal adoption as an ETS or an I-ETS.

This ETR consists of 5 parts as follows:

Part 1: "Overview, technical description and radio aspects";

Part 2: "Radio channels, network protocols and service performance";

Part 3: "Direct Mode Operation (DMO)";

Part 4: "Network management";

Part 5: "Guidance on Numbering and addressing".

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1 Scope

This guide is written as a "Read-me-first" manual or "Getting started with TETRA DMO". It is not intended to be a guide to the TETRA DMO standard nor an authoritative interpretation of the standard. If any conflict is found between this guide and the corresponding subclauses in the TETRA standard then the standard takes precedence.

The aims of this guide are:

- to provide the reader with sufficient knowledge to engage in qualified discussions with the equipment and service suppliers;
- to expose the reader to the specific language and technical terminology used in the standard;
- to enable the reader to understand the flexibility in system design, system network topography, system availability, various modes of operation and security features;
- in the Radio Aspects part of the guide, sufficiently detailed design information is given to allow link budget calculations to be carried out and outline radio coverage planning to be performed. Some preliminary calculations are also given for co-existence between trunked and direct mode terminals and also for the number of direct mode talk groups (Nets) that can operate simultaneously at the same location.

The scope of this first edition of the DMO Designers' Guide is limited to examining in detail mobile station to mobile station direct mode operation. The basic mobile station operation is placed in the wider context of direct mode operational requirements by outlining repeater and gateway functionality. However detailed consideration of repeaters and gateways will be dealt with in a later edition.

It should be understood that, as in all standardisation activities, there is an inherent conflict between the Users' wish to have as broad a standard as possible and at the same time wanting to have as much of that broad standard available and implemented right from the beginning of service. Potential equipment purchasers, network operators and service users must make sure they influence the suppliers to have their required functionality available when they need it.

Equipment manufacturers will use the broad flexibility provided within the standard to develop and implement equipment in various ways, and still be conforming to the standard. This broad availability of equipment, each optimised around certain features and functionalities, needs to be carefully analysed by network operators and system users to find the supplier with equipment suited best for their needs.

2 References

For the purposes of this ETR, the following references apply:

[1] ETSI ETS 300 396-1: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 1: General network design".

[2] ETSI ETS 300 396-2: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 2: Radio aspects".

[3] ETSI ETS 300 396-5: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 5: Gateway air interface".

[4] ETSI ETS 300 392-5: "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 5: Peripheral Equipment Interface (PEI)".

[5] ETSI ETS 300 392-1: "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 1: General network design".

[6] ITU-R Recommendation 329-6: "Proposal for a propagation model to be used in models for calculating spurious emission interference".

[7] ETSI ETR 300-1 (1996): "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Designers' guide; Part 1: Overview, technical description and radio aspects".

[8] ETSI ETS 300 396-3: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 3: Mobile Station to Mobile Station (MS-MS) Air Interface (AI) protocol".

[9] ETSI ETR 300-5: "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Designers' guide; Part 5: Guidance on Numbering and addressing".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this ETR, the following terms and definitions apply:

call: there are two types of call, individual call or group call. An individual call using a gateway is a complete sequence of related call transactions between a DM user and a user on the V+D network (or accessed via the V+D network). There are always two participants in an individual call. A group call is a complete sequence of related call transactions involving at least two or more DM-MSs. The number of participants in a group call is not fixed, but is at least two. Participants may join (late entry) and leave an ongoing group call.

call transaction: all of the functions associated with a complete unidirectional transmission of information during a call. A call is made up of one or more call transactions. In a simplex call these call transactions are sequential.

called user application: user application which receives an incoming call.

calling user application: user application which initiates an outgoing call.

changeover: within a call, the process of effecting a transfer of the master role (and hence transmitting unit) at the end of one call transaction so that another can commence.

Direct Mode (DM): mode of simplex operation where mobile subscriber radio units may communicate using radio frequencies which may be monitored by, but which are outside the control of, the TETRA V+D network. DM is performed without intervention of any base station.

DM Call Control (DMCC): layer 3 entity responsible for setting up and maintaining a call in DMO.

DM channel: specific grouping of timeslots in the DM multiplex structure related to a particular DM RF carrier i.e. DM frequency (or to a pair of duplex-spaced RF carriers for operation with a type 1B or type 2 DM-REP or a type 1B DM-REP/GATE). The grouping may not always be fixed, but in DMO when operating in frequency efficient mode as an example, there are two DM channels, identified by the letters A and B.

Direct Mode Mobile Station (DM-MS): physical grouping that contains all of the mobile equipment that is used to obtain TETRA DM services. A DM-MS may have one of three states:

- **Master:** if the DM-MS is active in a call transaction transmitting traffic or control data;
- **Slave:** if the DM-MS is receiving traffic and/or signalling in a call;
- **Idle:** if the DM-MS is not in a call.

DM-REP presence signal: message transmitted by a DM-REP in order to indicate its presence on an RF carrier.

Dual Watch Mobile Station (DW-MS): MS that is capable of both TETRA DMO and TETRA V+D operation. The MS is capable of periodically monitoring the V+D control channel while in a DM call, a DM RF carrier while in a V+D call and, when idle, it periodically monitors both the DM RF carrier and the V+D control channel.

DM GATEway (DM-GATE): device which provides gateway connectivity between DM-MS(s) and the TETRA V+D network. The gateway provides the interface between TETRA DMO and TETRA V+D mode.

DM REPeater (DM-REP): device that operates in TETRA DMO and provides a repeater function to enable two or more DM-MSs to extend their coverage range. It may be either a type 1 DM-REP, capable of supporting only a single call on the air interface, or a type 2 DM-REP, capable of supporting two calls on the air interface. A type 1 DM-REP may operate on either a single RF carrier (type 1A DM-REP) or a pair of duplex-spaced RF carriers (type 1B DM-REP). A type 2 DM-REP operates on a pair of duplex-spaced RF carriers.

DM REPeater/GATEway (DM-REP/GATE): device that combines the functions of a DM repeater and a DM gateway in a single implementation and is capable of providing both functions simultaneously (so that, during a call transaction initiated by a DM-MS, the DM-REP/GATE provides gateway connectivity to the TETRA V+D network and also provides a repeater function on the DM channel). The repeater part of the combined implementation may be either a type 1A repeater, operating on a single DM RF carrier, or a type 1B repeater, operating on a pair of duplex-spaced DM RF carriers.

frequency efficient mode: mode of operation where two independent DM communications are supported on a single RF carrier (or pair of duplex-spaced RF carriers for operation with a type 2 DM-REP). In frequency efficient mode the two DM channels are identified as channel A and channel B.

gateway: generic term used to describe either a pure DM-GATE or a combined implementation with a repeater (DM-REP/GATE).

logical channel: generic term for any distinct data path. Logical channels are considered to operate between logical endpoints.

managed DMO: form of direct mode operation that requires authorisation from the infrastructure or a master M-DMO terminal in order for service to be obtained.

master link: communication link used for transmissions between master DM-MS and DM-REP or DM-REP/GATE.

net: traditional name for a group call

normal mode: mode of operation where only one DM communication is supported on an RF carrier (or pair of duplex-spaced RF carriers for operation with a type 1B DM-REP or type 1B DM-REP/GATE).

presence signal: signal transmitted by a gateway or a repeater in order to indicate its presence on a DM RF carrier.

quarter symbol number: timing of quarter symbol duration 125/9 µs within a burst.

recent user: DM-MS that was master of the call transaction immediately prior to the current master's call transaction in a call.

recent user priority: service which gives the recent user preferred access to request transmission when the current master is ceasing its call transaction in a group call. This service is controlled by the current master.

registration phase: period of time during which a gateway is actively soliciting registration requests.

RF carrier: distinct radio frequency on which the DM channel may be active.

simplex: mode of working in which information can be transferred in both directions but not at the same time.

slave link: communication link used for transmissions between the DM-REP or DM-REP/GATE and slave DM-MSs.

solicited registration: registration request which is made by a DM-MS during a registration phase initiated by a gateway.

surveillance: process of determining the current state of the DM RF carrier when in idle mode.

timebase: device which determines the timing state of signals transmitted by a DM-MS.

type 1 DM-REP: DM repeater that supports a single call on the air interface. There are two varieties of type 1 DM-REP. A type 1A DM-REP operates on a single RF carrier. A type 1B DM-REP operates on a pair of duplex-spaced RF carriers, one used as the "uplink" from DM-MSs to the DM-REP and the other used as the "downlink" from the DM-REP to DM-MSs.

type 2 DM-REP: DM repeater that is capable of supporting two simultaneous calls on the air interface. A type 2 DM-REP operates on a pair of duplex-spaced RF carriers, one used as the "uplink" from DM-MSs to the DM-REP and the other used as the "downlink" from the DM-REP to DM-MSs.

unsolicited registration: registration request which is made by a DM-MS at any time other than within a registration phase.

V+D operation: mode of operation for communication via the TETRA V+D air interface which is controlled by the TETRA Switching and Management Infrastructure (SwMI).

3.2 Abbreviations

For the purposes of this ETR, the following abbreviations apply:

CEPT	Committee European des Postes et Telecommunications
DLB	Direct Mode Linearisation Burst
DLL	Data Link Layer is a synonym for the whole layer 2
DM	Direct Mode
DM-GATE	Direct Mode Gateway.
DM-MS	Direct Mode Mobile Station
DM-REP	Direct Mode Repeater.
DM-REP/GATE	Direct Mode Repeater/Gateway.
DMCC	Direct Mode Call Control entity
DMO	Direct Mode Operation
DNB	Direct Mode Normal Burst
DO-MS	Direct Mode Only Mobile Station
DSB	Direct Mode Synchronisation Burst
DU-MS	Dual Mode (Trunked Mode / Direct Mode) Switchable Mobile Station
DW-MS	Dual Watch Mobile Station
EU	European Union
GSSI	Group Short Subscriber Identity
GTSI	Group TETRA Subscriber Identity
ISSI	Individual Short Subscriber Identity
ITSI	Individual TETRA Subscriber Identity
M-DMO	Managed Direct Mode Operation
MAC	Medium Access Control
MCC	Mobile Country Code (see note 1)
MMI	Man Machine Interface
MN	Multi-frame number
mod	modulo (base for counting)
MS	Mobile Station (see note 2)
OTAR	Over The Air Re-keying
PDU	Protocol Data Unit
PNP	Private Numbering Plan
PTT	Press To Talk switch, otherwise known as pressel
R&TTE	Radio and Telephone Terminal Equipment
RSSI	Radio Signal Strength Indication
SCK	Static Cipher Key
SDS	Short Data Service sub entity
SSI	Short Subscriber Identity
STCH	Stealing Channel
SwMI	Switching and Management Infrastructure
TCH	Traffic Channel

TDMA	Time Division Multiple Access
TE	Terminal Equipment
TM	Trunked Mode
TMO	Trunked Mode Operation
TN	Timeslot Number
TP	Traffic Physical channel
TSI	TETRA Subscriber Identity
TVP	Time Variant Parameter
Ud	TETRA Direct Mode air interface.
Um	Abbreviation for Trunked Mode Air Interface

NOTE 1: These values may be different and their implementation different from other radio systems (such as GSM).

NOTE 2 The generic term MS includes hand portable and vehicular mounted radio terminals.

4 What is direct mode and why do we need it?

4.1 General

Direct mode is a TETRA mode of operation in which two or more mobile stations communicate together without using the switching and management infrastructure (SwMI). This mode of operation is similar to the back-to-back operation of conventional half duplex radio schemes used by many existing private mobile radio systems such as that of the emergency services.

The use of direct mode is appropriate in the following situations:

- Rural areas with no infrastructure;
- Urban areas with poor coverage e.g. in-building, car parks and underground;
- Covert and special operations;
- Contingency operational reasons e.g. when trunked system is not operational due to fault or is overloaded and the access time can not be guaranteed;
- Secondary coverage from vehicle to handheld terminal.

Conventional back-to-back operation has the following disadvantages:

(i) it leads to unstructured communications since the command structure can not intervene;

(ii) it leads to fragmented communications since there is no connection between back-to-back mobile stations and mobile stations using the infrastructure;

(iii) it is not possible to record the communication.

The DMO capability standardised by ETSI overcomes these deficiencies in particular situations but to use the extended capability it will often be necessary to define operational procedures to ensure that the communication net is set up correctly. One of the purpose of this document is to describe the extended functionality included in the DMO standard and to explain the basis of the procedures which must be put in place to make full use of this functionality.

As with all parts of the TETRA standard (V+D and DMO) the specification is not prescriptive about whether or how something must be implemented. All that the standard strives to achieve is compatibility between different implementations. Hence in many instances a particular user requirement may be stated to be "an implementation issue" i.e. it is supported by the protocol but how the functionality is invoked is left for the manufacturer and the user to agree.

Addressing the drawbacks of back-to-back operation identified above we will briefly outline the methods defined in the TETRA DMO standard for overcoming them. The technical terms used to define the functionality and the methods of achieving the desired objectives will become more apparent in the following clauses.

In all direct mode operation (remember that there are several types of DMO operation namely MS-MS, via a repeater and including a gateway) a pre-emption facility is included which allows higher priority direct mode MSs to seize the channel from lower priority users. If a gateway is included in the call then it is even possible for a dispatcher to take over the call.

The dual watch facility is of use when one of the radios in a local back-to-back group is within the range of the trunked system. By selectively listening in to the infrastructure it is possible for the MS in a back-to-back conversation group to be contacted if required by anyone else using the trunked system i.e. the DMO MS is contactable from the infrastructure if within range. In a similar way, if an MS operating in trunked mode is within range of its DMO talk group then it is able to dual watch on that group and be included in any calls that are set up.

NOTE: It is possible to perform dual watch in today's conventional FDMA radio systems so long as the mobile is not in a call. The TDMA structure of DMO/V+D allows dual watch even within a call without losing any information.

On point (iii) above, if a DMO/TMO gateway is included in the DMO group then it is possible for the direct mode message exchanges to be recorded (so long as the transmitting MS is within range of the gateway).

In direct mode there are the normal issues of blocking and desensitisation as suffered in conventional radio systems. These problems are however more acute for direct mode than trunked mode since there is no power control in direct mode (except repeater operation). Furthermore there is a potential for interference of the direct mode MSs with the trunked mode infrastructure leading to degraded performance of the trunked system. This is a problem that needs to be recognised and controlled if direct mode is to operate effectively within the coverage area of the trunked system. These issues are examined in clause 11.

Note however, that mutual interference is not a problem particular to TETRA. Similar effects are experienced with conventional analogue radio systems if operated in close proximity.

4.2 Frequency of operation

A major difference between TETRA trunked and direct mode operation is that in the latter only simplex voice operation (see Note) is supported for both individual and group call operation, and multi-slot circuit mode data is not allowed. There are other differences between the functionality supported by trunked and direct mode. This is summarised in annex A.

NOTE: In simplex operation only one party can speak at any time. The other party(ies) must listen.

To minimise the risk of mutual interference it is desirable to provide frequency separation between the allocation for DMO and TMO services. This can be achieved by operating DMO in a sub-band at one end of each of the available TETRA allocations (see figure 1). This has been proposed for internationally agreed common channels but for national use each country is also free to allocate DMO channels within the BS transmit and BS receive bands.

Since DMO is basically single frequency operation (except Repeater types 1B and 2) other channel arrangements are possible depending on the National regulatory administration.

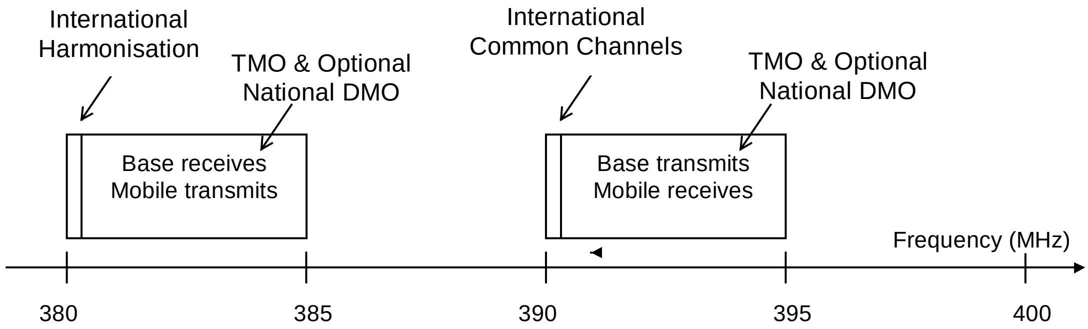

Figure 1: Proposal for spectrum lay-out in the 380 MHz to 400 MHz frequency range

This draft CEPT arrangement proposes that the DMO frequencies are symmetrically positioned at the bottom of each of the uplink and downlink frequency bands. This has the advantage of allowing pairing the DMO frequencies (as in trunked operation) so that at least 2 well isolated direct mode frequencies would be available simultaneously at the same location. Furthermore it allows easy co-ordination between user groups and between neighbouring countries. However there are many disadvantages especially if many co-incident DMO groups (see Note) need to be set up at the same physical location.

NOTE: If intermodulation free DMO channels are to be set up then there is a defined relation between the frequencies.

The detailed effect of the DMO frequency assignments in different spectrum positions will be considered in subclause 11.11. As a preview we can state that if the DMO RF carrier is positioned in the BS transmit band then any interference it produces will be confined to surrounding TMO MSs in its immediate vicinity.

If the DMO RF carrier is positioned in the BS receive band (MS transmit band) then the interference it produces will affect the BS Rx sensitivity and consequently reduce the cell size of any BS in close proximity.

Both situations have advantages and disadvantages. It could be argued that whilst BS desensitization potentially affects many mobiles this situation is statistically less likely due to greater number of MSs compared to BSs.

4.3 Managed Direct Mode

The subject of this document is a form of direct mode operation (DMO) which can independently operate either within trunked radio coverage or outside of trunked radio coverage. This form of direct mode operation will be of interest to Emergency Service users and other professional users who will have DMO channels allocated for their exclusive use within a country.

Unfortunately the TETRA DMO frequencies are not yet fully harmonised (see subclause 4.4) and in any case, due to the uncontrolled nature of DMO use, i.e. ability to transmit before receiving an authorisation signal, there is a need to restrict operation of DMO MSs outside their country of origin. This is why managed DMO (M-DMO) is being developed.

The aim of M-DMO is to deliver direct mode operation (DMO) which is under the control of the trunked infrastructure. Like the basic "unmanaged" DMO, M-DMO can operate both inside or outside infrastructure radio coverage. M-DMO will provide a high level of service similar to the basic DMO and will again be of interest to Emergency Service and other professional users.

Managed DMO can be controlled in several ways:

- *Under coverage of the trunked network*, the base station will authorise use of pre-assigned DMO channels to a dual watch M-DMO terminal or to a number of dual watch M-DMO terminals. Alternatively an authorised dual watch M-DMO terminal can set up a "Presence" signal that allows registered M-DMO capable terminals to communicate on that RF carrier within range of the presence signal. These types of operation are normally both time and location limited under the control of the local base stations (infrastructure).

- *Outside coverage* a "Master M-DMO terminal" will normally be used to generate the "Presence" signal. Again, this allows registered M-DMO capable terminals to communicate on that RF carrier within range of the presence signal. Time or geographical location, or both control the MASTER M-DMO terminal.

At the time of release of edition 1 of this guide, standardisation of Managed DMO is not yet complete but is at a mature stage. More information on its uses and properties will be contained in the second edition of this document.

4.4 Direct Mode on European shared harmonised spectrum

ETSI has recently requested that the CEPT Frequency Management (FM) Working Group allocate a number of RF carriers (6) at around 446 MHz where also the "PMR 446" initiative has been allocated spectrum for a similar application. These RF carriers will be able to support a large number of users, without significant interference being experienced, because of the limited range of the DMO terminals and because of the usage profile. The driving force behind having European wide harmonised DMO spectrum is that this would make it legal to have DMO in a terminal that could roam into other countries. The problem, at least for Civil Tetra, is that the standard DMO, as described in this document, will require individual national license to be issued to the end-user of the equipment. This immediately implies that the equipment cannot be used outside its home country. Thus, until the EU R&TTE Directive enters into force, any equipment supporting standard TETRA DMO will also need a national type approval certificate.

5 Direct mode services and facilities

5.1 Service definitions

In TETRA DMO three distinct classes of service are provided, teleservices, bearer services and intrinsic services.

The following subclauses explain the difference between these services.

5.1.1 Teleservice

A teleservice is defined as a type of service that provides the complete capability, including terminal equipment (TE) functions, for communication between users according to TETRA protocols. In other words a teleservice provides the user with the possibility of gaining access to various forms of applications via the TE, and it is carried through the network by the bearer service.

Figure 2 illustrates in a simple sense the basic differences between these two services in terms of user access point within the MS.

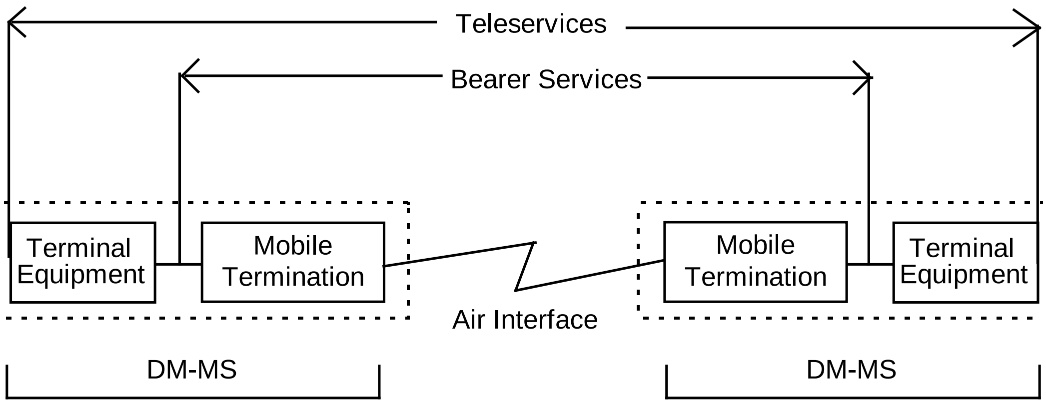

Figure 2:DMO teleservices and bearer services

5.1.2 Bearer service

A bearer service is defined as a type of service that provides the capability for information transfer between user-network interfaces and only involves lower layer functions (layers 1-3 in the OSI model as described in clause 8 of this document). The user application may use any set of higher layer protocols for communication, but the bearer service shall not ascertain compatibility between applications at these layers.

Bearer services are provided in DMO as a means to transfer data between DM-MSs via the DM air interface. This data may be speech or any other form of data. What the DMO bearer service offers is similar to a data "pipe", and the transmission effected through that pipe is independent of its content.

5.1.3 Intrinsic service

An intrinsic service is a service which is inherently available within a normal teleservice or bearer service. An intrinsic service exists by virtue of it being included as an integral part of the signalling associated with the basic services. In this respect it is different from the Supplementary Services (SS) supported in V+D mode as it requires no explicit invocation. Options may however exist within an intrinsic service which require application level intervention.

5.1.4 Summary of tele/bearer services offered in TETRA DMO

Table 1 provides a summary of the tele and bearer services supported within TETRA DMO.

Table 1: Voice and Data (V+D) services supported in DMO

	Teleservice	**Bearer service**
TETRA speech	Individual Call (pt-to-pt) Group Call (pt-to-multipoint)	N/A
Circuit mode unprotected data	N/A	7,2 kbit/s (point-to-point) or (point-to-multipoint)
Circuit mode low protected data (one of three different interleaving schemes can be demanded).	N/A	4,8 kbit/s (point-to-point) 4,8 kbit/s (point-to-multipoint)
Circuit mode high protected data (one of three different interleaving schemes can be demanded).	N/A	2,4 kbit/s (point-to-point) 2,4 kbit/s (point-to-multipoint)
Short data service - type 1	N/A	16 bits user defined data
Short data service - type 2	N/A	32 bits user defined data
Short data service - type 3	N/A	64 bits user defined data
Short data service - type 4	N/A	2047 bits user defined data
Status messages	N/A	16 bits

Speech and circuit mode data services may, as an option, have end-to-end encryption and/or air interface encryption. Short data messages and status messages may have air interface encryption.

A table identifying the intrinsic services supported in direct mode operation is given in annex A.

5.2 Direct mode teleservices

TETRA DM voice teleservices support the transmission of speech utilising a TETRA specific voice codec as defined in ETS 300 392-5 [4]. They use standard TETRA speech and channel coding as defined in ETS 300 396-2 [2]. Optional encryption is discussed in clause 10 of this Designers' Guide.

TETRA DM voice teleservices support speech on a point-to-point (individual call) and point-to-multipoint (group call) circuit mode basis. The voice mode of operation is always simplex.

5.2.1 Individual call

An individual call is a point-to-point communication between one calling party and one called party. It may only be set up between two MSs which have selected the same DM RF carrier. An individual MS has a pre-defined number (ITSI) by which it is addressed. The mode of operation is simplex.

Individual calls may be set up with or without a presence check. The presence check is a method by which the call initiator can find out whether the called party terminal is switched to the RF carrier and responds to an interrogating message in advance of the call being set up.

Unlike V+D trunked mode, in DMO there is no facility for ON/OFF hook signalling. With DMO response to all calls comes from the radio terminal (i.e. there is no facility to wait for the user to go off hook).

5.2.2 Group call

A group call is a two way point-to-multipoint communication between a calling party and one or more called parties. It may only be set up between MSs which have selected the same DM RF carrier.

The members of a group have one common pre-defined number which is called their group number (GTSI) and by which they are addressed. The Ud air interface uses the same addressing scheme for group numbers as defined in ETS 300 392-1 [5]. The air interface supports more than one group on a DM RF carrier (see Note) although, for normal mode of operation, only one group is able to communicate using the channel at any given time.

NOTE: Note that in normal mode of operation there is one DM channel per RF carrier, whilst in frequency efficient mode there are two.

In addition, there may be an 'open' or 'common' group number which includes all users to allow calls to be made to all users who have selected the same DM RF carrier, providing for open channel operation.

Only one number (group number-GTSI) is sent on the air interface and no acknowledgement is expected. The primary objective is to have a fast call set up. The mode of operation is simplex.

5.3 Direct mode bearer services

A circuit mode bearer connection is a point-to-point or point-to-multipoint data communication between one calling MS and one or more called MSs. It may only be set up between MSs which have selected the same DM RF carrier. The mode of operation is simplex.

Three types of circuit mode bearer service are offered within TETRA DMO depending on whether or not the data is protected or unprotected, and depending on the level of protection provided. The difference between the protected and unprotected bearer services is that the protected bearer service provides error protection as defined in ETS 300 396-2 [2] clause 8 for the user data being transmitted. The result as far as the user is concerned is a more reliable and robust channel at the expense of a reduction in the net user data rate.

5.3.1 Circuit mode unprotected bearer services

Circuit mode unprotected bearer services support circuit mode data on a point-to-point (individual call), and point-to-multipoint (group call) basis. Data throughput at the user interface is 7,2 kbit/s.

5.3.2 Circuit mode protected bearer services

Circuit mode protected bearer services support data on a point-to-point and point-to-multipoint basis. Six protected bearer services are defined in TETRA DMO offering two different levels of protection against bit error by using forward error protection in the transmitted bit stream. Error protection is as defined in ETS 300 396-2 [2], clause 8 and the six services offer data throughput at the user interface at 4,8 kbit/s or 2,4 kbit/s with error protection rates of approximately 2/3 or 1/3 respectively. In order to provide further protection against errors, interleaving at depths 1, 4 or 8 may be applied along with the two levels of error protection, resulting in the six service options.

5.3.3 Short data service (SDS)

The TETRA DM SDS is similar to the SDS offered within the TETRA V+D standard. Both point-to-point and point-to-multipoint services are supported in DM SDS. Point-to-point SDS offers optional acknowledgement whereas the point-to-multipoint service is unacknowledged.

The SDS is essentially a message service which can be optimised for speed, enabling the user to exchange a short user defined message or a short pre-defined message such as an emergency message. The message is sent within signalling capacity and may be sent or received in parallel with an ongoing speech or data call. The SDS may be used for applications such as automatic vehicle location, status or Over The Air Re-keying (OTAR) etc.

The SDS in DM supports up to the same number of data bits as the SDS in V+D mode (2 047 bits max.) with the content being user defined or pre-defined.

DMO SDS may be carried on an individual call or group call basis across the DMO air interface. It may also be carried via a DM-REP and may be directed into or received from the V+D system via a DM-GATE or a DM-REP/GATE.

A point-to-point short data message is sent from one originating MS to one receiving MS using the currently selected DM RF carrier. The receiving MS is addressed by its ITSI in the usual manner [5]. The receiving MS acknowledges receipt of the message if acknowledgement has been requested and the originating MS may retry a number of times if acknowledgement is expected and no acknowledgement is received.

A point-to-multipoint short data message is sent from one originating MS to a group of one or more receiving MSs using the currently selected DM RF carrier. The group is addressed by its GTSI in the normal manner [5]. There is no acknowledgement from the receiving MSs in this case, but the originating MS may re transmit the message a number of times for reliability.

The following SDS/status message functional capabilities may be supported in DMO terminals:

(a) send/receive short data messages of defined length;

SDS type	Size of user defined message (bits)
1	16
2	32
3	64
4	up to 2047

(b) send/receive pre-defined status messages.

Status number	Definition
0	Emergency
1 to 32 767	Reserved
32 768 to 65 535	Available for user/network definition

(c) address a single party by using the ITSI address of the target message receiver;
(d) receive the ITSI address of the message sender and to relay it to the user application;
(e) address multi-parties by using the GTSI of the target message receivers;
(f) apply priority to the message;
(g) receive the priority applied to the message and to relay it to the user application.

5.4 Intrinsic services

The following subclauses describe the intrinsic services which are supported by DMO. Intrinsic services are offered in association with all of the voice and data services described in the previous clauses and form an integral part of the signalling on the Ud interface.

5.4.1 DM late entry

This intrinsic service allows an MS, when it accesses an active DM RF carrier, to enter an ongoing call if that call is addressed to a group of which it is a member. An MS may access a DM RF carrier in a number of ways, for example:

- the user switches on the MS and selects that RF carrier;
- the user switches from another DM RF carrier to that RF carrier;
- the MS returns to DM coverage after a period of lost coverage;
- the user switches the MS from V+D mode to DM and selects that RF carrier.

5.4.2 Transmitting party identification

This intrinsic service provides the ability for the MSs receiving a call to receive the number of the currently transmitting MS. This requires that, at the beginning of each call transaction, the transmitting MS transmits an individual subscriber number. This allows the receiving MS(s) to display the identity of the transmitting MS.

A user option allows details of the originating ITSI to be concealed. This option allows a transmitting MS to withhold its identity (by substituting a pseudo SSI), a feature which may be required for certain authorised users.

NOTE: The pseudo SSI is an identity chosen at random by the MS and declared as such when it is used.

5.4.3 Emergency calls

The DM air interface supports emergency calling. A DM-MS initiating an emergency call out of coverage of the system may use a DM channel and, if necessary, over-ride any call on that channel. The only exception is if the existing call is also an emergency priority call.

This intrinsic service provides the ability for the DM communication to be pre-empted in order to support the emergency calling service.

5.4.4 OTAR

TETRA DMO provides extensive security services (see clause 10). To support these services a special data service called Over The Air Re-keying (OTAR) is required.

DMO supports OTAR by means of a specially designated MS. The OTAR MS may generate and distribute Static Cipher Keys (SCKs) for each MS using a sealing key distributed from an authentication centre in a secure manner that is specific to each DM-MS (derived from the secret key K associated with each ITSI). A multi-pass protocol for key request and key delivery is defined with implicit authentication only required (as the SCK can only be recovered by the holder of K).

Any DM-MS may act as a store and forward station for a Sealed Static Cipher Key (SSCK).

6 Description of direct mode equipment types

6.1 General

In this clause a number of reference models are identified which apply to TETRA DMO. The purpose behind these models is to assist in providing a definition of the interfaces which exist between various device types and, if relevant, to any other involved terminal or network entities.

The reference models cover all distinct operating possibilities and provide a framework for describing the technical operation for the various interfaces.

The abbreviations used in the reference models are defined in clause 3. The abbreviation DM-MS is used throughout the Designers' Guide as a generalised term to include all MSs capable of working in DMO. The full capability of any particular DM-MS is not a standardised parameter but is an issue for implementation.

Some basic assumptions on the likely types of mobile station are however useful in order to define specific operational issues and, where this is appropriate in this document, the following terminology is used:

- DM-MS: generalised term for any DMO capable MS;
- DO-MS: Direct mode Only MS;
- DU-MS: DUal mode switchable MS (i.e. between direct and trunked modes);
- DW-MS: Dual Watch MS;
- DM-REP: Direct Mode REPeater;
- DM-GATE: Direct Mode GATEway;
- DM-REP/GATE: Direct Mode REPeater/GATEway.

Implementations which combine dual functionality in a single unit, e.g. a DM-REP and MS end equipment are not considered to be distinct and separate stations, but for the purposes of this document are considered to be combinations of those listed above.

The general term DM-MS will be used as applying to all DM-MSs, but the other terms listed above may be applied where specific differentiation is necessary.

Each Direct Mode type of operation identified above (i.e. MS, REP, GATE) has a different air interface protocol. To differentiate them in this document we have labelled them as Ud_1, Ud_2 and Ud_3 respectively. In the ETSI standards documents this differentiation has not been made since each DM air interface is dealt with in a separate document and there is no ambiguity which is being referred to. They are all designated as Ud. To the casual reader this may imply that they are all the same. Beware, they are different.

Hence to achieve the required functionality it is important to realise at the outset that each Direct Mode type of operation needs the appropriate software to be present in the mobile station and to be manually selected by the User.

One of the distinguishing features of the different DM equipment types is the number of RF carriers required to provide the defined functionality and the maximum number of ongoing voice calls supported by the equipment type. This information is summarised in table 2 :

Table 2: **Characteristics of the different DM equipment types**

DM type	No. of RF carriers	No. of voice calls
MS-MS Normal	1	1
MS-MS Frequency Efficient	1	2
Repeater Type 1A	1	1
Repeater Type 1B	2	1
Repeater Type 2	2	2
DM-GATE	1	1
Type 1A REP-GATE	1	1
Type 1B REP-GATE	2	1

6.2 Direct mode mobile station (DM-MS)

The basic reference model for DMO applies to a simple point-to-point or point-to-multipoint communication between DM-MSs using the DM air interface, Ud_1. Figure 3 shows the most basic configuration and is the most simple with which to define the range of services which are to be supported by DMO.

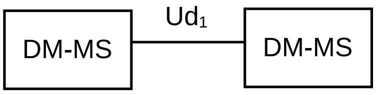

Figure 3: DM-MS connected to DM-MS via DM air interface, Ud_1

The basic Ud_1 air interface protocol is further described in clause 8 of this document. In the definition of the air interface, differentiation is made between the current transmitting and the current receiving MSs at any point in a call.

The transmitting DM-MS provides the synchronisation reference and is defined as the "master" DM-MS. A DM-MS which initiates a call becomes the master for the duration of that transaction. Any DM-MS which synchronises on a "master" DM-MS is defined as a "slave" DM-MS.

The general DM-MS to DM-MS network configuration is shown in figure 3. The dual watch capability of the DM-MS allows it to monitor activity on the trunked mode air interface and detect calls addressed to it. The inverse functionality can be supported in trunked mode terminals allowing them to monitor activity on the direct mode channel and detect DMO calls intended for them whilst they are operational in trunked mode. This will be described further in the next subclause.

The same Ud_1 air interface applies to a DO-MS, a DU-MS when set for DMO and the DM aspects of a DW-MS (either in active or monitoring mode). The Ud air interface also applies to links between DM-MSs and DM-REPs, or to links between DM-MSs and DM-GATEs, though in these latter cases there are slight differences within the protocol operating over the air interface in order to cater for additional functionality. The differences between the air interface protocols for each different type of direct mode operation is signified by the different subscripts following Ud.

There are two types of MS-MS direct mode of operation. Normal mode of operation permits a single simplex call to be supported per 25 kHz channel. "Frequency Efficient mode" permits two simplex calls per 25 kHz channel. These two DM-MS modes of operation will be further described in clause 8.

6.3 Dual watch mobile station (DW-MS)

The reference model shown in figure 4 applies to a DM-MS which is capable of dual watch.

Figure 4: Dual Watch reference model

The DW-MS can be in any one of three states as follows:

- idle in both modes and periodically monitoring both the V+D mode control channel and a selected DM RF carrier;
- communicating with another DM-MS via the Ud air interface and periodically monitoring the V+D mode control channel over the Um air interface without interrupting direct mode operation;
- communicating with the TETRA Switching and Management Infrastructure (SwMI) in V+D mode via the Um air interface and periodically monitoring a selected DM RF carrier without interrupting trunked mode operation.

It is important to stress that simultaneous active communication over the two air interfaces is not supported by the standard.

For dual mode mobile stations (DU-MS), a similar reference model applies. However the MS is firmly in one mode or the other (trunked or direct mode). There is no capability to monitor the inactive mode (as there would be for a DW-MS).

For a DMO terminal to perform dual watch the basic principle is to register on the trunked network and then declare economy mode operation. The V+D network subsequently only attempts to contact the subscriber in known time slots. The DMO terminal will monitor these time slots to see if there are any messages for the subscriber on the trunked network. The drawbacks are similar to V+D economy mode operation. For instance if the subscriber is a member of a group then, unless all members of the group are in the same economy mode regime, trunked mode group call starts will be missed (or optionally group call starts delayed).

6.4 Direct mode repeater (DM-REP)

This reference model applies to operation using a direct mode repeater (DM-REP) between the end MSs.

Figure 5 shows the simplest form of link between DM-MSs using the Ud air interface via a DM-REP.

Figure 5: DM-REP reference model

The DM-REP receives information from a transmitting mobile station on an "uplink timeslot" and re-transmits this information to another mobile station or group of mobile stations on a "downlink timeslot". The DM-REP specified within the standard is regenerative i.e. it decodes and re-encodes received speech and signalling bursts which it receives (one slots-worth at a time), to improve the overall link performance.

The standard defines three different types of repeater:

- Type 1A: single call single frequency repeater.
- Type 1B: single call two frequency repeater.
- Type 2: two call two frequency repeater.

Each of these repeater types have advantages and disadvantages in different operational scenarios. Type 1A is suitable for single vehicle operation. Type 1B is needed for operational vehicles which must support multiple repeaters whilst Type 2 provides a better solution for non-interfering operations vehicle. Each of these repeater types will be described further in the second edition of this guide.

The direct mode repeater network configuration is illustrated in figure 5. Note that two way dual watch between trunked and direct mode terminals is supported for repeater operation.

6.5 Direct mode gateway (DM-GATE)

This reference model applies to operation when using a direct mode gateway (DM-GATE) into a TETRA V+D network. In this guide DM-GATE concerns only the link between TETRA DMO and TETRA V+D mode.

Figure 6 shows the simplest form of link between a DM-MS and the TETRA V+D SwMI (and hence onward, e.g. to a V+D MS or Line connected Station (LS)) using the Ud air interface via a DM-GATE.

Figure 6: Gateway into a TETRA SwMI

The DM-GATE caters for the differences in protocol between the Ud_3 and Um air interfaces and provides for the required inter-connectivity between DM and the TETRA V+D network.

It is important to realise that DM-GATE supports only a single ongoing call interconnected between the trunked network and the DM group or individual.

Dual watch is not supported by the DM gateway protocol. This is not an oversight but an accepted limitation in functionality for the DM terminals when in gateway mode. The function of a DM gateway is to provide access to the V+D network to those mobile stations out of coverage of the trunked network or those MSs working only in direct mode. Dual watch and gateway operation provides similar capability so the DMO protocol has no need to support dual watch in gateway operation.

If a user has access to the trunked network (i.e. within coverage) then a better service will be obtained by dual watching trunked mode and accepting calls directed by the dual watch capability.

6.6 Direct mode repeater/gateway combination (DM-REP/GATE)

This is a special case of combined repeater/gateway functionality, e.g. in a single equipment where a vehicle based repeater serving a DM network is also required to have a link back to the TETRA V+D network over the Um air interface. Figure 7 shows a DM-GATE combined with a Type 1 DM-REPEATER.

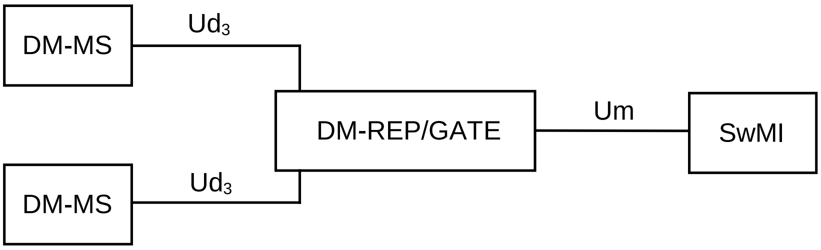

Figure 7: Repeater/gateway into a TETRA SwMI

This device can offer a combination DM-REP/GATE and may offer a DM-REP function. The user will select which functionality is required when setting up the call. When no call is in progress the DM-REP/GATE will be broadcasting a presence signal identifying itself to potential users.

In the DM-REP/GATE mode a single call is relayed to the trunked network and also repeated to a wide range with the DM operation.

As previously discussed in the introduction to this subclause, it is important to realise that a DM-MS needs to have additional protocols to work with a repeater or a gateway.

6.7 Direct mode power classes

There are ten power classes defined for direct mode equipments, ranging from 22,5 dBm to 45 dBm in 2,5 dB steps. Direct mode equipment does not support power control. When operated on DM repeaters the transmitting MS may optionally control its uplink transmit power (in a manner similar to trunked mode terminals). The direct mode power classes are defined as follows in table 3.

Table 3: Nominal power of MS transmitters

Power class	Nominal power
1 (30 W)	45 dBm (not defined for DM-MS)
1L (17.5 W)	42.5 dBm (not defined for DM-MS)
2 (10 W)	40 dBm
2L (5.6 W)	37.5 dBm
3 (3 W)	35 dBm
3L (1.8 W)	32.5 dBm
4 (1 W)	30 dBm
4L (0.56 W)	27.5 dBm
5 (0.3 W)	25 dBm
5L (0.18 W)	22.5 dBm

A direct mode MS may be switched to operate in more than one power class.

6.8 Limitations imposed by the physical layer for direct mode type equipment

Some DMO equipment needs to support inter-slot switching i.e. the ability to transmit on one slot and to receive on the adjacent slot. These limitations are as follows:

- One slot switching required for direct mode MS-MS communications and for MSs operating with a repeater or gateway.
- Half slot switching Tx/Rx and Rx/Tx is needed to support dual watch with its additional requirement to synchronise to both DMO and TM simultaneously.
- Repeaters and gateways require interslot working i.e. the ability to transmit/receive on adjacent slots.
- Repeater and gateway protocols have not been designed to achieve high energy economy and hence practical implementations are unlikely to be handheld equipment, more likely to be vehicle mounted.
- Type 2 repeaters need to be frequency duplex (i.e. transmitting and receiving at the same time as in trunked mode base stations). Hence they require some form of antenna filtering and diplexing arrangement similar to trunked mode base stations.
- There are extra physical requirements for DM-REP/GATE as specified in ETS 300 396-5 [3].

7 Direct mode operational examples

7.1 General

This subclause presents examples of how communication between the various types of TETRA V+D and DMO radio equipment can take place. Details of how the protocols work for different types of direct mode operation are given in later clauses.

Figures 8 to 11 show two groupings of mobile stations:

- Direct Mode Net – Mobile Stations working in Direct Mode using one of the following:
  - Ud_1 – Direct Mode: mobile-to-mobile radio air interface (see Note);
  - Ud_2 – Direct Mode: via repeater radio air interface;
  - Ud_3 – Direct Mode: radio air interface gateway from Trunked Mode.

  NOTE: Note that the direct mode air interface nomenclature used in the Designers Guide Part 1 ETR 300-1 [7] is slightly different from that shown here. In ETR 300-1 [7] Ud_1 is called I6, Ud_2 is called I6'' and Ud_3 is called I6'.

- Trunk Mode Net – Mobile Stations working in Trunk Mode using the Um Trunked Mode radio air interface.

It is assumed that for the operational examples shown here, all MSs are members of the same Talk Group, whether active in Direct Mode or Trunked Mode. The MSs can simultaneously be members of other talk groups and potential operational conflicts are identified.

In figures 8 to 11 , the following key is used.

Key:	—— – – ——	Denotes Transmissions initiated by active Trunk Mode MSs
	————————	Denotes Transmissions initiated by active Direct Mode MSs

7.2 MS to MS communication with Dual Watching

The first example (shown in figure 8) considers two separate physical groupings of mobile stations (called mobile nets). One net is working in direct mode and the other net is working in trunked mode. One mobile station in each net is eavesdropping (dual watching) on activity in the other net.

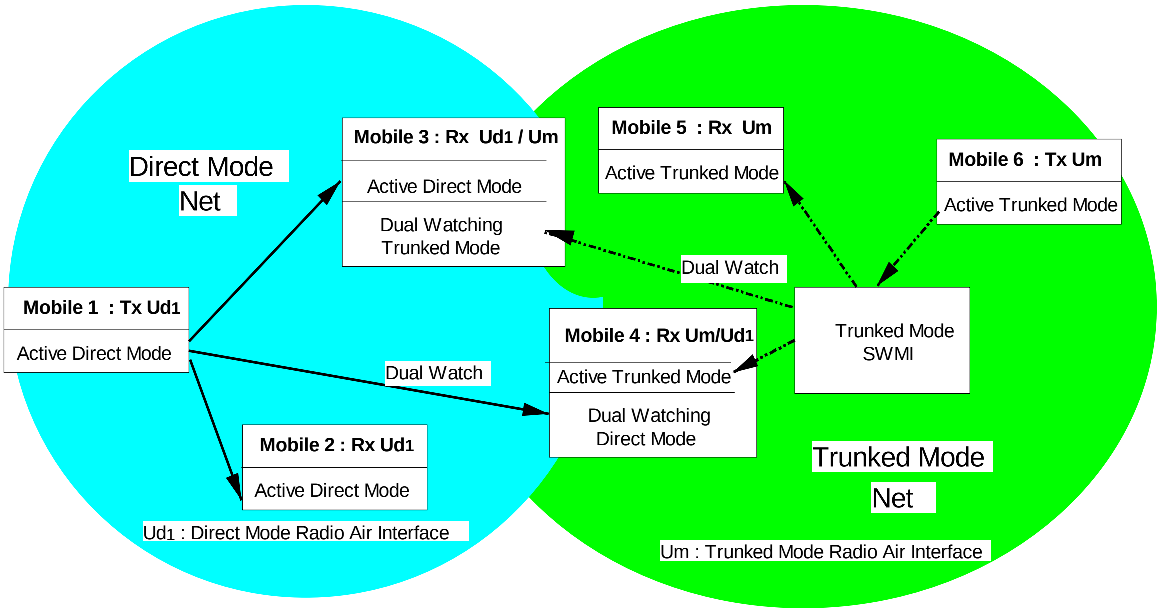

Figure 8: Functional network configuration showing Direct Mode MS-MS air interface.

MS 1 transmits on the Direct Mode channel and this is received directly by MS 2 and MS 3. MS 4 is in active Trunk Mode but has a Dual Watch facility monitoring the Direct Mode Channel and is also in range of MS 1. Therefore MS 4 also receives the Direct Mode set-up from MS 1 and the user receives an indication that a Direct Mode set-up has been received. The user of MS 4 may choose to switch to direct mode operation to join the direct mode call that is being set up. Note that once the direct mode call has been set up there is an intrinsic late entry message sequence transmitted during the call transaction and at the start of each call transaction when other dual watch trunked mode MSs may join the call.

NOTE: The dual watch capability is not restricted to circuit mode voice and data. It can also be used to send and receive SDS messages and packet mode data if the destination MS is not busy in a call.

Alternatively, MS 6 transmits on the Trunk Mode channel and is received via the infrastructure by both MS 5 and MS 4. MS 3 is in active Direct Mode but has a Dual Watch facility and is in range of the infrastructure. Therefore MS 3 periodically monitors the Trunk Mode Control channel and receives the Trunk Mode set-up from the infrastructure. The user of MS 3 may choose to switch to trunked mode operation to join the trunked mode call that is being set up. Note that while all MS may be members of the same talk group in the example shown there are two independent calls set up, one on the trunked network and the other a DMO call.

7.3 DMO communication via a repeater with Dual Watching

To achieve extended and stable radio coverage two or more direct mode MSs can communicate using a Direct Mode Repeater, as is shown in figure 9.

DMO Repeaters are similar in operation to the DM-MS terminals described previously so far as pre-determined choice of RF carrier is concerned. However the 10 bit address identifying the repeater also needs to be known by each operational MS which will be allowed to use the repeater. This can be done by prior arrangement or by the DMO MS receiving the repeater presence signal containing the 10 bit address. If access to the repeater is to be restricted it needs to know in advance which MSs it will be required to serve.

Repeaters may optionally transmit a presence signal which may include the individual and group addresses to which it offers service. This aspect is discussed further in annex D.

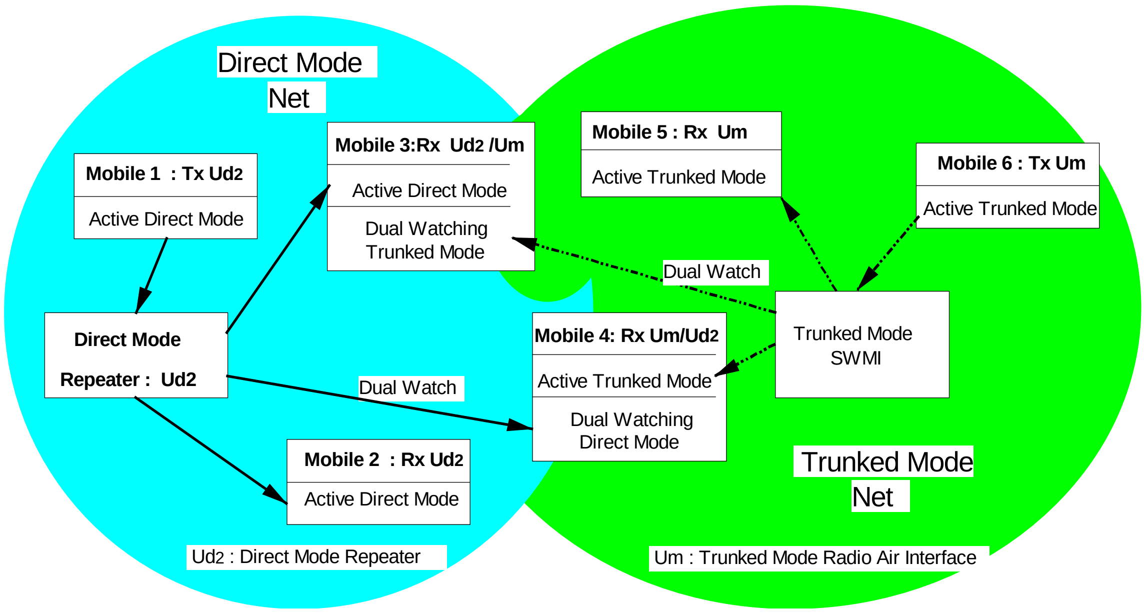

Figure 9: Functional network configuration showing Direct Mode Repeater air interface.

MS 1 is instructed either by pre-programming or by detection of the Repeater presence signal to address the Repeater when transmitting to the Talk Group. MSs 2 and 3 both ignore the set-up received directly from MS 1 due to inclusion of the Repeater address. The Repeater repeats set-up from MS 1 and is received by both MSs 2 and 3. MS 4 is in active Trunk Mode but has a Dual Watch facility monitoring the Direct Mode Channel and is also in range of the Repeater. Therefore MS 4 also receives the Direct Mode set-up from the Repeater and the User receives an indication that a Direct Mode call set-up has been received.

Alternatively, MS 6 transmits on the Trunk Mode channel and is received via the infrastructure by both MS 5 and MS 4. MS 3 is in active Direct Mode but has a Dual Watch facility and is in range of the infrastructure. Therefore MS 3 periodically monitors the Trunk Mode Control channel and receives the Trunk Mode set-up from the infrastructure.

7.4 Gateway operation

A Direct Mode Gateway provides connectivity between a Direct Mode mobile station and the Tetra trunked network. A gateway can only ever handle one call at a time. This means that for DMO gateway operation the direct mode group call and the trunked mode group call effectively operates as single group call. This situation is depicted in figure 10.

A Direct Mode Gateway may optionally transmit presence signals on the Direct Mode channel. The optional presence signal may contain the 10 bit address of the gateway and the individual and group addresses which are offered gateway service. Knowing the gateway 10 bit address, the DM MS may register on to the Direct Mode Gateway.

Users wanting to include a gateway in their direct mode call need to select the appropriate instruction/switch position on their MS (so that the correct gateway protocol is used). The Direct Mode MSs will then incorporate the Gateway address in the call set up. A call set up is directed to the Gateway. The Gateway will grant the Direct Mode call as soon as the trunked network has allocated a time slot. A Direct Mode call that incorporates a Gateway will only be possible if there is capacity available on the Trunked network. This means that the gateway call may take some time to set up. Some users (such as emergency services) may choose to set up the gateway access in advance and keep it "alive" if a rapid response is required. However users should be aware that this blocks access to the gateway for other user groups.

The Direct Mode Gateway can make adjustments to the Direct Mode timing in order to avoid interference with the trunked mode time slots.

An example of use for a Direct Mode Gateway would be to extend the range of a hand portable mobile station via a car mounted Gateway.

As is the case for DMO repeaters, the MSs again need to know the pre-determined RF carriers for operations and the 10 bit gateway address (either by prior arrangement or by receiving the presence signal). Likewise the Gateway needs to know the MSs that will be allowed to use it. The MSs may indicate their presence to the gateway and the gateway may then send the list of active MSs to the trunked infrastructure.

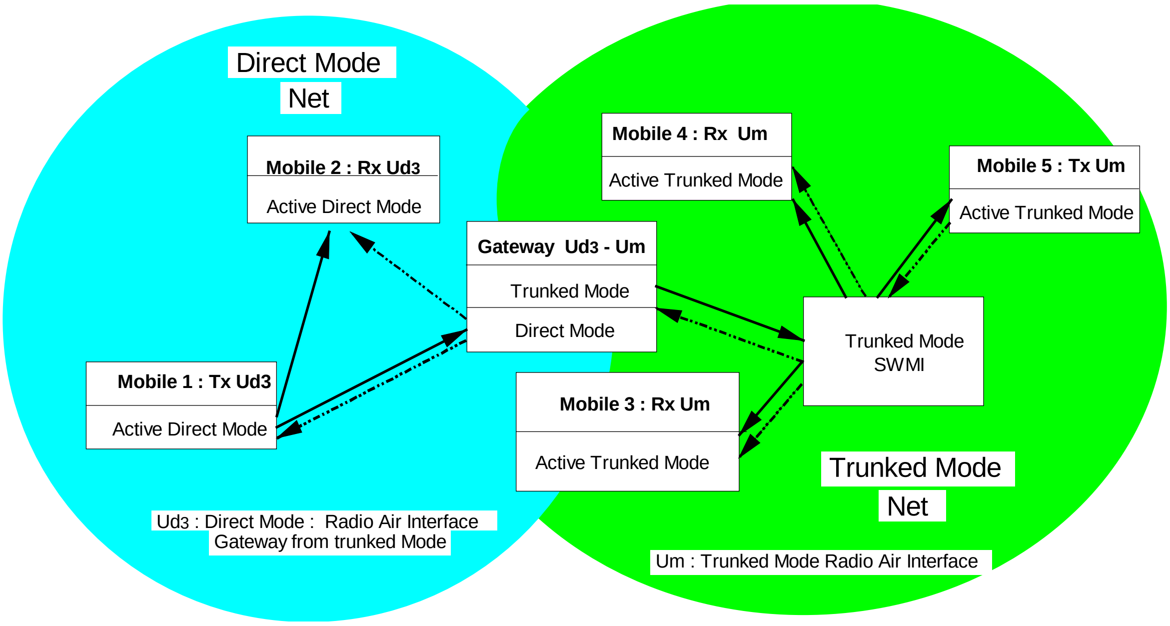

Figure 10: Functional network configuration showing Direct Mode Gateway air Interface

This example considers a single TMO/DMO call spanning the gateway. The call can be set up either from the direct mode side or the trunked mode side of the gateway as follows:

MS 1 (call initiator) is instructed either by pre-programming or by detection of the Gateway presence signal to address the Gateway when transmitting to the Talk Group. The Gateway detects the set-up message from MS 1 and forwards it to the infrastructure. The infrastructure goes through the normal trunked mode set-up procedure allocating a channel to MSs 3, 4, and 5 and also the gateway when resources are available. On receiving the trunked mode channel allocation the gateway then informs MS 1 that the call can proceed. MS 1's traffic is then received by MS 2 and also by the gateway which forwards it to the infrastructure for re-transmission to MSs 3, 4, and 5.

When initiated from the trunked network the call set-up is as follows:

MS 5 transmits a call set-up request on the Trunk Network. A normal trunked mode call is set up to include MS numbers 5, 4, 3 and the Gateway. The Gateway then sets up a direct mode group call to include MS numbers 1 and 2.

Note that dual watch (on trunked mode) is not supported when in DMO gateway operation. Similarly dual watch (on DMO) is also incompatible with participation in a trunked mode gateway group call. This restriction is not serious if the MS operates principally in a single group. However if the MS is a member of several groups it means that when active in a gateway call the MS can not dual watch to detect its individual or group calls on the other mode.

7.5 Direct mode repeater/gateway operation

A Direct Mode Repeater / Gateway combines the functionality of a Direct Mode Repeater and a Direct Mode Gateway in a single unit. In normal operation gateway functionality takes precedence. Any call is initially set up as a gateway call and then repeated with the DM-REP/GATE equipment as the master. An example of such a network configuration is given in figure 11.

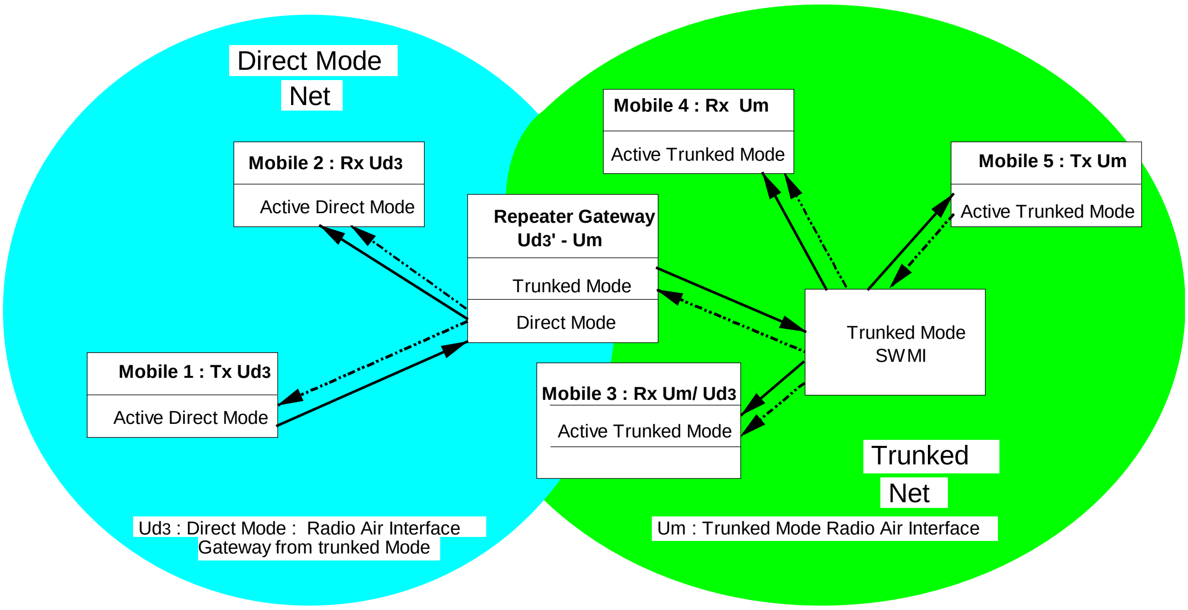

Figure 11: Functional network configuration showing Direct Mode Repeater/Gateway air interface

The single TMO/DMO call spanning the gateway/repeater can be set up either from the direct mode side or the trunked mode side of the repeater/gateway as follows:

MS 1 (call initiator) is instructed either by pre-programming or by detection of the Repeater/Gateway presence signal to address the Gateway/repeater when transmitting to the Talk Group. The Gateway detects the set-up message from MS 1 and forwards it to the infrastructure. The infrastructure goes through the normal trunked mode set-up procedure allocating a channel to MSs 3, 4, and 5 and also the gateway when resources are available. On receiving the trunked mode channel allocation the gateway then informs MS 1 that the call can proceed. MS 1's traffic is then received by the repeater/gateway which forwards it to MS 2 and also to the infrastructure for re-transmission to MSs 3, 4 and 5.

When initiated from the trunked network the call set-up is as follows:

MS 5 transmits a call set-up request on the Trunk Network. A normal trunked mode call is set up to include MS numbers 5, 4, 3 and the Gateway. The Gateway/repeater then sets a direct mode group call to include MS numbers 1 and 2.

Dual watch restrictions on gateway operation apply as described in the previous subclause.

8 Basic direct mode MS-MS protocol

The OSI model shown in figure 12, with seven functional layers identified, is generally accepted for reference description and specification of layered communication architectures.

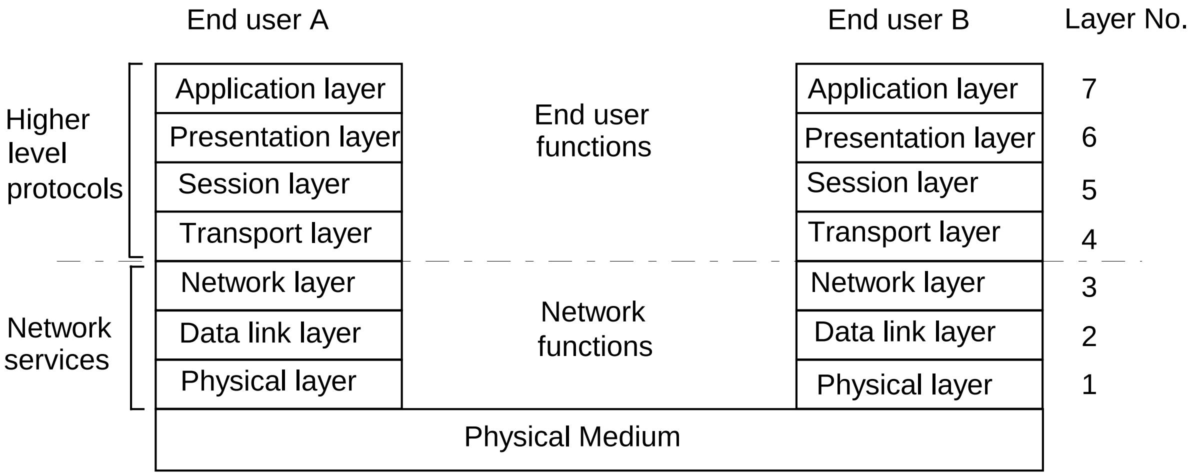

Figure 12: OSI reference model for communication architectures

The bottom three layers of the protocol stack are associated with the network services. The upper four layers of the protocol stack provide services to the end users.

The philosophy of layered architectures is based on each layer being independently specified in terms of the services it provides to its immediately higher layer and the services it relies on from its immediately lower layer. The whole layered architecture concept is based on "peer-to-peer" exchanges in which each layer exchanges information with its peer entity at the remote end. Layers at each location are thus self contained and isolated from one another.

The layered architecture concept leads to equipment (usually with large software content) in which each layer can in theory be developed separately The result of any changes to a layer is transparent to the layers above and below provided the interface signals passed between layers remain unchanged (see also the remarks below on testable boundaries).

The TETRA standard defines the network protocols only up to layer 3 of the OSI model.

8.1 Testable boundaries

It is important to realise that the layered architecture represents only a conceptual model and does not impose any particular implementation of the protocol except at the testable boundaries. For DMO the only testable boundary is at the bottom of the physical layer. Defining the tests to be performed at the testable boundaries is a meticulously detailed task that is only carried out for the conformance test specifications.

In the following subclauses the protocol architecture of the radio air interface will be described in more detail.

8.2 DM protocol layering

The DM MS-MS protocol stack for MS-MS operation is shown in figure 13.

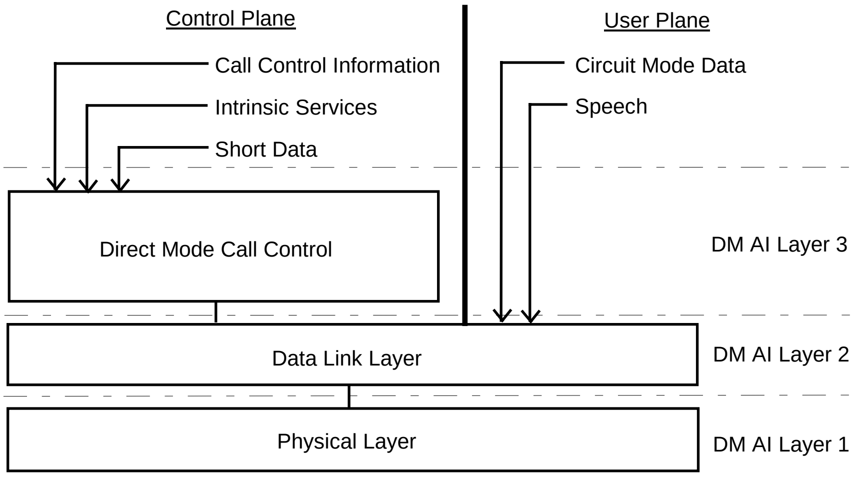

Figure 13: Protocol stack for direct MS-MS operation

The Data Link Layer (DLL) deals with sharing the radio medium by a number of radio users. At the DLL, the protocol stack is divided vertically into two parts:

- the User plane (U-plane) is responsible for transporting circuit mode speech or data information without addressing information;
- the Control plane (C-plane) is responsible for transfer of signalling with addressing capability.

Layer 3 (the direct mode call control entity (DMCC)) lies in the C-plane and is responsible for control of the call, provides the intrinsic services supported in DM and supports the carriage of short data messages. U-plane access at layer 2 (DLL) supports the speech teleservice and the circuit mode data bearer services which are available in TETRA DMO.

8.3 Direct mode functionality

Direct Mode offers the following functionality:

- a channel surveillance mechanism designed to control access to the channel in order to prevent transmission over an ongoing call, while allowing access in emergency situations;

- a changeover mechanism designed to prevent several users transmitting simultaneously when responding within an ongoing call;

- a pre-emption mechanism whereby a transmitting radio can be interrupted to enable a higher priority call to take place;

- a channel reservation mechanism to enable an existing call to have priority access over a new call;

- a dual watch mechanism which enables a radio to monitor the trunked mode system even while participating in a Direct Mode call;

- the ability to offer effective battery economy while maintaining a rapid response to incoming calls.

Each of these features will be described here in order to give the potential user an understanding of the way in which they operate and to enable the best use to be made of these facilities.

In order to fully understand how these facilities are provided and operate it is first of all necessary to understand the TDMA slot and frame structure of Direct Mode operation and the way in which the slots are used to carry the traffic and signalling necessary for the set-up, maintenance and clearing of calls.

8.4 Physical resources

A Direct Mode call takes place on a "DM channel". In normal mode, only one DM channel may exist on a DM RF carrier. In frequency efficient mode, two DM channels (designated channel A and channel B) may exist on a DM RF carrier. A call using channel A is primarily conducted in timeslots 1 and 3 in each frame (see Note), whereas a call using channel B occupies the other two timeslots. (From the perception of the DM-MSs on channel B, the channel B timeslots are also regarded as being timeslots 1 and 3).

NOTE: The TDMA slot structure is similar to that of trunked mode. It is shown in annex E. Its operation is different from trunked mode as described in this clause.

In TETRA DMO, the absence of a base station requires that special procedures have to be followed in order to achieve synchronization between MSs participating in a call. The procedures vary depending on the state of the channel.

8.5 Slot timing diagrams

The method of operation of Direct Mode protocol is best illustrated using slot timing diagrams. For reasons of clarity only single occupancy of a DM RF carrier (i.e. normal mode) will be shown in the diagrams presented here.

Abbreviations are used in the slot timing diagrams to represent Protocol Data Units (PDUs which are basically signalling messages) sent within the protocol. The actual message types and the TDMA burst types which carry them are set out below:

cn ≡ DM-CONNECT (sent in DSB);
cnk ≡ DM-CONNECT ACK (sent in DSB);
occ ≡ DM-OCCUPIED (sent in DSB);
pa ≡ DM-PRE ACCEPT (sent in DSB);
par ≡ DM-PRE ACCEPT + DM-RELEASE (sent in DNB);
prq ≡ DM-PREEMPT (sent in DSB);
rsv ≡ DM-RESERVED (sent in DSB);
sdk ≡ DM-SDS ACK (or first fragment if fragmented) (sent in DSB);
sdo ≡ DM-SDS OCCUPIED (sent in DSB);
sds ≡ DM-SDS DATA (or first fragment if fragmented) (sent in DSB);
sdu ≡ DM-SDS UDATA (or first fragment if fragmented) (sent in DSB);
su ≡ DM-SETUP (sent in DSB);
sup ≡ DM-SETUP PRES (sent in DSB);
txa ≡ DM-TX ACCEPT (sent in DSB);
txc ≡ DM-TX CEASED (sent in DNB or DSB);
txr ≡ DM-TX REQUEST (sent in DSB).

Other abbreviations used are:

tc representing traffic transmission;
lch representing slots available for linearization;
p? representing slots available for pre-emption requests;
sd representing continuation fragments of DM-SDS UDATA or DM-SDS DATA; and
sda representing continuation fragment of DM-SDS ACK.

8.5.1 Constraints on the frame structure (including synchronisation)

In DMO the entire protocol procedure is based on a fixed frame structure and a knowledge of the current position (in time) within this structure. The essential building blocks of the DMO structure are the frame which comprises four timeslots, and the multiframe which comprises 18 frames (see annex F). To allow mobile stations to operate in this frame structure there must be regular synchronisation burst transmissions by the transmitting MS.

Furthermore, in order to facilitate the DMO protocol, a number of other constraints are placed on this structure, in terms of what can be transmitted in any particular slot:

- frame 18 is always used for synchronization purposes, and usually carries a DMO Synchronisation Burst (DSB) in both slots 1 and 3;
- frames 6 and 12 carry channel occupation information in a DSB in slot 3 (note that the DSB carries both synchronisation and control messages identified above in the same slot) and may carry traffic in a DM Normal Burst (DNB) in slot 1;
- frames 6 and 12 carry reservation information in DSBs in slots 1 and 3;
- pre-emption is permitted, during occupation, in slot 3 of frames 2, 5, 8, 11, 14 and 17;
- linearization, which is carried out in a DMO Linearization Burst (DLB), may be permitted in slot 3 of frame 3 during a call;
- during occupation, frames 1 to 17 usually carry traffic in slot 1 (in a DNB).

8.5.2 Direct Mode operation

For an MS to operate in Direct Mode it must first be tuned to a suitable RF carrier and then it must determine the state of that carrier.

The means by which the DM-MS selects the appropriate RF carrier on which to operate is not specified in the Direct Mode standard. The available channels are likely to be programmed into the radio and selection will be made by the user via a channel select knob or a keypad, just as with conventional non-trunked analogue equipment.

When the channel has been chosen, the DM-MS then continuously carries out a monitoring process in order to detect any signalling that may be present on the channel. This serves two main purposes: firstly it enable the MS to detect calls that are addressed to it. Secondly, it permits the MS to know if other users are on the channel when its user wishes to make a call. The MS can then take the appropriate action to either place the call or alert the user to the fact that the channel is busy. This monitoring process is called channel surveillance and will be described in more detail later in this clause.

8.6 Call set-up protocol

In DM MS-MS operation there are two protocol options for call set-up:

- a call set-up without presence checking whereby transmission commences without explicit knowledge of the presence of any receiving MS(s);
- a call set-up with presence checking whereby a specific acknowledgement is sought from the called MS before transmission commences.

For calls to an individual radio either type of call set-up may be used. For calls to a group, only call set-up without presence check may be used.

8.6.1 Call set-up without presence check

For group (point-to-multipoint) and individual (point-to-point) calls a set-up without presence check is the most basic mode of setting up a call in a DM channel. Figure 14 illustrates this procedure.

Frame #	17				18				1				2				3				4			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Channel	su	su	su	su	su	su	su	su	tc				tc		p?		tc		lch		tc			

Frame #	5				6				7				8				9				10			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Channel	tc		p?		tc		occ		tc				tc		p?		tc				tc			

Figure 14: Call sequence for set-up without presence check

The Direct Mode call works in the following manner:

- After following the channel surveillance procedures to ascertain the state of the channel, and provided the channel is found to be available, the calling DM-MS may linearize its transmitter. It then initiates the call by sending a number of call set-up messages ("su" in figure 14), with 8 being sent in this example (2 frames, each containing 4 slots).

The call set-up messages are sent using the DSB structure as given in annex E. The synchronization bursts sent by the transmitting MS establish the channel synchronization (both frequency and time) and hence the transmitting MS is known as the "master". The synchronisation bursts, as well as carrying the call set-up messages also contain information which permits the receiving "slave" MS's to synchronise to the transmitting master MS in both frequency and time. It is necessary for the receiving MSs to synchronise closely to the master in order to reliably demodulate and decode the master's signalling and traffic messages.

After the call set-up messages have been sent, the master DM-MS may then immediately transmit traffic ("tc" in figure 14) using the DNB structure in the next available frame which in this example is frame number 1. Traffic message continue to be sent in slot 1 of all frames (apart from frame 18) until the message is ended.

Slot 3 of the frames are used for a variety of call maintenance purposes. Figure 14 also illustrates some of these: the position of slots which are allocated to allow pre-emption requests to be made ("p?"), the slot available for linearization ("lch"), and the synchronization bursts denoting occupation of the channel ("occ") which occur in slot 3 of frames 6, 12 and 18 following the initial synchronization.

This simple example highlights a number of the key aspects of direct mode functionality and these are discussed in the following subclauses.

8.6.2 Call set-up time (fundamental constraints)

The number of set-up messages sent is permitted to lie in the range of 2 to 4 frames, the actual number being determined by the MS configuration. The minimum of 2 frames worth gives faster call set-up while 4 frames worth improves reliability at the expense of set-up time. For the MS to reliably decode the traffic messages carried in DNBs, it must have first achieved good frequency and timing synchronisation from the DSBs. For reasons of battery economy (discussed later) an MS may not keep its receiver permanently active while performing channel surveillance but may only bring it alive at specific intervals. With a call set-up period of 2 frames, an MS must wake up at least once every two frames in order to have an opportunity to detect any call set-up messages that may be present. The number of DSBs that must be received in order to achieve synchronisation and to decode the set-up message may vary according to the design of the MS and is also affected by factors such as received signal strength, fading etc.

In the example of figure 14, traffic is shown as being available immediately after the set-up messages are sent. This may well occur when for instance, circuit mode data is being sent. However, for voice, there will generally be some delay between pressing the PTT and speaking. In any case, the TETRA codec requires some processing time to prepare the speech and so it is unlikely that actual speech would be available so quickly.

Two frames of call set-up comprise approx. 114 ms while 4 frames comprise approx. 228 ms.

8.6.3 Call set-up with presence check

For call set-up with presence check the call set-up time will obviously be longer as an acknowledgement is required from the called party.

Figure 15 illustrates this type of call set-up.

Frame #	17				18				1				2				3				4			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	sup	sup	sup	sup	sup	sup	sup										cnk		cnk		tc			
Slave									lch		cn		cn		cn									

Frame #	5				6				7				8				9				10			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	tc		p?		tc		occ		tc				tc		p?		tc				tc			
Slave																								

Figure 15: Call sequence for set-up with presence check

The procedure starts in a similar manner to the set-up without presence check, but the set-up message in the synchronization burst ("sup", with 7 being sent in this example) now requests a response indicating presence of the DM-MS which has been addressed as the recipient in the set-up attempt. This DM-MS, which is defined as a "slave" for the transaction, responds with a connect message ("cn") indicating its wish to receive the call; the slave may send this message several times. On receipt of a connect message the master responds with a connection acknowledgement message ("cnk" in the figure). This is sent in a number of frames determined by a frame countdown element, after which the master commences to transmit traffic. Note that in this example, compared to call set-up without a presence check, the start of transmission of traffic is delayed by three frames (approx. 171 ms).

8.6.4 Late entry

The ability to late enter a call is an intrinsic feature of Tetra Direct Mode. This permits an MS which for some reason missed the initial call set-up messages, to enter the call while it is still in progress.

This is achieved by causing the currently transmitting master MS to periodically send "occupation" messages. These are sent using DSBs in slot 3 of frames 6, 12 and 18 and also in slot 1 of frame 18. These occupation messages are very similar to the original call set-up messages and contain all the information necessary to join the call. As these are sent 4 times a second it permits many chances to late enter an ongoing call.

These occupation messages can also be received by other idle MSs which are carrying out channel surveillance, and serve to indicate that the channel is currently in use and by whom (encryption permitting).

Late entry is generally only applicable for calls set up without presence check as it is these calls that proceed without an acknowledgement from the called party.

8.6.5 Channel reservation and changeover in a call

In a DM call, each call transaction constitutes a separate transmission, with a designated master and slave(s) for each call transaction. The procedure for terminating one call transaction and starting another during a call is termed changeover and is illustrated in figure 16.

Frame #	11				12				13				14				15				16			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	tc		p?		txc		txc		txc						p?		txa		txa		txa		txa	
Slave															txr									

Frame #	17				18				1				2				3				4			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Slave*																								
Master*	su		su		su		su		tc				tc		p?		tc		lch		tc			

NOTE: * indicates roles changed around after "txa" messages

Figure 16: Call sequence for changeover with no collisions

In order to change over the talker (or sender) in a call, the master DM-MS first indicates that its call transaction has come to an end, using a transmit ceased message ("txc" in figure 16). This message is sent at least twice in slot 1 in consecutive frames and using the same burst format (i.e. DNB) as for normal traffic. Recipients of the call are therefore aware of the termination of that call transaction and of the fact that the master is reserving the channel for a period of time. While the reservation period is in force the master MS sends reservation messages using DSBs in slots 1 and 3 of frames 6, 12 and 18. These DSBs can be received by other idle MSs on the channel and serve to inform them that the call is not necessarily finished but may restart with another speaker. This prevents another user group setting up their own call during a momentary break in traffic within the previous call.

Within this reservation period, the master MS may start transmitting again (simply starting up again with set-up messages followed by traffic) or one of the slave MSs in the call may apply to the master to continue the call with a new call transaction. If no MS starts up again the call is considered terminated at the end of the reservation period and the channel is available for use for another call.

A slave MS requests to continue with the call by using a changeover request message ("txr" in figure 16) which may be sent in a slot 3 of certain frames. On receipt of a valid changeover request, the master then surrenders the channel to the successful applicant using a series of changeover acknowledgement messages ("txa" in figure 16). On transmission of the changeover acknowledgement messages, the master then becomes a slave and has no further responsibility for the channel. On receipt of the changeover acknowledgement, the requester transmits a sequence of synchronization bursts ("su" in figure 16) the action of which effects the call changeover with the requester becoming the new master for the next call transaction.

Figure 16 applies to both group and individual calls but, in group calls, there may be additional potential for contention between DM-MSs wishing to talk next and transmitting simultaneous changeover requests on the channel. In such instances a contention control random retry procedure is adopted as illustrated in figure 17.

Frame #	12				13				14				15				16				17			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	tc		occ		txc				txc		p?												p?	
Slave 1							txr																txr	
Slave 2							txr																	

Frame #	18				1				2				3				4				5			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	txa		txa		txa		txa																	
Slave 1									su		su		su		su		tc				tc		p?	
Slave 2																								

Figure 17: Call sequence for changeover with one collision

In this example two slave DM-MSs transmit a changeover request at the same time. These requests may interfere at the master and produce an unintelligible result. The master thus receives no clear request and maintains the channel in reservation mode, transmitting reservation signalling when appropriate, until such time as another changeover request is successfully received or the reservation timer times out and the channel is released totally. In the example, slave 1 is shown to transmit a second changeover request, which in this case is shown to be successful. Slave 1 then becomes the master and goes to traffic in the normal way. The contention control/retry mechanism is fully described in ETS 300 396-3 [8] subclause 8.5.7.

The channel reservation mechanism ensures an orderly use of the channel by giving a degree of priority to the existing call while the change-over mechanism overcomes one of the major drawbacks with conventional analogue equipment used in a simplex manner by ensuring that only one user can speak at a time within the call.

Direct Mode does however, offer a mechanism which permits the current transmitting MS to be interrupted. This is achieved by a process known as pre-emption.

8.6.6 Pre-emption of a DM call

During a DM call, a DM-MS, which may or may not be involved in the present call, may wish to access the DM channel for a priority reason such as an emergency. In this case a mechanism for pre-empting the already occupied channel exists. It is illustrated in figure 18.

Frame #	9				10				11				12				13				14			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	tc				tc				tc		p?		par		pa		par		pa					
Pre-emptor											prq										su		su	

Frame #	15				16				17				18				1				2			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pre-emptor	su		su		tc				tc		p?		occ		occ		tc				tc		p?	

Figure 18: Call sequence for pre-emption of a DM call

The first master sequence shows normal progress of a call, with traffic bursts in slot 1. A DM-MS wishing to use the channel would in any case have had to first determine the state of the channel and in this illustration would have discovered the ongoing call. It would then have synchronized to the master MS and in the process determined the timing state of the channel, including the frame and slot numbers.

To perform pre-emption, the DM-MS transmits a pre-emption request message ("prq" in figure 18) in one of the slots allocated for this purpose. During occupation, pre-emption is allowed in slot 3 of frames 2, 5, 8, 11, 14 and 17, giving 6 opportunities per second which allows for a rapid pre-emption.

An ongoing call can be pre-empted only by a call of higher priority. Direct Mode supports 4 levels of call priority which are (in order of increasing priority): normal, high, pre-emptive priority and emergency pre-emptive priority. Only the latter 2 priorities are sufficiently high in priority to pre-empt another call.

When the master successfully decodes the pre-emption request, assuming it is a valid request, it announces that the channel has been pre-empted to both the pre-empting DM-MS and the other DM-MSs which were involved in the ongoing call. This announcement is by means of the pre-emption acknowledgement message ("par" and "pa" in figure 18), and on issuing this message the master ceases its role and relinquishes the channel.

The successful pre-emptor now transmits synchronization bursts for the new call, with a new group or individual addressee, and becomes master for the initial transaction of this new call.

NOTE: In this example, the pre-empting DM-MS has not included a timing adjustment indication within the pre-emption request and so, in the new call set-up, it adopts the timing reference and frame numbering used by the old master DM-MS.

8.6.7 Terminating a call

At the end of a call transaction, the master DM-MS sends transmit ceased messages (as usual) and then provides reservation DSBs in frames 6, 12 and 18. If the channel reservation timer expires without either a changeover of the master role having occurred or the master DM-MS resuming traffic transmission then the master DM-MS stops sending reservation DSBs and the call ends.

Alternatively, there is an option for the master DM-MS to terminate the call prematurely by sending channel release messages (DM-RELEASE PDU).

8.7 Channel surveillance

A DM-MS carries out channel surveillance while tuned to an RF carrier in order to determine the state of the channel and to detect incoming calls that may be addressed to it. A DM channel is perceived by a DM-MS as being available, occupied or reserved.

A DM RF carrier is available when there is no Direct Mode activity detected on that channel above an appropriate defined power threshold. A threshold is needed to permit frequency re-use of the RF carrier. It is entirely possible for two independent normal mode calls to exist on the same RF carrier (frequency efficient mode is a special case) without mutual interference if the strength of the unwanted signal is sufficiently below that of the wanted. Without such a threshold effective frequency re-use would not be possible, limiting the flexibility and capacity of Direct Mode.

Note that frequency efficient operation permits two independent calls to exist on the same RF carrier by means of an appropriate timing alignment. This mode of operation is described in more detail in subclause 8.9

Direct Mode channel surveillance offers the possibility of implementing a number of threshold within the MS which can be used to vary the performance of the MS under different circumstances.

A mandatory signal strength threshold, T_L, is defined, below which the carrier is considered completely free. Any signal received at a level below T_L will be considered to be sufficiently far away that the MS may transmit just as if the RF carrier were completely free.

The threshold, T_L, is used in conjunction with the priority of the received call and that of the new call, to make a decision whether or not to transmit or whether to attempt pre-emption if pre-emption is possible.

The rules by which an MS is able to decide whether to transmit, to attempt pre-emption or to wait are summarised below:

(i) Ongoing emergency priority call - new emergency priority call:
- if ongoing call < T_L then proceed with new call;
- if ongoing call > T_L then do not proceed.

(ii) Ongoing non-emergency call - new emergency priority call:
- if ongoing call < T_L then proceed with new call;
- if ongoing call > T_L then attempt pre-emption for time $T_{1.}$ If pre-emption fails then MS may proceed.

(iii) Ongoing emergency priority call - new non-emergency call:
- if ongoing call < TL then proceed with new call;
- if ongoing call > TL then do not proceed.

(iv) Ongoing non-emergency call - new non-emergency call:
- if ongoing call < TL then proceed with new call;
- if ongoing call > TL and pre-emption is possible then attempt pre-emption for time T2. if pre-emption fails then do not proceed;
- if ongoing call > TL and pre-emption is not possible then do not proceed.

(v) Ongoing hidden call - new emergency priority call:
- if ongoing call < TL then proceed with new call;
- if ongoing call > TL then MS may proceed with new call.

(vi) Ongoing hidden call - new non-emergency call:
- if ongoing call < TL then proceed with new call;
- if ongoing call > TL then do not proceed.

The MS may implement additional optional signal strength thresholds. One example of these is to use a threshold to determine if the MS should respond to an incoming call - this is equivalent to the "squelch" threshold used in analogue FM radio systems.

The fourth case is the most common instance occurring in practice and T_L is normally chosen to ensure satisfactory operation given the known frequency re-use.

A number of channel surveillance procedures are standardised in Direct Mode not all of which may be implemented in a particular MS. Direct Mode specifies a minimum level of surveillance which must be carried out if the MS is to be able to perform "fast call set-up". This requires the MS to carry out the surveillance on the RF carrier with sufficient frequency that it reliably knows the state of the RF carrier at all times. Under these circumstances the MS can immediately make a decision on call set up when the user initiates a call request. This form of channel surveillance also has the benefit that an MS will also reliably detect incoming calls addressed to it. The disadvantage of "fast call set-up" surveillance is that the MS has less opportunity for battery economy.

An MS need not implement the "fast call set-up" surveillance and can implement a reduced degree of surveillance instead. In this case, when a call is initiated, the MS must carry out surveillance on the channel to glean the necessary information to process the call request. This obviously adds a delay to call set-up times and also means that the MS may not detect calls addressed to it. This "slow call set-up" can offer very good battery economy which may be necessary in certain specialised applications

8.8 Battery economy

A further feature of Direct Mode is the possibility for energy economy techniques to extend the operating time of the MS. This is particularly important for battery operated equipment such as hand portable MSs. Direct Mode does not standardise any recommended means of achieving battery economy but offers designers the possibility of implementing suitable schemes given the known characteristics of Direct Mode operation. The most important characteristics are the number and frequency of transmission of DSBs and the channel surveillance scheme.

A DM-MS does not need to keep its receiver permanently powered but may choose to come awake only at specified intervals. For "fast call set-up" surveillance, knowing that call set-up messages are sent in a minimum of 2 frames and that occupation and reservation messages on an occupied channel are sent periodically during the call, an MS designer can design a battery economy regime that permits the MS receiver to be powered off for periods of time, powering up only when necessary to permit it to reliably detect the necessary signalling messages.

As well as those aspects resulting from the DMO protocol, the degree of energy efficiency that can be achieved depends on many factors, such as the number of DSBs the receiver requires to see to the necessary synchronisation information. Thus MSs from different manufacturers may vary in their battery economy performance.

8.9 Frequency efficient operation

Direct Mode offers a method whereby 2 calls can take place simultaneously on the same RF carrier. This is known as frequency efficient mode and uses the fact that a single call generally only uses 2 of the 4 timeslots available in the TDMA frame structure. It is therefore possible for a second call to take place using the 2 vacant slots on the carrier. This does require the second call to be synchronised to the first call in order to initially obtain and subsequently maintain the necessary slot timing alignment.

Note that frequency efficient operation permits 2 calls to take place on a single RF carrier in the same geographical area at similar signal strengths without interference due to the timing synchronisation. This is in contrast to the situation that may arise with channel surveillance, where 2 calls can take place on the same carrier but by virtue of the necessary difference in signal strengths, these calls are not in close proximity and can be completely unsynchronised to each other.

In order that inter DM channel interference on an RF carrier is minimized the master MS on channel B monitors channel A in order to acquire timing synchronization and subsequently re-align its transmission timing. From the perception of a DM-MS on channel B, operation is conducted in timeslot 1 (i.e. timeslot 2 as seen by channel A), and timeslot 3 (i.e. timeslot 4 as seen by channel A). This structure is illustrated in figure 19. The master DM-MS on channel B aligns its frame numbering with the frame numbering on channel A so that the slot and frame numbering on channel B lags one timeslot behind the slot and frame numbering on channel A.

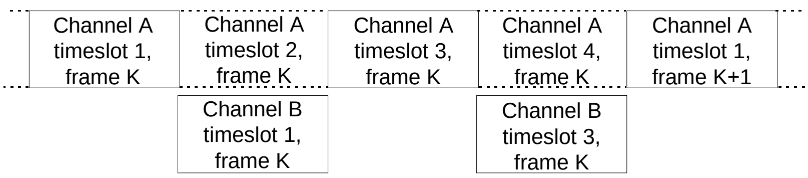

Figure 19: Illustration of DM channel A and B timeslots

If the channel A call finishes, but the channel B call is still continuing, then the channel B master no longer has a signal with which to align its timing and will use its own master reference clock to maintain the timing. If a new call starts up on the RF carrier while channel B is still present then the new call sets up as the channel A call, taking its initial timing from the existing channel B master. Following this initial synchronization, the channel A master is no longer required to monitor channel B and it is the responsibility of the channel B master to then track the new channel A master.

An issue arises if frequency efficient MSs are permitted to operate on the same RF carrier as normal mode MSs. Whereas a normal mode mobile may be able to pre-empt another normal mode mobile in order to access the DM RF carrier, it is not able to do so with a frequency efficient mode mobile as no pre-emption mechanism exists for this situation. Normal mode mobiles would therefore be disadvantaged to some extent by the presence on the same RF carrier of frequency efficient mobiles.

However, for the frequency efficient MS, if it finds that the carrier is occupied by an existing normal mode call, then it could not use the channel as a channel B call as the existing normal mode call may on occasions use slots 2 and 4 i.e. for set-up messages at the start of a new call transaction. Thus a normal mode call effectively prevents a frequency efficient mode MS from using the channel (other than by pre-emption) so losing the benefits of frequency efficient operation. To get the full benefits of frequency efficient mode operation the RF carrier should be devoted to this type of operation.

9. Implementation and operation issues affecting dual watch

9.1 General

Dual watch operation is the underlying feature that allows a suitably enabled MS to keep track of calls addressed to its individual identity (ITSI) or one of its group identities (GTSIs) on both the trunked and direct mode nets as described in clause 7. As is common throughout the TETRA standardisation documentation wide ranging functionality is supported in a standard manner but no particular implementation is prescribed. It is thus necessary for the equipment manufacturers to choose a sub-set of the available functionality to satisfy user operational requirements.

It is advantageous for the users to understand the functionality supported by the technology in order to better articulate their requirements.

This clause examines a particular implementation of the dual watch functionality and should serve as a basis for developing user specific solutions based on using standard options defined in the TETRA DMO specifications.

9.2 Basis for dual watch operation

A Dual Watch mobile station (DW-MS) can operate in both Direct Mode and Trunked Mode. The MS can only be active in one mode at a given time but the MS is capable of monitoring the Trunked Mode control channel while in Direct Mode or a Direct Mode channel while in Trunked Mode.

In order to operate with the V+D system a DW-MS must first register with the SwMI in the same manner as a normal V+D mode MS.

The monitoring of the control channel or a Direct Mode channel will be combined with one or more selected addresses (e.g. groups and own address).

The signalling in Direct Mode allows a MS that operates in Dual Watch to make adjustments to the Direct Mode timing in order to optimise the Dual Watch abilities. However, points to note are:

NOTE 1: Dual watch is not supported in frequency efficient mode.

NOTE 2: Dual watch is not supported for gateway calls neither in the Direct Mode nor trunked mode groups.

An MS in Dual watch uses energy economy mechanisms at the Trunked Mode control channel to ensure that the MS listens at the correct time.

9.3 Implementation of dual watch operation

Dual watch operation, as defined in the TETRA DMO standard ETS 300 396-3 [8] subclause 8.4.7.10, allows for a dual watching MS to select the incoming call based only on priority and addressing. However in a practical implementation there are several other possibilities to deal with an incoming call in the monitored mode. These are however local implementation specific applications in the Dual Watch mobile station.

For instance a Dual Watch mobile station could be implemented such that it will always transmit in the selected (preferred) operational mode even if the mobile station is receiving a monitored call in the other mode.

In an automatic mode the mobile station could switch to the monitored mode if this is active and as long as the selected operational mode is in idle. This automatic mode will only deal with unacknowledged calls.

In a manual mode the mobile station could give an indication of activity in the monitored mode. The user can then accept this manually and the mobile station could switch to the active monitored mode as long as the selected operational mode is in idle. This manual mode can deal with all calls.

The user could also accept this manually by changing the selected operational mode. This manual mode will be suitable for acknowledged calls.

The indication of activity in the manual mode could also include information about the type of call. This indication could also be used in the automatic mode if a call is in progress in the operational mode and a call is started in the monitored mode. Note however that user acknowledged calls are never generated in DMO so that manual intervention in DMO is meaningless.

There could also be an indication to distinguish the receiving of a monitored call from the receiving of a call in the selected operational mode. This could be especially useful in the automatic mode.

9.3.1 Switching from idle to active

When no calls are active in the dual watch MS it is relatively easy to ascertain what should happen. This is shown in table 4a below.

Table 4a: Impact of incoming calls on Dual Watch Operation - switching from idle to active

Direct Mode Call	Trunked Mode Call	Received in Dual Watch			
		Direct Mode selected operational		Trunked Mode selected operational	
Incoming	Incoming	Manual	Automatic	Manual	Automatic
no	no	-	-	-	-
no	yes	0*	T#	T	T
yes	no	D	D	0*	D#
NOTE:	0= No call is being received; D= Switch to DMO and accept call; T= Switch to TMO calls and accept call; - = No action; * = give indication to the Dual Watch user of call in the monitored mode. User may accept call. # = give indication to the user that the call is from the monitored mode, not preferred mode.				

When no calls are presently active on the MS and dual watch (DW) indications on the monitored mode are received as follows:

(i) No DW calls are incident and so no indication is given of incoming calls.
(ii) A trunked mode call addressed to the resident ITSI or one of its GTSIs is detected by the MS performing dual watch. Depending on the default setting one of the following actions is performed:
- DMO manual mode selected - indication given to user that a call in monitored mode has been detected.
- DMO preference automatic mode selected: switch to trunked mode accept the call but give an indication to the user that the call is from the monitored mode and not the preferred mode.
- Trunked manual mode selected - call is incident in the preferred mode & immediately accepted.
- Trunked preference automatic mode selected: switch automatically to trunked mode & accept the call.

(iii) A DMO call addressed to the resident ITSI or one of its GTSIs is detected by the MS performing dual watch when one of the following functions is selected:

- DMO manual mode selected - call is incident in the preferred mode & immediately accepted.
- DMO preference automatic mode selected: switch automatically to DMO & accept the call.
- Trunked manual mode selected - indication given to the user that a call in monitored mode has been detected.
- Trunked preference automatic mode selected: switch to DMO and accept the call but give an indication to the user that the call is from the monitored mode and not the preferred mode.

9.3.2 Switching from active to active

When a call is already in progress on a dual watch MS it becomes unclear what should happen with the new call from the monitored mode. The example shown below in table 4b illustrates the principle of a possible implementation. It ignores any effects that would arise due to different call priorities on the active and monitored channel.

Table 4b: Impact of incoming calls on Dual Watch Operation - switching from active in one mode to active in the other model

Direct Mode Call	Trunked Mode Call	Received in Dual Watch			
		Direct Mode selected operational		Trunked Mode selected operational	
		Manual	Automatic	Manual	Automatic
incoming	active	D	D#	÷*	÷*
active	incoming	*	*	T	T#
NOTE:	= Ongoing Direct Mode call continues; ÷= Ongoing Trunked Mode call continues D= Switch to DMO and accept call. T= Switch to TMO calls and accept call. * = give indication to the Dual Watch user of a call in the secondary monitored mode. # = give indication to the user that the received call is from the preferred monitored mode.				

When the MS is active in a trunked mode call and the dual watch facility detects a call to one of its TSIs on DMO:

- if DMO manual mode is selected, it means that the ongoing trunked mode call was not accepted by the user. The incident call is in the preferred mode and is immediately accepted;
- if DMO automatic mode is selected; the MS should switch to direct mode and accept the incoming call but also give an indication to the user that the call is from the monitored mode;
- if trunked manual mode is selected the ongoing call should continue but with an indication that a call in monitored mode is incident;
- if trunked automatic mode is selected the ongoing call should continue but with an indication that a call in monitored mode is incident.

When the MS is active in a direct mode call and the dual watch facility detects a call to one of its TSIs on trunked mode:

- if DMO manual mode is selected the ongoing call should continue but with an indication that a call in monitored mode is incident;
- if DMO automatic mode is selected the ongoing call should continue but with an indication that a call in monitored mode is incident;
- if trunked manual mode is selected, it means that the ongoing direct mode call was not accepted by the user. The incident call is in the preferred mode and is immediately accepted;
- if trunked automatic mode is selected; the MS should switch to trunked mode and accept the incoming call but also give an indication to the user that the call is from the monitored mode.

10. Security features

TETRA DMO contains mechanisms for security of control signalling and user speech and data at the air interface.

Mechanisms are included for:

- authentication;
- confidentiality;
- key management, including an OTAR mechanism; and
- enable/disable of terminals.

TETRA DMO can also support end-to-end encryption using a synchronous stream cipher to provide a high level of protection for user traffic.

10.1 Authentication.

10.1.1 Mobile to mobile operation.

Implicit authentication is provided between mobile stations belonging to the same DMO net when successful encrypted communication takes place, due to the fact that static cipher keys are used (which are generated, controlled and distributed through the DMO system security management).

10.1.2 Dual Watch Operation.

In dual-watch mode a DM-MS is a valid member of the TETRA V+D network and authenticates itself to that network using the procedures for V+D operation.

10.1.3 Gateway mode operation.

Calls established through a gateway are considered as multi-hop calls and as such use a multi-pass call set-up protocol.

For secure calls the gateway authenticates itself to the TETRA V+D network.

10.2 Confidentiality

10.2.1 Air Interface (AI) encryption

AI encryption provides confidentiality on the radio link between a DM-MS and either a single DM-MS or a group of DM-MSs.

AI operates as a synchronous stream cipher by combining the output of an encryption algorithm (keystream sequence (KSS)),implemented in a Key Stream Generator (KSG) with the contents of messages to be transmitted across the air interface. The encryption process takes place in the upper MAC layer of the TETRA protocol stack.

Air interface encryption is a separate function to the end-to-end encryption service described below. In DMO the encryption synchronisation applies only to the current call.

The key stream bits are modulo 2 added (XORed) with plain text bits in data, speech and control channels to obtain encrypted cipher text bits, with the exception of the MAC header bits and fill bits.

The ciphering process is shown in figure 20.

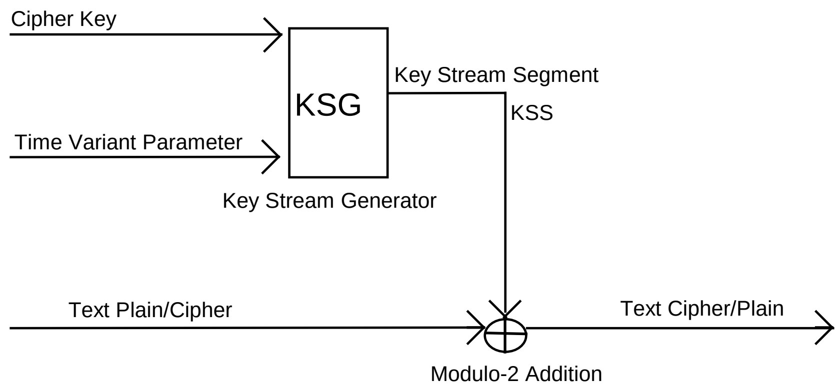

Figure 20: Speech and control information encryption

The KSG has two inputs, a Time Variant Parameter (TVP) and a cipher key. The KSG produces a sequence of key stream bits referred to as a Key Stream Segment (KSS).

10.2.1.1 Cipher Key

For Direct Mode only one type of cipher key is defined:

- the Static cipher key (SCK).

The SCK can be considered a binary vector of 80 bits.

For use in Direct Mode up to 32 SCKs can be stored.

10.2.1.2 The Time Variant Parameter (TVP).

To prevent the same segment of keystream being used more than once a TVP is included in the keystream generation. The initial value of the TVP can be randomly chosen by the call master. TVP on messages from master to slave is independent of TVP on messages from slave to master.

To provide some degree of protection against the possibility of messages being recorded and replayed later the initial TVP may contain a time of day element. The TVP is incremented on every time slot as explained in annex B.

10.2.2 End-to-end encryption

End-to-end encryption algorithms and key management can be provided. End to end encryption operates in addition to Air Interface encryption but can only be applied to user traffic, not control traffic. The mechanism is not standardised but is intended to offer a higher level of protection, and so be specific to the user. There is however, a recommended mechanism for synchronisation of the encryption system to be employed when using a synchronous stream cipher. This is described in annex B.

10.3 Key Management.

10.3.1 Air Interface Encryption keys.

The keys used in DMO air interface encryption are Static Cipher Keys (SCKs) and these may be loaded directly or from a SIM card.

10.3.2 End to End Encryption keys.

The keys used in end to end encryption are user defined. These may be loaded directly or from a SIM card or by other means.

10.3.3 Over The Air Re-keying (OTAR)

Keys for the air interface encryption unit (KSG) may be transmitted over the air interface in a secure manner. This requires the establishment of a peer-to-peer messaging service at layer 3.

Keys for end to end encryption may be transmitted over the air interface in a secure manner by means of the Short Data Service with user defined data content (SDS message type 4).

10.4 Secure Enable and Disable

An optional mechanism is provided for the enabling and disabling of terminal equipments and subscriptions. The mechanism allows an authorised DM-MS to disable or enable another DM-MS over the air interface. The disablement may be of two classes: permanent; and temporary.

There may a number of reasons for wishing to disable a DM-MS: faulty equipment operation; illegal or damaging use of radio resource by user; etc.

In the case of a temporary disablement the disabled DM-MS may be enabled over the air interface by an authorised DM-MS. A permanent disablement can only be reversible at an authorised service centre.

11. Radio Aspects

11.1 DMO deployment constraints

The physical deployment of Direct Mode Operations differs from that of trunked mode operations as the transmitter and receiver are on the same RF carrier for direct mode.

The direct mode RF carrier assignment can in principle be placed anywhere, either within the same band as used for the trunked mode, outside it or between the BS transmit and receive segments. In many implementations, for example the CEPT frequency planning model outlined in figure 1 they will be in the same band as those used for trunked mode. Therefore system designers have two options. The direct mode channels can be placed in the same band as the trunked mode base station transmit band (downlink channels) or they can place them in the same band as the trunked mode base station receive band (uplink channels). The rest of this clause will be based on the CEPT frequency planning model.

This inevitably means that there will be a risk that a direct mode transmitter will be transmitting when a trunked mode receiver is receiving in the same frequency band or vice versa. If this occurs, two main effects can arise.

The first is unwanted transmitter noise, where the transmitter, transmitting on its own frequency, produces unwanted noise at the receiving frequency. The second is the desensitisation of the receiver by signals on adjacent frequencies (blocking). Both these effects decrease in importance as the frequency separation between the unwanted transmitter and the receiver increases and also as the physical separation between the unwanted transmitter and the receiver increases.

These two effects occur on all radio systems no matter what their modulation method and is not unique to TETRA DMO. In the past, back-to-back communications schemes such as direct mode have had to be provided with a separate direct mode band as well as the normal transmit and receive band of the parent system. However, the modulation scheme employed by TETRA is sufficiently robust to permit direct mode systems to be implemented within the trunked mode frequency band.

The purpose of this subclause is to explore the effects of transmitter noise and blocking on direct mode and trunked mode systems and to provide a methodology for assessing the effects of sharing either the trunked mode transmit or receive band with Direct Mode Operations.

11.2 Transmitter noise

Any radio transmitter produces unwanted transmissions in frequencies to either side of its own transmission frequency. If these unwanted transmissions coincide with a receiver frequency then they produce additional noise at the receiver, hence requiring an increase in the wanted signal. As the noise increases, so the wanted signal must also increase in power to compensate and thus maintain the required signal-to-noise ratio for successful reception. This has the effect as far as the user is concerned of reducing the range of the receiver as signals at the maximum range are those just above the noise floor. Thus increasing the noise drowns out these signals and the effective range is reduced.

The TETRA specification lays down maximum levels of transmitter noise that can be produced by a TETRA transmitter, depending on the transmitter class (ie power) and the frequency offset from its transmission frequency. These levels are expressed relative to the power of the of the transmitter rather than as absolute levels.

The levels are given in table 5 which have been extracted from subclause 6.4.3.2.1 of the DMO radio specification (ETS 300 396-2 [2]). This covers both wideband noise (100 kHz or more) and adjacent channel power levels.

Table 5: Maximum adjacent power levels and wideband noise limits (relative to carrier)

Frequency offset	Maximum adjacent power levels and wideband noise limits			
	Class 5 and 5L mobile	Class 4 and 4L mobile	Class 3 and 3L mobile	Class 2 and 2L mobile
25 kHz	-60 dBc	-60 dBc	-60 dBc	-60 dBc
50 kHz - 100 kHz	-70 dBc	-70 dBc	-70 dBc	-70 dBc
100 kHz - 250 kHz	-75 dBc	-75 dBc	-78 dBc	-80 dBc
250 kHz - 500 kHz	-80 dBc	-80 dBc	-83 dBc	-85 dBc
> 500 kHz	-80 dBc	-80 dBc	-85 dBc	-90 dBc

Above 500 kHz, there is a further limit of -100 dBc which applies, depending on the frequency offset and the frequency of the transmitting DM-MS.

The following terms are defined:

- f_{rb} is defined as the frequency offset between the edge of the V+D base station receive band and the near edge of the V+D base station transmit band. In all cases, $f_{rb} \geq 5$ MHz ($f_{rb} \geq 10$ MHz for frequencies above 520 MHz).
-

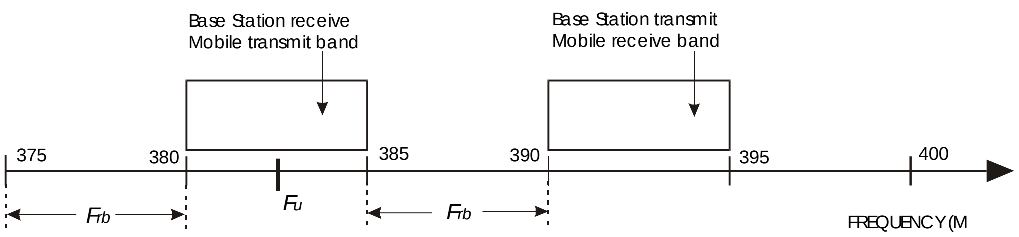

Figure 21: Definition of f_{rb}

- f_x is defined as is the range of frequencies over which the equipment is able to transmit (as declared by the equipment manufacturer) plus a guard band of 5 MHz on either side (10 MHz for frequencies above 520 MHz).

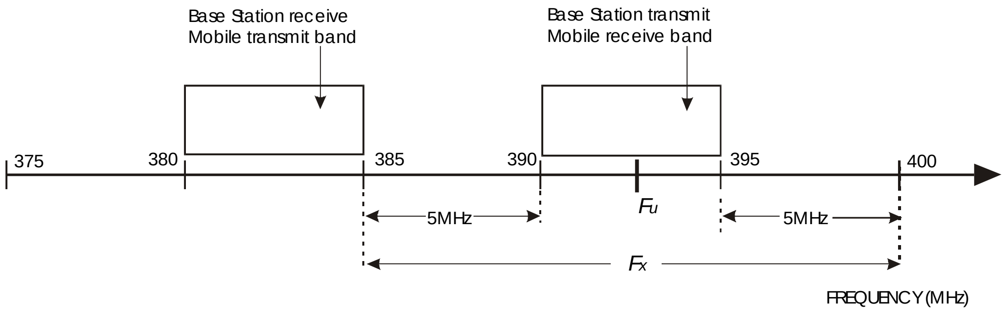

Figure 22: Definition of f_x

For a DM-MS transmitting at a frequency, f_U, within the V+D base station receive band, if the frequency offset exceeds f_{rb} then transmitter noise at these frequencies must not exceed -100 dBc.

In all other cases (ie for a DM-MS transmitting at a frequency, f_U, outside the V+D base station receive band), if the frequency offset, Δf, is such that the frequency where the measurement is made lies outside the frequency range f_x, then transmitter noise at these frequencies must not exceed -100 dBc.

In additional to the relative limits on noise as given above there is an absolute upper limit on the restrictions that shall apply. Regardless of the limits implied by table 6, no limit shall be applied which is stricter than those given in table 5 below. Again, these are taken from subclauses 6.4.3.2.1 and 6.4.3.3.2 of the DMO radio specification (ETS 300 396-2 [2]).

Table 6: Maximum absolute wideband noise level

Frequency offset	Maximum absolute wideband noise level			
	Class 5 and 5L mobile	Class 4 and 4L mobile	Class 3 and 3L mobile	Class 2 and 2L mobile
< 100 kHz	-36 dBm	-36 dBm	-36 dBm	-36 dBm
100 kHz - f_{rb}	-55 dBm	-55 dBm	-55 dBm	-55 dBm
> f_{rb}	-70 dBm	-70 dBm	-70 dBm	-70 dBm

As an example, for a frequency offset between 100 kHz and f_{rb}, if the relative limit implies an absolute limit of -60 dBm then the upper limit in the table above shall apply, ie the noise shall be no more than -55 dBm.

A final note on transmitter noise concerns the power levels of the MS. As the limits are given relative to the power of the transmitter, it is necessary to define what is meant by transmitter power. Here and in the following calculations, it is assumed that the transmitter is operating at its nominal power for the given class.

11.3 Blocking

Blocking is caused by a strong signal in an adjacent frequency to the required frequency. The presence of such a signal causes noise on the receiver local oscillator signal to be mixed on to the wanted signal. Note that it is assumed that there is a linear relationship between the signal level and the noise produced. However, this implies that the receiver has a very large dynamic range and this assumption of linearity should be checked.

Blocking performance is specified in Subclause 6.5.1.2 of the DMO radio specification (ETS 300 396-2 [2]). This is in terms of the level of interfering signal in an adjacent channel that will produce a 3 dB increase in noise in the wanted channel. These are reproduced in table 7 below.

Table 7: Blocking levels of the receiver

Frequency Offset	Level of blocking signal
50 kHz to 100 kHz	-40 dBm
100 kHz to 200 kHz	-35 dBm
200 kHz to 500 kHz	-30 dBm
> 500 kHz	-25 dBm

If the level of the adjacent signal exceeds that given above, then it is assumed that the noise produced also increases linearly.

11.4 Effects of transmitter noise and blocking

Unwanted wideband transmitter noise and blocking signals both produce noise in the receiver on the wanted channel so the wanted signal must increase in power to compensate and maintain the required signal-to-noise ratio for successful reception. This has the effect, as far as the user is concerned, of reducing the range of the receiver since signals at the maximum range are those just above the noise floor. Thus increasing the noise drowns out these wanted signals and the effective range is reduced.

One attempt to quantify the effect of the interference would therefore be to calculate the reduced effective range of the receiver depending on the location and class of the unwanted transmitter.

However, from a user perspective, the reduction in range is not an immediately noticeable effect. All the user perceives is whether or not they can make or receive a call. Therefore, a more practical calculation is to determine the "exclusion zone" or "stay-away" distance required between the receiver and the unwanted transmitter for the wanted signal to be received.

A methodology to calculate this distance, based on the required path-loss, is given in subclause 11.5.

11.5 Methodology

This subclause gives a general methodology for calculating the effect of transmitter noise and blocking on a given receiver. The following subclauses give several worked examples and also discuss the implications of the effects of transmitter noise and blocking.

For a given wanted signal, what is required is the acceptable level of unwanted transmission noise and blocking. As the effects of unwanted transmitter noise and blocking decrease with separation (due to increased path loss between the receiver and transmitter) there will be some distance where the effects on the receiver will be below the critical level needed to disrupt communications. The methodology presented here allows the user to calculate that critical distance.

To do so, the following terms are defined:

- *unwanted transmitter* the transmitter responsible for generating the unwanted transmitter noise and the blocking;
- *victim receiver* the receiver for which the critical distance is being calculated;
- *wanted signal* the signal which the victim receiver is trying to receive.

The following general symbols are also defined:

- f_U the frequency at which the unwanted transmitter is transmitting (unwanted signal);
- f_W the frequency of the wanted signal being received by the victim receiver;
- Δf the frequency offset between the wanted and unwanted signal (= $|f_W - f_U|$);
- C the power class of the unwanted transmitter;
- P_C the power of the unwanted transmitter in dBm at the transmitter output socket;
- N_F the noise floor of the receiver in dBm;
- N_U the uplift in the allowed noise floor of the receiver in dB;
- L the total path loss experienced between the victim receiver and the unwanted transmitter in dB;
- L_A the additional path loss due to antenna gains and body loss, etc, experienced between the victim receiver and the unwanted transmitter in dB.

The following symbols are defined for calculating the effect of unwanted transmitter noise:

- P_{NR} the allowed unwanted transmitter noise relative to the transmitter power in dBc;
- P_{NA} the absolute level of allowed unwanted transmitter noise in dBm;
- L_N the required path loss such that transmitter noise has negligible effect on the unwanted signal in dB;
- d_N the stay-away distance such that transmitter noise has negligible effect on the unwanted signal in metres.

The following symbols are defined for calculating the effect of blocking:

- P_B the allowed level of blocking signal in dBm;
- L_B the required path loss such that blocking has negligible effect on the unwanted signal in dB;
- d_B the stay-away distance such that blocking has negligible effect on the unwanted signal in metres.

11.5.1 Assumptions

The following assumptions have been made:

- the noise floor of the receiver, N_F, is -122 dBm;
- the additional path loss, L_A, is 14 dB (made up of 7dB body loss per MS and assumed isotropic antennas).

Note that these two assumptions hold only for mobile stations. In particular, the noise floor of the receiver is different for a base station, which is more sensitive. Therefore, it is recommended that for a base station the noise floor of the receiver, N_F, is assumed to be -125 dBm.

11.5.2 Calculating the effect of transmitter noise

Assume that the unwanted transmitter is of power class *C* and that the frequency offset between it and the victim receiver is Δf. From **Error! Reference source not found.**5, the allowed noise, P_{NR}, can be determined. The maximum absolute noise level, P_{NA}, is then:

$$P_{NA} = P_C + P_{NR} \,. \qquad (1)$$

If this is less than the absolute level given in table 6, then it shall be replaced with the level given in table 5.

If this absolute level of noise is greater than the noise floor of the receiver, N_F, then the wanted signal will be affected by the noise. Therefore, to reduce the noise incident on the receiver, there will need to be a total path loss, *L*, of:

$$L = P_{NA} - N_F = L_A + L_N \qquad (2)$$

where the total path loss is made up of the loss due to the separation of the victim receiver and the unwanted transmitter, L_N, and the loss due to other effects, L_A. Therefore, rearranging equation (2), the required path loss is given by:

$$L_N = P_{NA} - N_F - L_A . \qquad (3)$$

11.5.3 Calculating the effect of blocking

Assume that the unwanted transmitter is of power class *C* and that the frequency offset between it and the victim receiver is Δf. From table 6, the allowed signal level at which blocking occurs, P_B, can be determined. If this incident signal from the transmitter, P_C, is greater than this at the victim receiver, then blocking will occur. Therefore, to reduce the signal incident on the receiver, there will need to be a total path loss, *L*, of:

$$L = P_C - P_B = L_B + L_A \qquad (4)$$

where the total path loss is made up of the loss due to the separation of the victim receiver and the unwanted transmitter, L_B, and the loss due to other effects, L_A. Therefore, rearranging equation (4), the required path loss is given by:

$$L_B = P_C - P_B - L_A . \qquad (5)$$

11.5.4 Allowing for a noise floor uplift

The above methodology assumes that the wanted signal is at the maximum range permissible, ie it is just above the noise floor and any additional noise will cause that signal to be indecipherable.

However, it is often the case that wanted signal will be transmitted from much closer than the maximum permissible range and therefore will be significantly above the noise floor. This can be allowed for in the above methodology by introducing a noise floor uplift.

The reference threshold defined by the TETRA standard is 19 dB above the receiver noise floor. Therefore, with a noise floor of -122 dBm, a signal of -103 dB will be the minimum that is capable of being received. However, if the signal is, for example, 39 dB above the noise floor, then an additional 20 dB of noise can be introduced and the signal will still be capable of being received. This 20 dB is the noise floor uplift, N_U.

When calculating the effect of unwanted transmitter noise, the noise floor uplift can simply be added to the noise floor. Thus equation (3) becomes:

$$L_N = P_{NA} - \left(N_F + N_U\right) - L_A . \qquad (6)$$

For blocking, the effect is similar. As blocking induces noise in the receiver, if the wanted signal is uplifted above the noise floor by an amount equal to the noise floor uplift, then the allowed level of interfering signal can also be uplifted by a similar amount (provided that the response of the receiver to blocking is linear). Thus equation (5) becomes:

$$L_B = P_C - \left(P_B + N_U\right) - L_A . \qquad (7)$$

11.5.5 Translating path losses into distances

The conversion of path loss into the physical distance separating the victim receiver and unwanted transmitter requires a knowledge of the local propagation conditions. The TETRA Designers Guide Part 1 uses the Hata model which is valid for separations of over one kilometre. However, for the vast majority of circumstances of interest here, the path losses will equate to separations of less than a kilometre.

While the user should use which ever model best suits their local propagation conditions, for the purposes of the worked examples and discussion given here, the Wickson model will be used (see annex C). The Wickson model has the advantage that it is intermediate between the Free Space and CEPT SE21 model and also gives the same path loss at one kilometre as the Hata model (so the two models together give a continuous curve over all distances).

The Wickson model gives a path loss, L, in dB, of:

$$L = 85.5 + 20 \cdot \log_{10} d + 33d \qquad (8)$$

where d is the separation between the victim receiver and unwanted transmitter in kilometres. The Wickson model is shown graphically in figure 23 below, along with the path loss in free space (for a frequency of 400 MHz) and the path loss given by the CEPT SE21 model.

As can be seen, the Wickson model is a fairly conservative model, giving more loss than in the free-space scenario, but not as much the CEPT SE21 model. However, it must be stressed that the Wickson model has been chosen purely for illustrative purposes and users must determine which propagation model best suites their own local propagation conditions.

A full discussion of the three models is given in annex C.

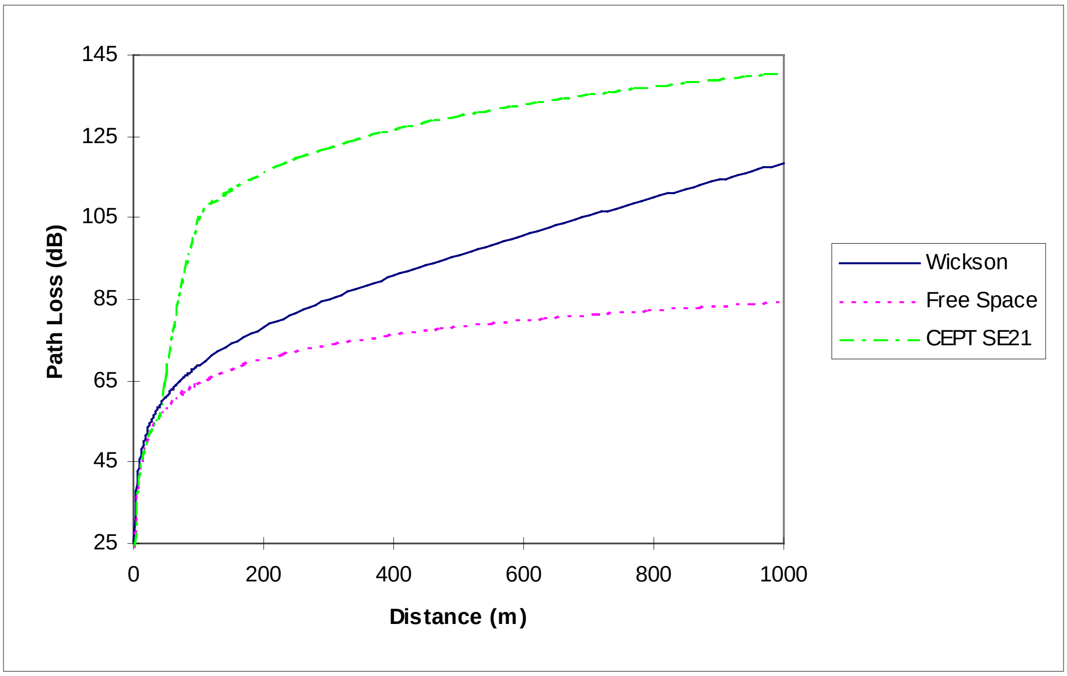

Figure 23: Characteristics of the short range propagation models

11.6 Example 1 - wanted signal at extremity of range, unwanted interferer close by

Consider a Class 4 transmitter (1 watt power at the output socket) with a transmit frequency 125 kHz away from the victim receiver. What is the required path loss and stay-away distance in order that the victim receiver can still receive a wanted signal at its maximum range?

11.6.1 Step 1 - Calculate allowable noise

A Class 4 transmitter produces a signal of P_C = +30 dBm. For a frequency separation of 125 kHz, table 5 gives a maximum wideband noise level of P_{NR} = -75 dBc. Substituting into equation (1), this gives an absolute noise level of:

$$P_{NA} = 30 + (-75) = -45 dBm$$

As this is a less stringent requirement than that given table 5 (which is -55 dBm for a frequency separation of 125 kHz), it can be assumed that the unwanted transmitter will produce -45 dBm of noise.

11.6.2 Step 2 - Translate allowable noise into path loss and stay-away distance

Assuming a noise floor of N_F = -122 dBm, other loses of L_A = 14 dB and a noise floor uplift of N_U = 0 dB (as the received signal is at the maximum range), substituting into equation (6) gives a required path loss due to noise, L_N, of:

$$L_N = -45 - (-122 + 0) - 14 = 63\text{dB}$$

using the Wickson model in equation (8), this equates to a stay-away distance of 59 m.

11.6.3 Step 3 - Calculate path loss and stay-away distance for blocking

A Class 4 transmitter produces a signal of P_C = +30 dBm. For a frequency separation of 125 kHz, table 6 gives a maximum blocking signal of P_B = -35 dBm. Substituting into equation (4), this gives a required path loss of:

$$L = 30 - (-35) = 65\text{dB}\,.$$

Assuming a noise floor of N_F = -122 dBm, other loses of L_A = 14 dB and a noise floor uplift of N_U = 0 dB (as the received signal is at the maximum range), substituting into equation (7) gives a required path loss due to blocking, L_B, of:

$$L_B = 30 - (-35 + 0) - 14 = 51\text{dB}$$

using the Wickson model in equation (8); this is equivalent to a stay-away distance of 17 m.

Therefore the limiting case is unwanted transmitter noise, which requires unwanted transmitters to remain 59 m or more away from the victim receiver.

This first example shows that if the wanted signal is at the limit of range then the unwanted interferer must stay some considerable distance away from the victim receiver to have negligible effect. We will show in the next example that if the wanted signal is not at the limit of range then the victim receiver is much more tolerant of interferers.

The first example above relates to an operational scenario in which the victim receiver is at range limit corresponding to a widely distributed DMO group, to a trunked mode receiver in communication with a distant base station, to a DMO/TMO gateway in communication with a distant trunked mode BS or to a dual watch DMO terminal listening to a trunked BS (for messages addressed to it).

The following example corresponds to a number of DMO terminals working in close proximity such as independent operational groups attending the same incident.

11.7 Example 2 - wanted signal at close range, unwanted interferer close by

Consider a Class 3 transmitter (3 watts) with a transmit frequency 225 kHz away from the victim receiver. What is the required path loss and stay-away distance in order that the victim receiver can still receive a wanted signal being broadcast from 300 m away by a Class 4 transmitter?

11.7.1 Step 1 - Calculate noise floor uplift

In this example, the receiver noise floor does not limit the performance of the receiver. The Class 4 transmitter produces a signal of P_C = +30 dBm, which is attenuated by a path loss caused by a separation of 300 m. The Wickson model gives a path loss of 85 dB. It is assumed that the wanted signal also suffers further losses of 14 dB. Therefore the signal incident on the receiver, P_W, is given by:

$$P_W = 30 - 85 - 14 = -69\text{dBm}.$$

Allowing that this signal has to be 19 dB above the noise floor, this gives an effective noise floor of -88 dBm, which is 34 dB above the receiver noise floor. Therefore the noise floor uplift, N_U, is 34 dB.

11.7.2 Step 2 - Calculate allowable noise

A Class 3 transmitter produces a signal of P_C = +35 dBm. For a frequency separation of 225 kHz, table 5 gives a maximum wideband noise level of P_{NR} = -78 dBc. Substituting into equation (1), this gives an absolute noise level of:

$$P_{NA} = 35 + (-78) = -43\text{dBm}.$$

As this is a less stringent requirement than that given table 5 (which is -55 dBm for a frequency separation of 125 kHz), it can be assumed that the unwanted transmitter will produce -43 dBm of noise.

11.7.3 Step 3 - Translate allowable noise into path loss and stay-away distance

Assuming a noise floor of N_F = -122 dBm, other loses of L_A = 14 dB and a noise floor uplift of N_U = 34 dB (see step 1), substituting into equation (6) gives a required path loss due to noise, L_N, of:

$$L_N = -43 - (-122 + 34) - 14 = 31\text{dB}$$

using the Wickson model in equation (8), this equates to a stay-away distance of 1,9 m.

11.7.4 Step 4 - Calculate path loss and stay-away distance for blocking

A Class 4 transmitter produces a signal of P_C = +35 dBm. For a frequency separation of 225 kHz, table 6 gives a maximum blocking signal of P_B = -30 dBm. Substituting into equation (4), this gives a required path loss of:

$$L = 35 - (-30) = 65\text{dB}.$$

Assuming a noise floor of N_F = -122 dBm, other loses of L_A = 14 dB and a noise floor uplift of N_U = 30 dB (as in step 1), substituting into equation (7) gives a required path loss due to blocking, L_B, of:

$$L_B = 35 - (-30 + 30) - 14 = 21\text{dB}$$

using the Wickson model in equation (8), this equates to a stay-away distance of 0,5 m.

Therefore the limiting case is again unwanted transmitter noise, which requires unwanted transmitters to remain 1,9 m or more away from the victim receiver.

In contrast to the victim receiver in contact with a distant transmitter (such as trunked mode base station for trunked mode terminals, DMO gateways or dual watch DMO terminals) it will be seen that a number of DMO groups working in close proximity to each other are tolerant of the blocking and transmitter noise they impose on each other.

11.8 Unwanted transmission noise versus blocking

The two worked examples above have shown that the transmitter noise dominates over blocking in both cases. It is worth noting that this is the general case for all frequency separations and for all classes of MS. This is illustrated for a Class 4 transmitter in figure 24, which shows the required path loss for a victim receiver receiving a signal at maximum range for frequency separations from 50 kHz to 600 kHz.

It can be seen that in all cases, the path loss for unwanted noise is greater than that for blocking.

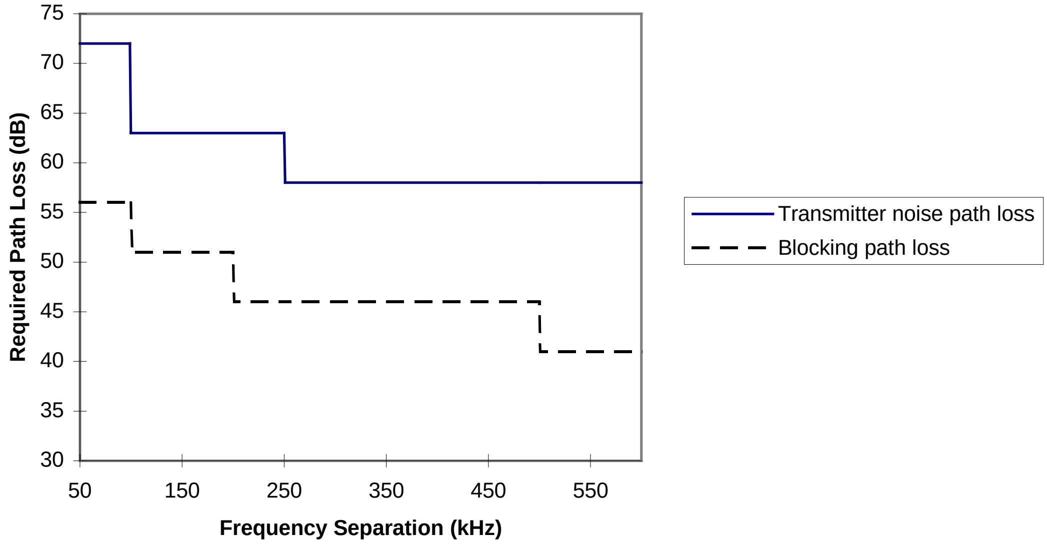

Figure 24: Path loss to reduce blocking Tx or wideband Tx interferer to negligible level

This path loss result can be translated into stay-away distances as given in figure 25.

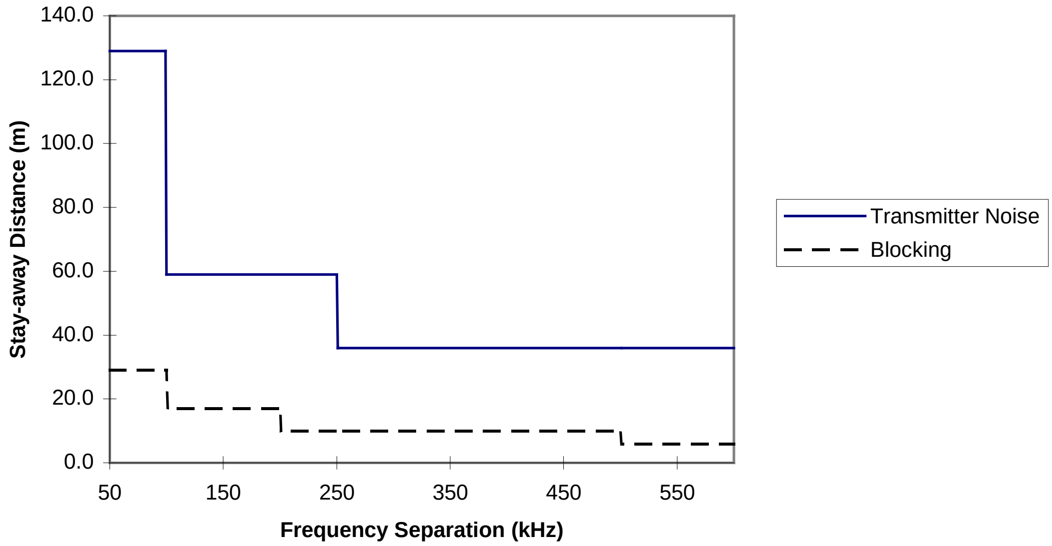

Figure 25: Stay away distance to ensure effects of blocking Tx or wideband Tx interferer are at negligible level

11.9 Variation of stay-away distance with transmitter power and frequency separation

The main variables in determining the stay-away distance, apart from the short range propagation model used, are the power of the unwanted transmitter and the frequency separation between the wanted and unwanted signals. This is illustrated in figure 26 for class 2, 3, 4 and 5 MSs with frequency separations from 50 kHz to 600 kHz.

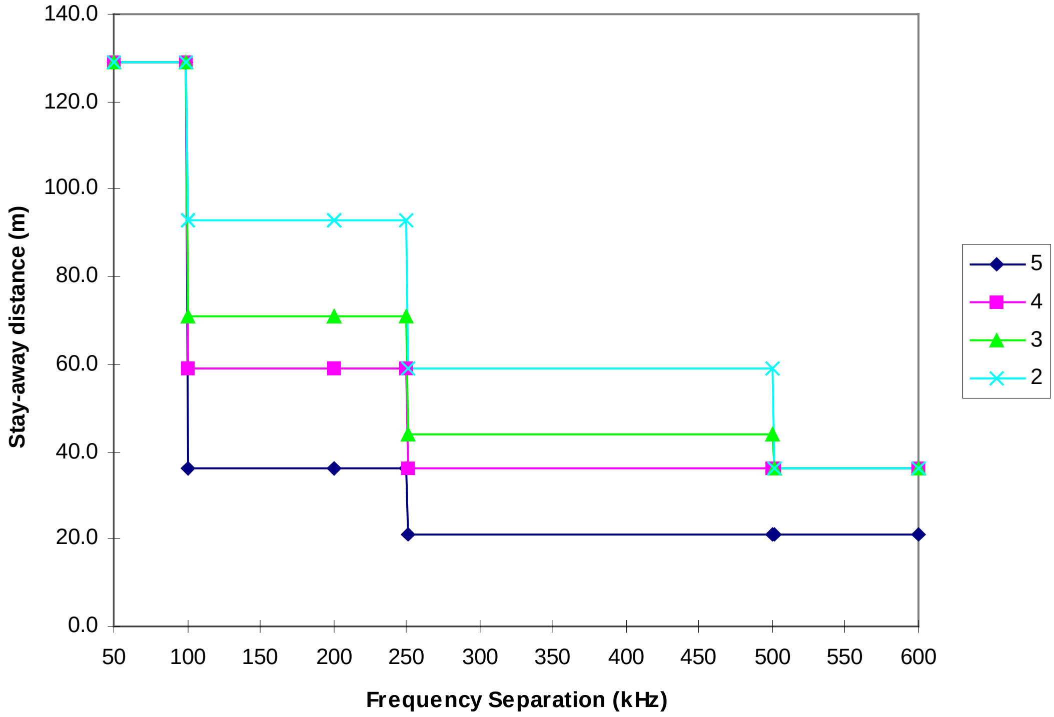

Figure 26: Stay away distance to ensure effects of blocking Tx or wideband Tx interferer are at negligible level for different interfering Tx power classes.

As can be seen, the effects increase with increasing class of MS (ie with increasing MS power) and decrease with increasing frequency separation. Note that the stay-away distances given here are for the unwanted transmitter noise case (as this is always the limiting case) and assume that the victim receiver is at the maximum range to receive the wanted signal. Therefore, these are the worst case stay-away distances.

Note also that the graphs are step functions rather than smooth curves. This is because they are based on the maximum permissible unwanted noise emitted by the unwanted transmitter in any given band. In reality, the transmitter noise is likely to be lower than the maximum permissible in the band as the frequency separation increases. However, without real data from real transmitters, this cannot be modelled here.

11.10 Effect of assumptions

One of the main assumptions made here has been that of receiver linearity, which impacts on the levels of blocking experienced by the receiver. Providing that the receiver maintains linearity across its whole input range, then the calculations are valid. However, if the receiver exhibits non-linear behaviour, then the levels of blocking experienced at high signal strengths may well have been underestimated.

The main assumption given here is the amount of attenuation and other path losses represented by the term L_A. This includes antenna losses and body losses. However, the loss produced by the human body is highly anisotropic and cannot be accurately defined by a single figure. Although a single figure has been used by necessity in these worked examples, in real scenarios the value of the term L_A will depend on the circumstances.

For example, the loss provided by human body absorption is going to be significantly different if the body in question is between the receiver and the transmitter or if the receiver has a clear line of sight to the transmitter. Therefore, provided that the wanted transmitter and the unwanted transmitter are not in the same direction, considerable extra protection can be provided by judicious positioning of the users' body.

Similarly, if the victim receiver is not a hand-held MS (e.g. a vehicle mounted MS) then the assumption of an additional loss term of L_A = 14 dB may well no longer hold.

It should be realised that for distances greater than about 30 m the choice of short range propagation model had a significant effect. All calculations have been performed with the Wickson model which is intermediate between the highly attenuating SE21 model (which allows MSs to work close together) and the free space model (which has lower attenuation and requires larger stay-away distance).

Finally, the assumed noise floor of the receiver will depend on whether the receiver is a mobile station or a base station, since under the TETRA specification, MS and base stations have different reference sensitivities. The assumption made for the calculations given here is that the receiver is a mobile station in all cases.

11.11 Implementation issues

One of the main issues facing DMO system designers is whether to place the direct mode band in the trunked mode base station transmit band or in the base station receive band?

This subclause discusses the various consequences associated with this decision, including the differing effects of the choice of band on the end user and the probability that, due to synchronisation between direct and trunked mode operation, transmissions will take place in different time slots.

The effects presented here apply equally to direct mode and trunked mode receivers. However, there are some differences, depending on whether the receiver in question is a base station or a MS, which in turn will influence whether the system designer places the direct mode carrier frequencies in the trunked mode base station transmit band or in the base station receive band.

If the direct mode frequencies are placed in the base station transmit band, this means that the base station and the direct mode MSs are both transmitting on the same frequencies. The following problems could therefore occur:

- direct mode MSs could suffer effects from trunked mode base station transmissions;

- direct mode MS transmissions could cause problems to trunked mode MSs.

If the direct mode frequencies are placed in the base station receive band, this means that both the trunked mode and direct mode MSs are transmitting on the same frequencies. The following problems could therefore occur:

- direct mode MSs could suffer effects from trunked mode MS transmissions;

- direct mode MS transmissions could cause problems for trunked mode base stations.

When considering the effects suffered by direct mode MSs, it can be seen that these are very different. In the first case, direct mode MSs will only be affected by base stations. In many operational scenarios, direct mode will be used to extend the range of users who will, by definition, be operating around the margins of trunked mode coverage and therefore unlikely to be affected by base station transmissions.

In the second case, direct mode MSs could suffer effects from trunked mode MSs operating in the same physical area. Again, in many operational scenarios, trunked mode and direct mode MSs will be deployed in the same physical location, which could lead to operational difficulties.

When considering the effect caused by direct mode MSs, it can be seen that these are also very different. In the first case, the presence of direct mode MSs could lead to problems for trunked mode MS users, while in the second case, the presence of direct mode MSs could lead to problems for the trunked mode base station.

While both of these will have consequences for users, effectively reducing the range of nearby trunked mode MSs will probably affect one or two users, while effectively reducing the range of a base station could potentially affect all users on that base station, which would be a more serious problem.

The restrictions caused by the choice of band are summarised in table 8 below, along with the equipment affected if the restrictions are not maintained.

Table 8: Service Restrictions and equipment affected by choice of DMO operating band.

Scenario	Restriction	Equipment effected
DMO band in TM base station transmit band	Stay-away zone between DMO MSs and TM MSs	TM MSs
	Stay-away zone around TM base stations for DMO MSs	DMO MSs
DMO band in TM base station receive band	1. Stay-away zone between DMO MSs and TM MSs	1. DMO MSs
	Stay-away zone around TM base stations for DMO MSs	TM base stations

Annex A (normative): Teleservices, bearer and supplementary services supported by TMO/DMO

Table A.1: Comparison of Trunked and Direct mode tele, bearer and supplementary services. The symbol 'p' stands for 'proprietary'.

Service	Trunked Mode	Direct Mode
Teleservices:		
Clear speech or encrypted speech in each of the following:		
Individual call (point-to-point)	✓	✓simplex only
Group call (point-to-multipoint)	✓	✓
Acknowledged group call,	✓	
Broadcast call (point-to-multipoint one way).	✓	✓
Data bearer services		
Circuit mode unprotected data 7.2, 14.4, 21.6, 28.8 kbits/sec.	✓	7.2(single slot)
Circuit mode protected data 4.8, 9.6, 14.4, 19.2 kbits/sec.	✓	4.8(single slot)
Circuit mode protected data 2.4, 4.8, 7.2, 9.6 kbits/sec.	✓	2.4(single slot)
Packet connection oriented data.	✓	
Packet connectionless data.	✓	
Short data service (type 1, 2, 3, 4)	✓	✓
Status messages	✓	✓
PMR type supplementary services:		
Access priority	✓	
Pre-emptive priority	✓	✓
Priority call	✓	
Include call	✓	
Transfer of control	✓	
Late entry	✓	✓
Call authorised by dispatcher	✓	
Ambience listening	✓	
Discreet listening	✓	
Area selection	✓	
Short number addressing	✓	
Talking party identification	✓	✓
Dynamic group number assignment	✓	
Telephone type supplementary services:		
List search call	✓	p
Call forwarding – unconditional/busy/no reply/not reachable	✓	
Call barring – incoming/outgoing calls	✓	
Call report	✓	p
Call waiting	✓	
Call hold	✓	
Calling/connected line identity presentation	✓	p
Calling/connected line identity restriction	✓	
Call completion to busy subscriber/on no reply	✓	p
Advice of charge	✓	
Call retention	✓	
Application: OTAR (over the air re-keying)	✓	✓

Annex B (informative): Support of security features

B.1 Time Variant Parameter

The Time Variant Parameter (TVP) is generally incremented on every time slot with a cycle of 2^{29} time slots. However during call set up the TVP is not incremented during the set-up synchronisation bursts but is repeated across each slot of the set-up synchronisation frames. TVP is first incremented on the first timeslot of the first frame following the set-up synchronisation burst as shown in figure B.1. It is important to note that TVP_S is the value of TVP used in the set-up synchronisation bursts.

FN17				FN18				FN1				FN2			
TN1	TN2	TN3	TN4	TN1	TN2	TN3	TN4	TN1	TN2	TN3	TN4	TN1	TN2	TN3	TN4
Synchronisation				Synchronisation											
TVP_S	TVP_S	TVP_S	TVP_S	TVP_S	TVP_S	TVP_S	TVP_S	TVP_S +1	TVP_S +2	TVP_S +3	TVP_S +4	TVP_S +5	TVP_S +6	TVP_S +7	TVP_S +8

Figure B.1: Incrementing of TVP after call set-up synchronisation bursts

B.2 Synchronisation of end-to-end encryption

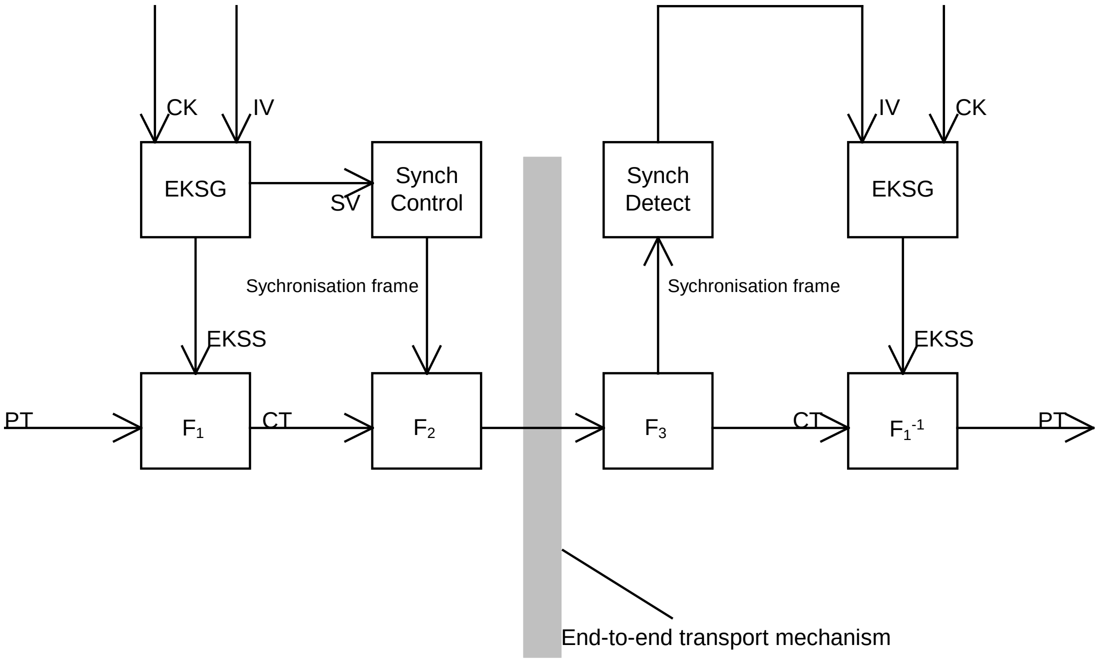

Figure B.2: Functional diagram of voice encryption and decryption mechanisms

Annex C (informative): Short range propagation models used in the co-existence studies

C.1 Introduction

This annex discusses three short range propagation models, all applicable for separations under a kilometre. The three models are:

- Free Space;
- Wickson;
- CEPT SE21.

Each model is discussed in turn in the subclauses.

C.2 Free space propagation

The free space propagation model serves as a baseline model against which other models can be judged. It can also be derived from first principles, as described.

Consider the ideal free space attenuation between separated antennas. If a transmitting antenna with gain G_T in the direction of the receiving antenna radiates P_T Watts of power then the power density, *W*, (in units of power per unit area) at a distance *d* is given by:

$$W = \frac{P_T G_T}{4\pi d^2}. \tag{1}$$

The available power at the receive antenna with effective area *A* is therefore:

$$P_R = \frac{P_T G_T}{4\pi d^2} \times A. \tag{2}$$

Substituting for the effective area, *A*, gives:

$$P_R = \frac{P_T G_T}{4\pi d^2} \times \frac{\lambda^2 G_R}{4\pi} \tag{3}$$

and thus the ratio of received to transmitted power is:

$$\frac{P_R}{P_T} = G_R G_T \left[\frac{\lambda}{4\pi d}\right]^2. \tag{4}$$

Using the fundamental relationship $c = f \cdot \lambda$

where:
- c is the speed of light (3×10^8 metres per sec);
- f is the operational frequency;
- λ is the free space wavelength;

and expressing the frequency units in MHz, distance in km, the path loss, *L*, in dB, can be written as:

$$\begin{aligned} L &= 10 \cdot \log_{10} \frac{P_R}{P_T} \\ &= 10 \cdot \log_{10} G_T + 10 \cdot \log_{10} G_R - 20 \cdot \log_{10} f - 20 \cdot \log_{10} d + k \end{aligned} \tag{5}$$

where:

$$k = 20\log_{10}\left[\frac{3\times10^8}{4\pi\times10^9}\right] = -32.44. \qquad (6)$$

The basic path loss between isotropic antennas can thus be stated as:

$$L = 20\cdot\log_{10} f + 20\cdot\log_{10} d + 32.44 \qquad (7)$$

where f is in MHz and d is in km. For a frequency of 400 MHz, equation (7) reduces to:

$$L = 52.0 + 20\cdot\log_{10} d + 32.44. \qquad (8)$$

This is the path loss for ideal free space propagation at 400 MHz.

C.3 Wickson model

Peter Wickson has proposed a model which gives a path loss, L, of:

$$L = 85.5 + 20\cdot\log_{10} d + 33\mathrm{d} \qquad (9)$$

where d is the separation between the victim receiver and unwanted transmitter in kilometres and L is in dB.

Comparing the Wickson model with free space propagation (equations 8 and 9), it is clear that as d tends to 0km, the two models approach each other. However, for a separation of d = 1 km, it is clear that the Wickson model gives a much higher path loss.

This is shown graphically in figures C.1, C.2 and C.3.

C.4 CEPT SE21 model

The CEPT SE21 propagation model is a three part model, which also incorporates the antenna heights as well as the propagation frequency.

Where:

- h_{min} height of smaller antenna;
- h_{max} height of larger antenna;
- d is the spacing between the antennas;

the three part CEPT SE21 model gives a path loss of:

$$L_1 = 20\log_{10} f + 20\log_{10} d + 32.44 \qquad d \le 0.04\text{km} \qquad (10)$$

$$L_2 = L_1(0.04) + \frac{\left(\log_{10} d - \log_{10} 0.04\right)\times\left(\mathrm{L}_3(0.1) - L_1(0.04)\right)}{\log_{10}(0.1) - \log_{10}(0.04)} \qquad 0.04 < d < 0.1\text{km} \qquad (11)$$

$$\begin{aligned} L = \; & 69.6 + 26.2\log_{10} f - 13.82\log_{10}\left[\max(30; h_{max})\right] \\ & + \left(44.9 - 6.55\log_{10}\left[\max(30; h_{max})\right]\right)\times\log_{10} d - a(h_{min}) \\ & - b(h_{max}) \end{aligned} \qquad d \ge 0.1\text{km} \qquad (12)$$

Where the constants *a* and *b* are given by:

$$a = \left(1.1\log_{10} f - 0.7\right) \times \min(10; h_{\min}) - \left(1.56\log_{10} f - 0.8\right) + \max\left(0; 20\log_{10}\left(\frac{h_{\min}}{10}\right)\right)$$

$$b = \min\left(0; 20\log_{10}\left(\frac{h_{\max}}{30}\right)\right)$$

Looking at the model terms, it is clear that the CEPT SE21 model for separations under 40m (equation 10) is none other than the free space propagation model (equation 7). Equation (12), which applies to separations greater than 100m, is quite a complex equation, but for a fixed frequency of 400 MHz and antenna heights of less than 30m, it reduces to:

$$L = 117.36 + 35.22 \cdot \log_{10} d - a(h_{\min}) - b(h_{\max}) \qquad (13)$$

which is similar to the free space propagation model (equation 7) except that the constants are significantly larger. The CEPT SE21 model for separations between 40 m and 100 m (equation 11) is simply a linear interpolation between the value of the model at 40 m and at 100 m.

C.5 Discussion

The three models are shown graphically in the figure. They have been calculated for a frequency of 400 MHz and the CEPT SE21 model for antenna heights of 2m and 1.5m respectively. It is immediately clear that for small separations (50m or less) the three models give similar results, but as the separation increases, so do the differences between the models, with the CEPT SE21 model giving by far the largest path loss, while the free space model gives much lower path losses.

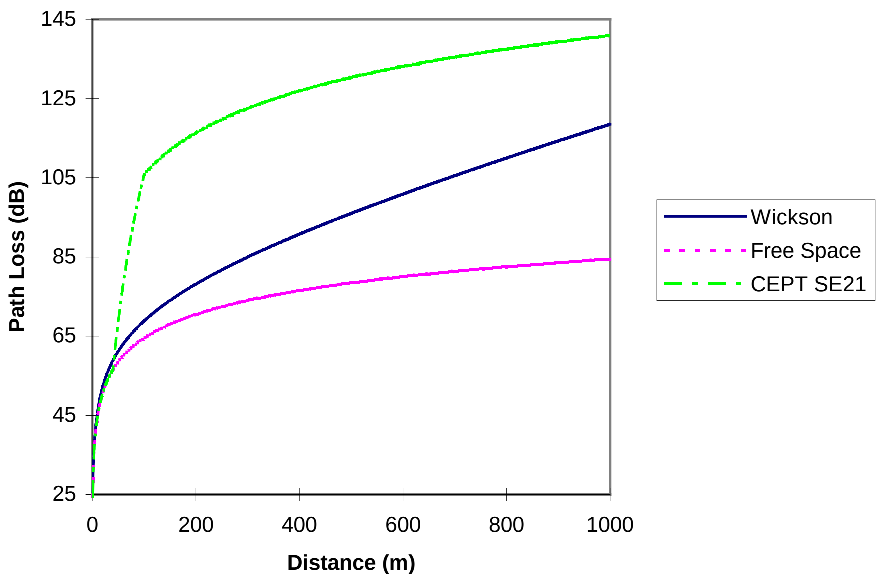

Figure C.1: Calculated path loss for the three propagation models h_1=1.5m, h_2=2m

Although figure C.1 is representative of the Wickson and Free Space models, the CEPT SE21 model also has the antenna heights as model parameters. The antenna heights significantly effect the behaviour of the CEPT SE21 propagation model at separations over 100 m.

Antenna heights of 2 m and 1,5 m are used in the above figure are representative of two hand portables. However, if one antenna is significantly higher than the other, then the path loss is reduced at large separations (approaching 1 km). This is illustrated in the figure for antenna heights of 30 m and 1,5 m.

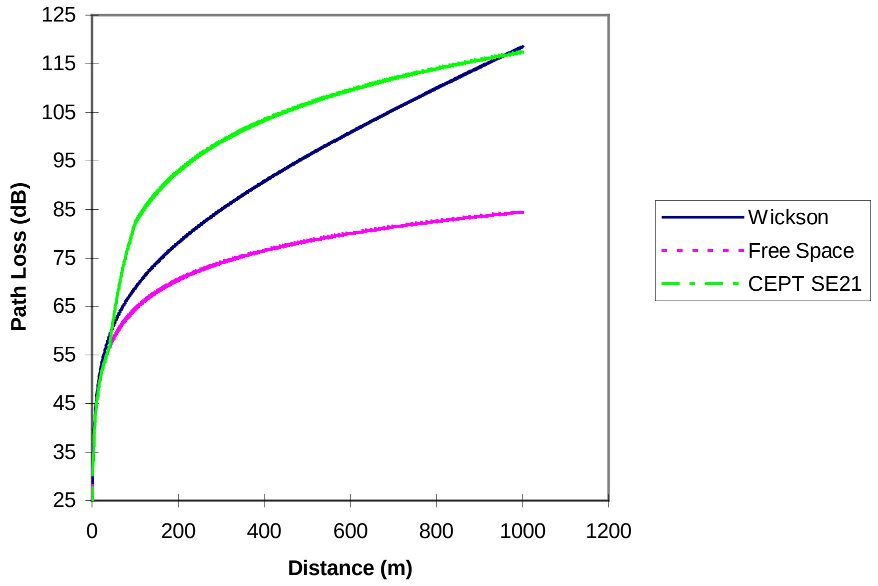

Figure C.2: Calculated path loss for the three propagation models $h_1 = 1,5$ m, $h_2 = 30$ m

Here the CEPT SE21 model actually gives a slightly lower path loss at a separation of 1 km when compared to the path loss predicted by the Wickson model. An antenna height of 30 m is equivalent to a tall mast, with 1,5 m equivalent to a hand portable.

To illustrate the extremes of the CEPT SE21 model, the figure shows the path loss for two antenna of 30 m and 10 m respectively.

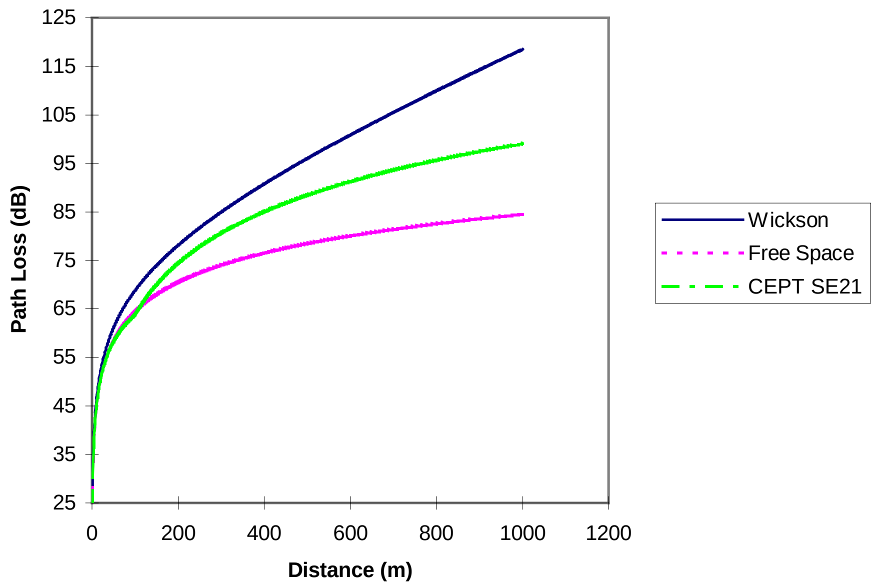

Figure C.3: Calculated path loss for the three propagation models $h_1 = 10$ m, $h_2 = 30$ m

Although these antenna heights are unrealistic for the scenarios considered in this document, it does illustrate the variation inherent in the CEPT SE21 model, as now it gives less path loss than the Wickson model at all separations.

This reinforces the message that it is the responsibility of the system designer to choose the most appropriate propagation model for their local conditions when working out the effects of mixed direct and trunked mode operation.

Annex D (informative): RF channel selection, numbering and addressing

D.1 Background

Traditional PMR only required the user to select an RF channel and speak to his colleagues on the same radio net. There was no concept of addressing. Other members of the same net would select the same RF channel (pre-arranged by their communications officer) and so the talk group could be set up. There was a type of individual addressing in the form of call signs that speakers were required to identify themselves by on the channel but it was by no means selective addressing. Everyone on channel heard everything and selected for themselves what was relevant to them.

Then came various automated selective addressing schemes that either selectively opened up a communication channel on the addressed mobile or, in the case of trunked radio systems (analogue or digital), allocated a separate traffic channel for the duration of the transaction for exclusive use of the addressed mobiles. These selective calling schemes provided user privacy on channel and required the addresses of the called party to be inserted in some form into the calling radio.

TETRA trunked mode has a fully automatic call control protocol. The control system of the MS first searches for the control channel, communicates with the BS to gain service and then manages the service on behalf of the user. As long as the MS has access to valid cipher keys for the air interface encryption all that the user needs to do is to key in or select the destination address and initiate the call.

TETRA DMO is not fully automated and lies somewhere between traditional PMR and trunked radio so far as user interfacing is concerned. In DMO the user (or application) must select the RF channel as well as to key in (or access) the required destination address. In a particular implementation both of these actions may be achieved by a single switch selection or operation but so far as the protocol is concerned they amount to two independent actions.

This annex examines a number of operational scenarios which are of relevance to direct mode users and explains some of the potential implementations which are supported by the TETRA direct mode standards. However they are only example implementations. The standard has been drafted with great flexibility and manufacturers will be able to offer other implementations which may more closely match the users' precise requirements. Users are encouraged to make known their precise requirements to service/equipment suppliers to get the best solution rather than accept supplier offerings as *the* TETRA standard solution. The disadvantage of this fully flexible approach (which is present throughout all of the TETRA standards) is that different suppliers will offer slightly different approaches but all based on and fully compliant with the TETRA standard protocol. When the manufacturers eventually implement all of the DM protocol in their MSs there will not be a problem but until that time user organisations may need to establish an interoperability profile (i.e. a minimum set of common procedures which all manufacturers implement) to ensure that there will be interoperability between DMO equipment from different manufacturers.

D.2 Numbering

Whilst not precluded by the ETSI standard it is unlikely (due to expected national licensing constraints) that DMO would be available for free standing operation. In other words DMO will usually operate in conjunction with a trunked radio system. Consequently users will expect that the same individual and group numbers will be applicable for both trunked and direct mode operation. This of itself is not difficult since both modes of operation use the same ITSI/GTSI numbering scheme (see ETS 300 396-1 [1]).

Where numbering does start to get more challenging is if a private numbering plan (PNP) is laid on top of the basic TETRA numbering scheme and if this PNP is to be made compatible with a corporate PABX or national PSTN numbering scheme. These options are considered at greater length in the Designers' Guide Part 5 (ETR 300-5 [9]) but will be briefly examined below.

As an example let us examine an emergency services or transport company type of scenario in which a simple telephone numbering scheme is to be used for identifying the terminals. Basically there needs to be an association between the simple telephone number of the called party and the required ITSI. In practice the user inputs the telephone number representing the called MS at the terminal MMI (keypad) and the destination ITSI is substituted for it, allowing the call to be completed. In trunked mode the number substitution can be done either in the handset or in the infrastructure. Clearly for operational expediency it is preferable to make the substitution in the infrastructure since it can be more easily updated. However if an MS can be called on trunked or direct mode with the same "telephone number" then there is a need for the translation to be done in the MS for DMO.

The need to perform the number translation in the DMO MS imposes stringent logistical problems on management of the DMO service in keeping the number translation directory up to date. The difficulties are further compounded if the terminals are not personal issue since it means either that a large database needs to be maintained in each DMO MS or that the MS database must be changed at each user change. Neither of these options are ideal but it would seem that use of a SIM card may provide a suitable solution and would also be compatible with the distribution of encryption keys.

D.3 Addressing in repeater and gateway direct mode operation

The addressing issues in repeater and gateway operation are similar to MS-MS operation so far as the basic need for number translation to support private numbering plans. The main difference in using repeaters and gateways is that that the repeaters and gateways themselves also need to be addressed by the transmitting MS at the start of each transaction. Further details will be given in a later version of this part of the Designers' Guide when repeater and gateway operation will be described in full.

Suffice to say for the moment that if access to the repeaters and gateways is to be limited (and for most operational purposes access will need to be restricted in some way) each DM MS will need to know in advance the address of the repeaters and gateways it will be allowed to use (otherwise much RF channel capacity will be used by DM MSs attempting access on the wrong repeaters and gateways). This joint need for address information can be satisfied in a number of different ways. For highly secure and covert operations the repeaters and gateways will stay silent or broadcast limited information. There will be no alternative but that the DM MSs will need to know in advance the addresses of the repeaters and gateways on which they will receive service. The repeater and gateway may not broadcast a presence signal or may broadcast a presence signal that only indicates its address and "available only by prior arrangement".

Besides their own identity, repeaters and gateways may broadcast Tetra Subscriber Identities (TSIs), individual or group addresses, which are allowed access. Besides individual access for particular TSIs, this mechanism also allows easy identification of repeaters and gateways operated by different organisations. For instance if all mobiles of a particular organisation are made members of an organisation-wide group then broadcast of that group identity could enable access from all members of that organisation, even if they are making individual calls or calls to different group numbers. Clearly access can be restricted to smaller groups as required.

The precise access control for DM repeaters and DM gateways are slightly different and will be explained further in the second edition of this document. Basically all that the gateway can do is check the ITSI address of the DM MS against its list. Also, if the gateway provides the DM-MS individual address to the infrastructure (optional), the infrastructure can check the address against a list. However, the rigorous authentication procedure to the SwMI authentication centre is not supported by the DM gateway.

Due to the use of pseudo identities in DM MS-MS and repeater operations it may be possible for rogue MSs to access DM repeaters but there are mechanisms for performing further identity checks of the calling parties on channel after the initial call set-up.

D.4 Summary

MSs need to know the addresses of gateways and repeaters on which they will be given service. This information can be gained by pre-arrangement or by receiving the broadcasts from active gateways and repeaters.

Conversely the repeaters and gateways will need to know the identities of the DM MSs which they will serve. This needs to be done by pre-arrangement, possibly using generic addresses or address ranges.

Annex E (normative): TDMA frame and slot structure for direct mode operation

The DMO access scheme is Time Division Multiple Access (TDMA). The carrier separation is 25 kHz.

The basic radio resource is a timeslot lasting 14,167 ms (85/6 ms) and transmitting information at a modulation rate of 36 kbit/s. This means that the timeslot duration, including guard and ramping times, is 510 bit (255 symbol) duration.

E.1 Frame structure

A diagrammatic representation of the TDMA frame structure is shown in figure E.1.

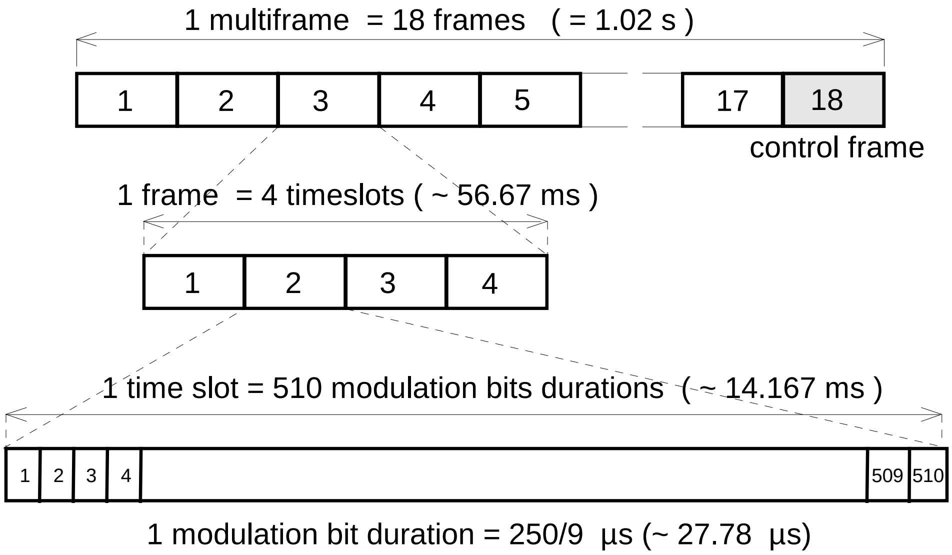

Figure E.1: DM framing structure

One multiframe is subdivided into 18 frames, and has a duration of 1,02 s. The eighteenth frame in a multiframe is a control frame.

Each frame is subdivided into 4 timeslots. Each frame has a duration of 170/3 ≈ 56,67 ms.

E.2 Timeslots and bursts

The timeslot is a time interval of 85/6 ≈ 14,167 ms, which corresponds to 255 symbol durations.

The physical contents of a timeslot is carried by a burst. There are three different types of DM-MS bursts.

Table E.1: Burst types for DM

Abbreviation	Burst type
DLB	DMO Linearisation burst
DNB	DMO Normal burst
DSB	DMO Synchronisation burst

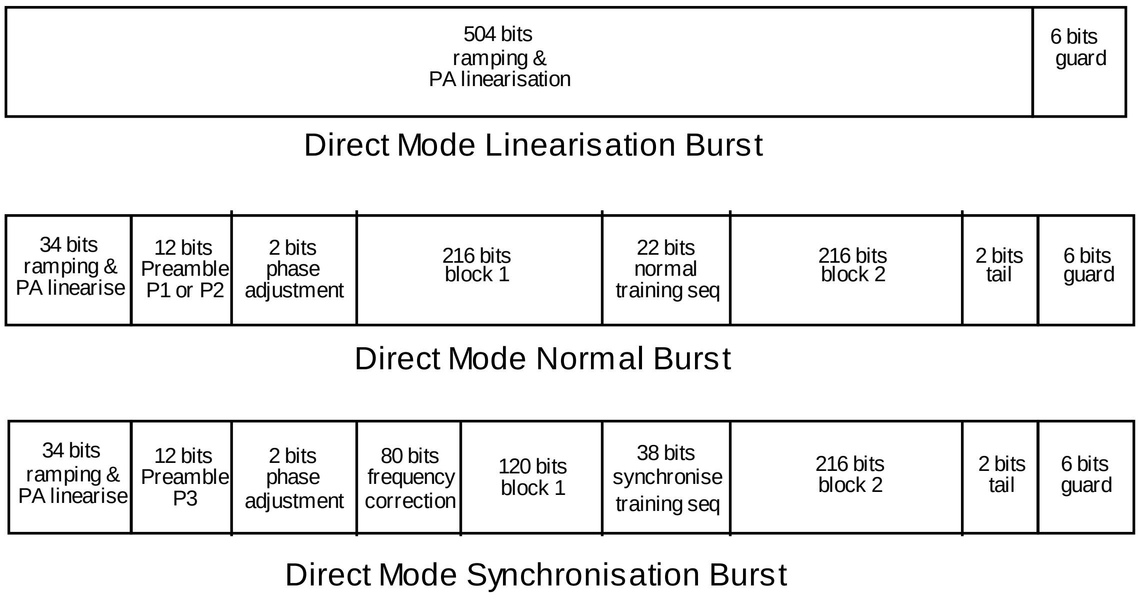

Figure E.2: DMO burst structures

Annex F (normative): DM support for short data messages

F.1 DM short data call

DM short data messages can use either unacknowledged or acknowledged protocols.

F.2 Unacknowledged short data message

A DM-MS wishing to send an unacknowledged short data message follows the procedures to ascertain the state of the channel. Provided that the channel is found to be available the DM-MS may linearize its transmitter. It then establishes the channel synchronization and simultaneously its role as "master" by transmitting a sequence of DM-SDS UDATA message headers using the DSB structure ("sdu" in figure F.1, with 8 being sent in this example). The DM-SDS UDATA message headers contain frame count information which in the example defines their position in the timing structure in frames 17 and 18 of the 18-frame cyclic multiframe structure. The master DM-MS then transmits the remaining parts of the short data message ("sd" in the figure), without repetition and using the DNB structure, in slot 1 of the following frames. In this example the remaining parts of the message occupy three slots and are sent in frames 1 to 3.

For reliability, the master DM-MS may repeat the complete message transmission immediately (without re-checking that the channel is available), and starting again with DSBs. In this example there is one complete message repetition, with the DSBs sent in frames 4 and 5, and the three DNBs sent in frames 6 to 8.

NOTE: The example assumes only single occupancy of the DM RF carrier i.e. normal mode. For frequency efficient mode, DSBs are not sent in timeslots 2 and 4 for the message repetition.

Figure F.1 also illustrates where pre-emption signalling is permitted during an SDS transmission. Short data occupation DSBs are sent in slot 3 of frames 6, 12 and 18 during the transmission of the DNBs.

Frame #	17				18				1				2				3				4			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Channel	sdu	sdu	sdu	sdu	sdu	sdu	sdu	sdu	sd				sd		p?		sd		lch		sdu	sdu	sdu	sdu

Frame #	5				6				7				8				9				10			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Channel	sdu	sdu	sdu	sdu	sd		sdo		sd				sd		p?									

Figure F.1: Call sequence for SDS - for unacknowledged data

F.3 Acknowledged short data message

When sending short data to an individual DM-MS, the calling DM-MS may request an acknowledgement from the called DM-MS. Figure F.2 illustrates this procedure.

If the channel is found to be available the calling DM-MS may linearize its transmitter. It then establishes the channel synchronization and simultaneously its role as "master" by transmitting a sequence of DM-SDS DATA message headers using the DSB structure ("sds" in figure F.2, with 8 being sent in this example, in frames 17 and 18). The master DM-MS then transmits the remaining parts of the short data message ("sd" in the figure), without repetition and using the DNB structure, in slot 1 of the following frames. In this example the remaining parts of the message occupy four slots and are sent in frames 1 to 4.

The receiving slave DM-MS sends an acknowledgement to the master DM-MS following the receipt of the last burst containing data. In this example data is included in the acknowledgement; the slave DM-MS sends SDS acknowledgement DSBs ("sdk") in slots 1 and 3 of frame 5, indicating that the message is fragmented and is continued in the next frame, frame 6 ("sda").

NOTE 1: In this example, the receiving slave DM-MS can linearize its transmitter in slot 3 of frame 3. It therefore does not need to use slot 1 of frame 5 for linearization, so sends the first transmission of its acknowledgement DSB in that slot.

NOTE 2: The short data occupation signalling DSBs which usually occur in slot 3 of frames 6, 12 and 18 following the initial synchronization are only sent during data message transmission and not during the acknowledgement period.

Frame #	17				18				1				2				3				4			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master	sds	sds	sds	sds	sds	sds	sds	sds	sd				sd		p?		sd		lch		sd			
Slave																								

Frame #	5				6				7				8				9				10			
Slot #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Master																								
Slave	sdk		sdk		sda																			

Figure F.2: Call sequence for SDS - for acknowledgement with data

Annex G (informative): Bibliography

The following material, though not specifically referenced in the body of the present document (or not publicly available), gives supporting information.

ETS 300 396-4: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 4: Type 1 repeater air interface".

ETS 300 396-6: "Terrestrial Trunked Radio (TETRA); Direct Mode Operation (DMO); Part 6: Security".

ETS 300 396-7: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 7: Type 2 repeater air interface".

ETS 300 396-1 [1]: "Terrestrial Trunked Radio (TETRA); Technical requirements for Direct Mode Operation (DMO); Part 1: General network design".

UK Home Office Study No. 95/27/256/4/CS201 "TETRA RF Co-Existence Study Final Rept" June 1996 Telecom Consultants Int (TCI).

History

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