ADVANCING GLOBAL COMMUNICATIONS

TIA TELECOMMUNICATIONS SYSTEMS BULLETIN

Project 25

Two-Slot TDMA Overview

TSB-102.BBAA

March 2010

TELECOMMUNICATIONS INDUSTRY ASSOCIATION

tiaonline.org

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(From Standards Proposal No. 3-0349, formulated under the cognizance of the TIA, TR-8 Mobile and Personal Private Radio Standards. TR-8.12 Subcommittee on Two Slot TDMA).

Published by

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Standards and Technology Department
2500 Wilson Boulevard
Arlington, VA 22201 U.S.A.

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Foreword

This document has been submitted to PROJECT 25 by the Telecommunications Industry Association (TIA), as provided for in a Memorandum of Understanding (MOU) dated December 1993. That MOU provides that PROJECT 25 will devise a Common System Standard for digital public safety communications (the Standard), and that TIA shall provide technical assistance in the development of documentation for the Standard.

This document has been developed with inputs from the TIA Project 25 Interface Committee (APIC), the APIC TDMA Task Group, TR8.12, and TIA industry members.

This document is being published because it is felt that there is a need for Project 25 to set a standard for spectrum efficiency equivalent to 6.25 kHz as stated by the FCC.

Technology choices for the TDMA Two-Slot Air Interface are based on Project 25 Steering Committee decisions regarding the vocoder, modulations, and overall bit rate made at their meeting of 27-April-2007.

This document defines an overview of Two-Slot TDMA in a P25 system.

Patent Identification

The reader's attention is called to the possibility that compliance with this document may require the use of one or more inventions covered by patent rights. By publication of this document no position is taken with respect to the validity of those claims or any patent rights in connection therewith. The patent holders so far identified have, we believe, filed statements of willingness to grant licenses under those rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such licenses.

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1. Objectives of the Project 25 Two-Slot TDMA Standard

The objectives of the Project 25 Standard that were expressed in the APCO Project 25 System and Standards Definition bulletin, TSB-102-A [1], are as follows.

- Obtain maximum radio spectrum efficiency
- Ensure competition in system life cycle procurement
- Allow effective, efficient and reliable intra-agency and inter-agency communications
- Provide user friendly equipment

The APCO Project 25 Statement of Requirements [2] defines a key goal to achieve spectrum efficiency in Phase 2 equivalent to four-to-one spectrum utilization in a 25 kHz channel. The Project 25 (P25) Two-Slot TDMA Standard for Phase 2 doubles the spectrum efficiency of the Phase 1 Standard for 12.5 kHz operation to contribute to the first objective of the Project 25 standard suite and a key goal of the Statement of Requirements. The Two-Slot TDMA Standard also maintains interoperability and compatibility with the Phase 1 Standard, including support for the Inter-RF Sub-System Interface (ISSI). The P25 Phase 2 Two-Slot TDMA Standard is based on the P25 Phase 2 12.5 kHz TDMA (i.e., Two-Slot TDMA) requirements defined in the P25 Statement of Requirements to preserve the achievement of the other three objectives.

Section 2 provides an overview of the scope of the P25 Two-Slot TDMA Standard. Section 3 identifies the informative references cited in this document. Section 4 gives a brief description of the suite of standards associated with the P25 Two-Slot TDMA Standard. Section 5 provides a general description of P25 Two-Slot TDMA Common Air Interface (CAI). Section 6 introduces the bit rate and modulation for the P25 Two-Slot TDMA CAI. Section 7 introduces the P25 vocoder associated with the P25 Two-Slot TDMA Standard. Section 8 introduces trunking control aspects of the P25 Two-Slot Standard. Section 9 introduces encryption and security aspects of the P25 Two-Slot Standard. Section 10 introduces aspects of interoperability, compatibility, and migration addressed by the P25 Two-Slot Standard. Section 11 introduces options associated with the P25 Two-Slot Standard.

1.1 Abbreviations and Acronyms

Abbreviations and acronyms used in this document include the following.

6.25e	Equivalent to 6.25 kHz channel efficiency, i.e.,efficiency equivalent to one voice per 6.25 kHz of channel bandwidth
A	Mobile Data Terminal Interface
ALGID	Algorithm Identifier for an encryption algorithm
APCO	Association of Public-Safety Communications Officials
C4FM	Compatible 4 Level Frequency Modulation
CAI	Common Air Interface
CAP	Project 25 Compliance Assessment Program
CCH	Trunking Control Channel
DCH	Data channel
E_c	Console Interface
E_d	Data Host Network Interface
E_f	Fixed Station Conventional Interface
E_n	Network Management Interface
ESS	Encryption Synchronization Signaling, concatenates MI, ALGID, KID
E_t	PSTN Interface
FDMA	Frequency Division Multiple Access
G	ISSI, Inter-RF SubSystem Interface
H-CPM	Harmonized Continuous Phase Modulation
H-D8PSK	Harmonized Differential 8 Phase Shift Keying, a proposed future modulation for TDMA for improved simulcast delay spread
H-DQPSK	Harmonized Differential Quadrature Phase Shift Keying
ID	Identifier
ISCH	Inter-slot Signaling Channel
ISSI	Inter-RF SubSystem Interface
kb/s	Kilobits per second
kHz	Kilohertz
KID	Key Identifier for an encryption key
LCW	Link Control Word for trunking control
MAC	Media Access Control sublayer
MI	Message Indicator for encryption synchronization
ms	Milliseconds
OTAR	Over The Air Rekeying
P25	Project 25, usually referring to the Project 25 standards
P25 Phase 1	Refers in part to Project 25 FDMA and CQPSK standards [2]
P25 Phase 2	Refers in part to Project 25 TDMA standards [2]
PDU	Protocol Data Unit, a term used frequently in the MAC layer
PHY	Physical layer
PSTN	Public Switched Telephone Network
RF	Radio Frequency
RTP	Real-time Transport Protocol

TCH	Traffic channel
TDMA	Time Division Multiple Access
TIA	Telecommunications Industry Association
TSB	Technical Systems Bulletin of the TIA
TSBK	Trunking Signaling Block for trunking control
U_m	P25 Phase 1 FDMA Common Air Interface
U_{m2}	P25 Phase 2 Two-Slot TDMA Common Air Interface

1.2 Revision History

Version 0.4, 29-September-2008, revised using comments from TR8.12, document 08-07-011

Version 0.5, 11-November-2008, revised using comments from TR8.12, documents 08-07-011-R1 through R3.

Version 0.6, 20-November-2008, revised using comments from TR8.12, document 08-07-011-R4

Version 0.7, 2-December-2008, revised using comments from TR8.12, document 08-07-011-R5

Version 0.8, 10-December-2008, revised using comments from TR8.12, document 08-07-011-R6 & R7

Version 0.9, 17-December-2008, revised using comments from TR8.12 conference call discussions on 17-December-2008 and document 08-011-R8 & R9

Version 1.0, 6-August-2009, revised using editorial comments from the TIA ballot process

Version 1.1. 10-August-2009, revised using second round of editorial comments from Version 1.0 review

2. Scope of the P25 Two-Slot TDMA Standard

This document describes the P25 Phase 2 Two-Slot TDMA Standard in a general way. The P25 Phase 2 Two-Slot TDMA Standard is a suite of P25 standards documents. The high level technical scope of the P25 Two-Slot TDMA Standard includes the following major items.

- Interface Description of the U_{m2} interface designated for the P25 Phase 2 TDMA Two-Slot CAI.
- TDMA CAI for Two-Slots operating at a gross bit rate of 12 kb/s with Harmonized-Continuous Phase Modulation (H-CPM) for the inbound link and Harmonized-Differential Quadratrure Phase Shift Keying (H-DQPSK) modulation for the outbound link. The P25 Two-Slot TDMA CAI is divided into a Physical layer (PHY) and a Media Access Control layer (MAC) to facilitate TDMA operation.
- Dual Rate Vocoder at a gross bit rate of 7.2 kb/s for the full rate for use with Phase 1 and 3.6 kb/s for the half rate for use with Phase 2.
- Trunking control signals using MAC Protocol Data Units (PDUs).
  - The MAC PDUs are compatible with Phase 1 addressing and trunking functions.
  - The Phase 1 trunking control channel also has additions to address TDMA calls and control TDMA operation for ease of migration.
- Encryption for voice messages uses the Message Indicator (MI), Key ID (KID), and Algorithm ID (ALGID) combined into an Encryption Sync Signal (ESS) that is compatible with the definitions used in Phase 1.
- Use of FDMA for Phase 1 trunking interoperability and direct mode (talkaround).
- Standardized signaling allowing optional synchronization of FDMA Control Channel (CCH) and TDMA Traffic Channel (TCH) for better access time.

Future work:

- Harmonized-Differential 8 Phase Shift Keying (H-D8PSK) modulation for downlink for improved simulcast delay spread.
- Slotted control channel:
  - Single slot TDMA CCH (either one of the Two-Slots running CCH protocol) – allows control and voice on a single RF channel.
  - Composite Control Channel (dynamically running one or no slots with CCH protocol) – allows voice operations on both slots of a single RF channel implementation.
  - Full TDMA CCH where both slots run the CCH protocol.
- Slotted data channel for OTAR or other data applications.
- Scrambling of the TDMA CCH and the Data Channel (DCH).
- Development of a vehicular repeater tp support TDMA.
- Development of a P25 Four-Slot TDMA Standard, including specification of P25 defined Four-Slot TDMA protocols for a P25 Four-Slot TDMA CCH, TCH, and DCH.

3. Informative References

This Telecommunications System Bulletin contains only informative information. There are references to TIA standards which contain normative elements. These references are primarily to indicate where normative elements are located. At the time of publication, the edition indications were valid. All standards and bulletins are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent edition of the standard or bulletin indicated in Section 3. ANSI and TIA maintain registers of currently valid national standards published by them.

[1] TSB-102-A; APCO Project 25 System and Standards Definition; November 1995

[2] APCO Project 25 Statement of Requirements; October 17, 2008

[3] TIA-102.BABA-1; Project 25 Half Rate Vocoder Annex

[4] TIA-102.AAAD; Project 25 Block Encryption Protocol; with Addendum for encryption protocol for a half rate vocoder

[5] TIA-102.AABC-B-4; Project 25 Trunking Control Channel Messages Addendum for TDMA

[6] TSB-102.BABE; Project 25 Vocoder Evaluation Mean Opinion Score Test; 2007

[7] TIA-102.AACA; Project 25 Digital Over the Air Rekeying Protocol; 2003

[8] TIA-102.BACA; Project 25 Inter RF Subsystem Interface Messages and Procedures for Voice Services; including addenda 1, 2, and 3; 2007

[9] TIA-102.AABD; Project 25 Trunking Procedures; 2007

[10] TIA-102.AABF-A; Project 25 Link Control Word Formats and Messages; 2004

[11] TIA-102.CBAA; Project 25 TDMA Methods of Measurements – proposal in TR8.1

Editor's Note: The above document is a work in progress and should not be referenced unless and until it is approved and published. Until such time as this Editors Note is remove the inclusion of the above document is for informational purposes only

[12] TIA-102.CXXX; Project 25 TDMA Performance Recommendations – proposal in TR8.6

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4. Documentation Suite for the P25 Phase 2 Two-Slot TDMA Standard

The envisioned documentation suite for the Two-Slot TDMA Standard includes planned development of the following Project 25 new and revised TIA standards and bulletins.

- Project 25 Vocoder Description with an annex to define a half rate vocoder [3]
- Project 25 Vocoder Overview and Performance
- Two-Slot TDMA Common Air Interface (CAI) consisting of two documents.
    - Two-Slot TDMA Physical Layer Description
    - Two-Slot TDMA Media Access Control Layer
- Additions to the Phase 1 Trunking Standards for Phase 2 [5]
- Additions to the Phase 1 Encryption Standards for Phase 2 [4]
- Two-Slot TDMA CAI Methods of Measurement [11]
- Two-Slot TDMA CAI Performance Recommendations [12]
- Two-Slot TDMA Conformance Tests
    - Two-Slot TDMA CAI Conformance
    - Two-Slot TDMA Messages and Procedures Conformance
- Two-Slot TDMA CAI Interoperability Tests
- Two-Slot TDMA Recommended Compliance Assessment Tests
- Additions to the Project 25 ISSI Messages and Procedures for Voice Services [8] for Phase 2

Each of these documents, or additions to the documents, is now described for the purposes of this overview. Table 4-1 identifies P25 standards documents that are associated with the P25 Two-Slot TDMA Standard, including indentification of the section in which they are described.

Table 4-1 – P25 Two-Slot TDMA Standards Summary

P25 Standards Documentation Area	**Section #**	**TIA Designation**
Two-Slot TDMA Overview	n/a	102.BBAA
Vocoder Overview	4.1	102.xxxx
Project 25 Half-Rate Vocoder Annex	4.1	102.BABA-1
Vocoder Performance	4.1	102.xxxx
Project 25 Phase 2 Two-Slot Time Division Multiple Access Physical Layer Protocol Specification	4.2	102.BBAB
Two-Slot TDMA Media Access Control Layer	4.2	102.BBAC
Two-Slot TDMA CAI Measurement Methods	4.5	102.CBAA
Two-Slot TDMA CAI Performance Recommendations	4.6	102.Cxxx
Two-Slot TDMA CAI Conformance	4.7	102.Cxxx
Two-Slot TDMA Messages and Procedures Conformance	4.7	102.CBBB
Two-Slot TDMA CAI Interoperability Tests	4.8	102.Cxxx
Additions to the Phase 1 Trunking Standards for Phase 2 • TSBK messages addendum for TDMA control • LCW messages addendum for TDMA control • Trunking Procedures call control addendum for TDMA	4.3	 102.AABC-B-4 102.AABF-B-x 102.AABD-A-x
Additions to the Phase 1 Encryption Standards for Phase 2 • Encryption protocol addendum for half rate vocoder • Digital Over the Air Rekeying Protocol	4.4	 102.AAAD-x 102.AACA-x
Two-Slot TDMA Compliance Assessment Recommendations	4.9	102.CBxx
Additions to the Project 25 ISSI Messages and Procedures for Voice Services for Phase 2	4.10	102.BACA-x

4.1 Project 25 Vocoder Description

The Project 25 Vocoder Description document [3], together with a half rate vocoder annex, provides description of a Dual Rate Vocoder. These documents, plus additional documentation intended to ensure a performance level equivalent to or better than that described in reference [6] enables the following Phase 2 vocoder functionality. The existing Phase 1 Vocoder is a full rate vocoder operating at a gross bit rate of 7.2 kb/s. The Phase 2 vocoder includes the following items.

- Dual Rate vocoder, consisting of a Full Rate mode and a Half Rate mode, with the Half Rate mode at 3.6 kb/s for Phase 2.
- Improved performance with background noise.
- Soft decision error correction.
- Tone encoding for specified tone signaling - tone frequencies and amplitudes are quantized.
- Parametric rate conversion from Full Rate to Half Rate or the reverse for interoperability between Phase 1 and Phase 2.

4.2 Two-Slot TDMA Common Air Interface

The Two-Slot TDMA CAI documents consist of a Physical layer description and a MAC layer description. Taken together the documents address a 12.5 kHz occupied channel with a Two-Slot TDMA design for spectrum efficiency equivalent to one voice per 6.25 kHz of channel bandwidth (6.25e).

The Physical layer description includes the following items.

- Two-Slot TDMA CAI architecture to define a U_{m2} interface for Phase 2.
- Physical layer transmission formats to support two time slots in a 12.5 kHz occupied channel, detailing 30 ms time slots, required ramp and guard times, and other features of the physical radio channel.
- Modulation definitions of Harmonized Continuous Phase Modulation (H-CPM) and Harmonized Differential Quadrature Phase Shift Keying (H-DQPSK) modulation. The 12.5 kHz physical layer operates at a gross bit rate of 12 kb/s. H-CPM is defined for the inbound link so that subscribers may use constant envelope modulation. H-DQPSK is defined for the outbound link so that simulcast delay spread is improved as compared to Compatible 4 Level Frequency Modulation (C4FM) modulation used in Phase 1.
- The principal time unit in the physical layer is the 30 ms time slot.

The MAC layer description includes the following items.

- Synchronization of the TDMA time slots and the modulation is defined so that two subscriber radios may transmit on separate sub-channels (i.e. separate slots) on one frequency, and also two or more subscriber radios on separate sub-channels may simultaneously receive on one frequency. A standardized protocol option for synchronization with an FDMA control channel is also provided.
- The principal time unit in the MAC layer is the 360 ms superframe consisting of twelve 30 ms time slots defined in the Physical layer.
- Media Access Control (MAC) layer synchronization, access, and control of the physical layer for use with voice, data, and control functions in higher layers. The higher signaling layers present information fields to the MAC layer that are formatted and encoded for scrambling and modulation in the underlying physical layer. After demodulation and descrambling in the physical layer of the receiver the code words may be decoded and presented to the higher layers for further processing.
- Dedicated signaling slots for simultaneous inbound and outbound signaling and control without interrupting voice communication. The signaling slot is physically spaced every 360 ms in time.
- Inter-slot Signaling Channel (ISCH) in the outbound channel, between slots, for synchronization and supervision of the channel.
- Inbound and outbound burst definitions for 4 voice frames and 2 voice frames with Encryption Synchronization Signaling (ESS) including slot definitions for the 3.6 kb/s Half Rate vocoder.
- The MAC Protocol Data Units (PDUs) use addresses for systems, units, talk groups, and traffic channel numbers that are in the Phase 1 trunking definitions. The functions of the MAC PDUs reproduce for Phase 2 the voice header, terminator, and embedded signaling features provided in Phase 1.
- Scrambling codes for co-channel interference protection.

4.3 Additions to Phase 1 Trunking for Phase 2

The Phase 1 Trunking standards have additions for Phase 2 [5]. Some additions are necessary for Phase 2 to address and control slotted traffic sub-channels on a trunked system. The additions to Phase 1 Trunking standards include the following items.

- TSBK messages for TDMA control, Addendum TIA-102.AABC-B-4 [5].
- LCW messages for TDMA control, to be an Addendum to TIA-102.AABF-B [10] as needed.
- Call procedures for TDMA, to be an Addendum to TIA-102.AABD-C [9] as needed.
- Synchronization broadcast message as a standard option to synchronize the FDMA control channel and the TDMA traffic channel.

4.4 Additions to Phase 1 Encryption for Phase 2

The Phase 1 Encryption standards include a Block Encryption Protocol [4], an Over the Air Rekeying (OTAR) protocol [7], and other related documents. The additions to these documents include the following items.

- Block encryption protocol: the Message Indicator (MI), Algorithm ID (ALGID) and Key ID's from Phase 1 are to be used in Phase 2. These are combined into an ESS that is paced at the same rate in Phase 2 as it is in Phase 1.
- Clocking schedule for TDMA voice encryption is updated for 49-bit voice frames for the Half Rate vocoder in addition to the 88-bit frames for the Full Rate vocoder.
- OTAR for Phase 2 follows the Phase 1 OTAR standard.

4.5 Two-Slot TDMA CAI Measurement Methods

The Two-Slot TDMA CAI Measurement Methods document [11] describes the methods to measure performance specifications for the full set of transmitter and receiver figures of merit for H-CPM and H-DQPSK modulation.

4.6 Two-Slot TDMA CAI Performance Recommendations

The Two-Slot TDMA CAI Performance Recommendations document [12] sets performance specification limits for the full set of transmitter and receiver measurements for H-CPM and H-DQPSK defined in the Two-Slot TDMA CAI Measurements Methods document.

4.7 Two-Slot TDMA CAI Conformance Tests

The Two-Slot TDMA Conformance documents, consisting of Two-Slot TDMA CAI Conformance and Two-Slot TDMA Messages and Procedures Conformance tests, define test procedures to determine if radio equipment conforms to the protocol requirements of the Two-Slot TDMA CAI Standard.

4.8 Two-Slot TDMA CAI Interoperability Tests

The Two-Slot TDMA CAI Interoperability Tests document defines how to test radio equipment from a vendor for interoperability with other vendor equipment implementing the Two-Slot TDMA CAI Standard and all related vocoder, trunking, and encryption documents.

4.9 Two-Slot TDMA Recommended Compliance Assessment Tests

The recommended Two-Slot TDMA Compliance Assessment Tests are documented in TIA informative documents (i.e., TSBs) to establish a subset of tests defined in the Two-Slot TDMA test documents to support the P25 Compliance Assessment Program (P25 CAP) for equipment implementing the P25 Two-Slot TDMA Standard.

4.10 Project 25 ISSI Messages and Procedures

The Project 25 ISSI Messages and Procedure document [8] includes messages to transport vocoder information with RTP packet structures. These messages will be supplemented to transport half rate vocoder information. Additionally, modified control messages may be necessary for the ISSI and related P25 wireline interfaces; for example, to communicate information within and among RF-Subsystems (RFSSs) and Console Subsystems concerning relevant capabilities of Phase 1 and Phase 2 equipment (i.e., 12.5 kHz FDMA and Two-Slot TDMA capabilities of radios, stations, and site/system infrastructures as described in Section 10). These changes are necessary for coordination of Phase 1 FDMA and Phase 2 TDMA interoperability.

5. General Description of the P25 Two-Slot TDMA CAI

The P25 Two-Slot TDMA CAI defines the functions and operations at a specified interface within the context of a general system model for a Project 25 system for trunked operations. A representative P25 system model in this regard, derived from TSB-102-A [1], is shown in Figure 5-1. The P25 interface for the Phase 2 Two-Slot TDMA CAI is designated as U_{m2} in the figure. The P25 interface for the Phase 1 FDMA CAI is designated as U_m in the figure.

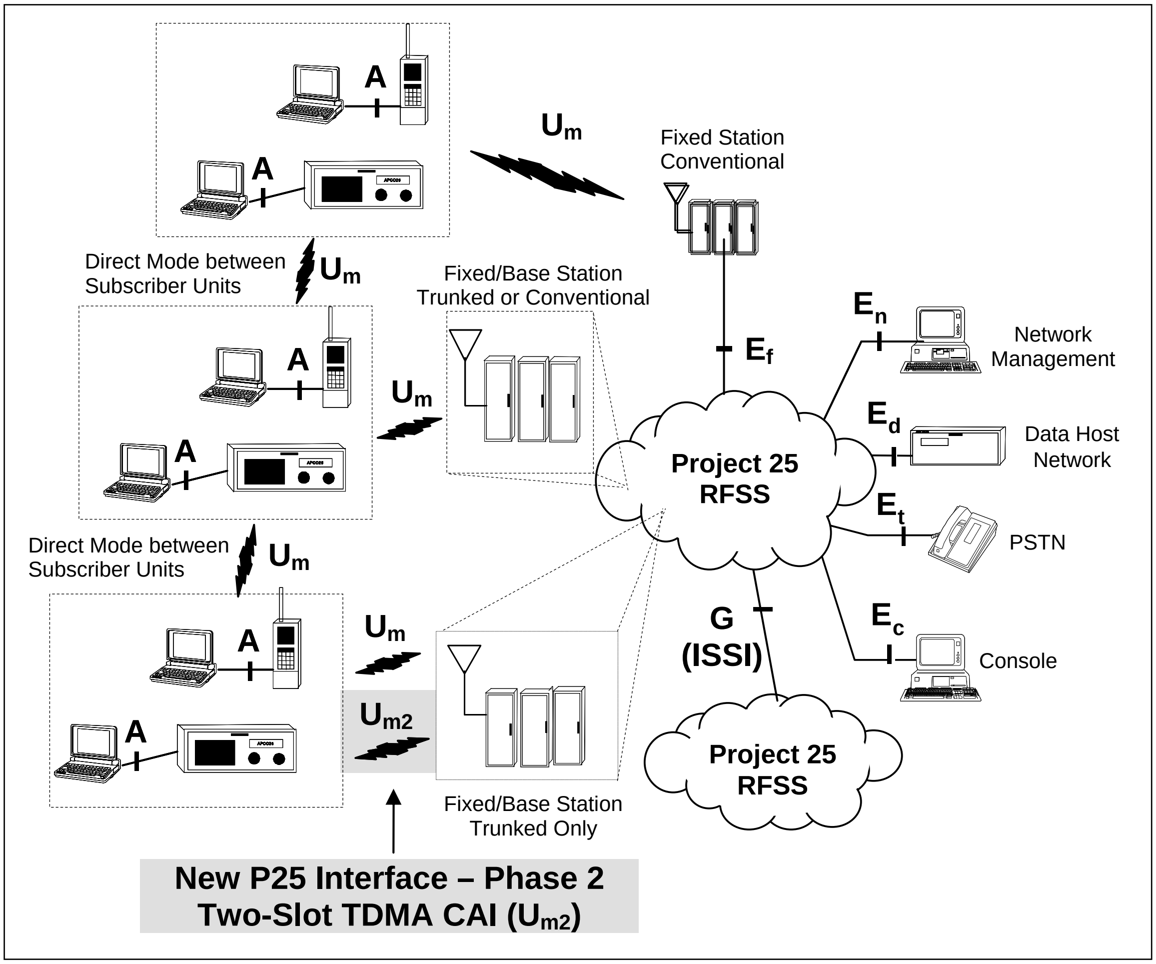

Figure 5-1 – Representative P25 Phase 2 System Model Illustrating Support of the New Phase 2 Two-Slot TDMA CAI (U_{m2}) and the Phase 1 12.5 kHz FDMA CAI (U_m)

6. Bit Rate and Modulation for the P25 Two-Slot TDMA CAI

The Two-Slot TDMA CAI operates at a gross bit rate of 12 kb/s. The modulation on the inbound path from the subscriber to the infrastructure is Harmonized Continuous Phase Modulation (H-CPM). The modulation on the outbound path from the infrastructure to the subscriber is Harmonized Differential Quadrature Phase Shift Keying (H-DQPSK).

H-CPM modulation is a constant envelope modulation, so that subscriber radio transmitters may use class-c RF amplifiers for higher average power from a fixed power supply voltage as is available from a battery on a portable radio. The infrastructure may use a coherent receiver technology to demodulate H-CPM.

H-DQPSK is a linear modulation that uses linear RF amplifiers in the infrastructure transmitters. H-DQPSK uses a raised cosine filter with a large excess bandwidth ratio, which is usually designated as a large alpha value. The large excess bandwidth widens the transmitter eye pattern for better simulcast delay spread. The simulcast delay spread for H-DQPSK is larger than the simulcast delay spread for C4FM modulation. The receiver in the subscriber may be non-coherent.

The radio occupied channel is 12.5 kHz to be compatible with the Phase 1 FDMA Standard. This simplifies migration from Phase 1 to Phase 2.

The Two-Slot TDMA Standard defines time slots that are 30 ms long for transmitting the TDMA traffic. A voice call occupies alternate 30 ms slots, so that two voice calls or logical channels, may be interleaved on single physical radio channel. The outbound transmission from the infrastructure may be a continuous carrier transmission alternating between the two logical channels. The inbound transmission for a subscriber would be a discontinuous carrier transmission with bursts spaced out to occupy alternating physical slots on a single TDMA logical channel. Each burst is shorter than the 30 ms slot duration to permit ramp up time for the RF amplifier in the transmitter, and a small interval for propagation delays, so that bursts on adjacent logical channels from different subscribers do not overlap and interfere.

7. Vocoder

The P25 vocoder includes both a full rate vocoder at a gross bit rate of 7.2 kb/s and a half rate vocoder at a gross bit rate of 3.6 kb/s [3]. The full rate vocoder is interoperable with the vocoder used in existing Phase 1 FDMA equipment. The half rate vocoder is for use in Two-Slot TDMA equipment. Both rates use the same fundamental speech processing so the vocoder is described properly as a dual rate vocoder. Parametric rate conversion is possible to convert between the two rates for purposes of interoperability.

The dual rate vocoder includes a feature to encode tones so that selected tones may be sent through the system with routine vocoder operation. The tones are quantized and encoded by the vocoder. This feature is defined in the half rate vocoder annex.

8. Trunking Control

The trunking control channel used in Phase 1 FDMA systems is extended with additional messages and signals to permit radios to identify their FDMA vs. Two-Slot TDMA capabilities during registration. Additional messages and signals are also added to be able to address and assign Two-Slot TDMA channels. This permits insertion of Two-Slot TDMA channels into Phase 1 trunking systems for migration to Two-Slot TDMA. The Two-Slot TDMA CAI also includes slot definitions for trunking control functions for future migration to a Two-Slot TDMA control channel.

9. Encryption

Voice is encrypted for end-to-end protection of messages, and the signals to synchronize and select keys and algorithms are sent along with the voice message. In Phase 1 the synchronization is called the Message Indicator (MI), and the encryption key is identified with a Key ID (KID). The encryption algorithm is identified with an Algorithm ID (ALGID). The MI, KID, and ALGID are transmitted together every 360 ms for voice messages in the Phase 1 FDMA Standard. The MI, KID, and ALGID are the same size in Two-Slot TDMA, and they are also transmitted every 360 ms. This preserves the same encryption performance in Two-Slot TDMA for late entry. Since the encrypted voice information is different with a half rate vocoder for Two-Slot TDMA, a different clocking schedule is used for the operation of encryption in Two-Slot TDMA.

Encryption keys are transmitted over the air interface following a Phase 1 OTAR standard [7]. Phase 2 TDMA will use Phase 1 FDMA data for OTAR services to support encryption The same Phase 1 OTAR standard operates in Two-Slot TDMA systems for interoperability and compatibility with Phase 1. The Two-Slot TDMA CAI also includes an item for future work for slot definitions for a Two-Slot TDMA data channel that may be used for OTAR.

For end-to-end encryption of voice service that involves one or more radios in FDMA mode with no intermediate decryption / re-encryption permitted, all radios involved in the encrypted voice service have to operate in the 12.5 kHz FDMA mode (see Section 11). If parametric rate conversion is permitted (see Section 10), then encrypted voice has to be decrypted before parametric rate conversion and then re-encrypted. Parametric rate conversion does not apply to data services and therefore end-to-end encryption of data messages may be maintained between FDMA and Two-Slot TDMA radios.

10. Phase 1 Interoperability, Compatibility, and Migration

The Phase 1 FDMA Standard is the mode of operation for interoperability with existing P25 radios and systems. In this way, Two-Slot TDMA and FDMA standards are mutually compatible.

An existing Phase 1 (12.5 kHz) FDMA system may migrate to Phase 2 (Two-Slot) TDMA operation by installing subscribers and infrastructure capable of Two-Slot TDMA operation. Calls among the Two-Slot TDMA subscribers may be in the Two-Slot TDMA mode for the benefit of spectrum efficiency. Calls that include FDMA subscribers may revert to the FDMA mode for the benefit of interoperability. Alternatively, for multi-RF site calls including a mix of FDMA and Two-Slot TDMA subscribers, some sites may operate in FDMA mode and some in Two-Slot TDMA mode. Vocoder parametric rate conversion between the sites is used for this interoperability approach. Parametric rate conversion is done in the clear mode and so, for secure calls, decryption is required prior to parametric conversion and re-encryption is required after parametric conversion. These two interoperability approaches are key enablers for migrating from Phase 1 FDMA to Phase 2 Two-Slot TDMA, for mixing Phase 1 FDMA and Phase 2 Two-Slot TDMA equipment within a system, and for communication between systems having Phase 1 FDMA and Phase 2 Two-Slot TDMA equipment.

Interoperability of Phase 1 and Phase 2 radios, channels, sites and systems uses tracking of the capabilities of the equipment involved in any given call. Three categories of equipment are intended to co-exist and interoperate with respect to development of the Two-Slot TDMA Standard. Phase 1 equipment operates in the 12.5 kHz FDMA mode only. Phase 2 equipment may operate in the 12.5 kHz FDMA mode only but with enhanced control capabilities or it may be capable of both operating in the 12.5 kHz FDMA mode and in the Two-Slot TDMA mode. These three interoperable equipment types are defined for the purposes of this document as follows;

- Phase 1 FDMA (12.5 kHz) only – Applies to radios, stations and site/system infrastructure equipment. This equipment is not capable of Two-Slot TDMA operation nor does it have any knowledge of new messages and procedures introduced in the Phase 2 standards associated with Two-Slot TDMA.
- Phase 2 FDMA (12.5 kHz) only – Applies to radios, stations and site/system infrastructure equipment. This equipment is not capable of Two-Slot TDMA operation but does have knowledge of new messages and procedures introduced in the Phase 2 standards associated with Two-Slot TDMA.
- Phase 2 FDMA (12.5 kHz)/TDMA (Two-Slot) – Applies to radios, stations and site/system infrastructure equipment. This equipment is capable of Two-Slot TDMA operation and has knowledge of new messages introduced in the Phase 2 standards associated with Two-Slot TDMA.

NOTE - TDMA (Two-Slot) only - Applies to stations, sites/systems with no FDMA control channel and radios with no FDMA capability. TDMA only stations capable of operating on sites/systems with FDMA control channels are discussed in this section.

Sites with no FDMA control channel and radios with no FDMA capability are not interoperable with Phase 1 and are not discussed in this section.

When Phase 2 FDMA/TDMA radios first register on a Phase 2 (FDMA only or FDMA/TDMA) system, they indicate their FDMA and TDMA capabilities. As the Phase 2 radios move from RF site to RF site within the system, the location update messages also include this same information on their FDMA and TDMA capabilities. This allows the Phase 2 FDMA only and the Phase 2 FDMA/TDMA infrastructures to know which radios have Two-Slot TDMA capability, where they are located and what talkgroup they are affiliated with.

When Phase 1 FDMA only radios first register on a Phase 2 FDMA only or a Phase 2 FDMA/TDMA system and as they move between RF sites within the system, they do not provide their FDMA and TDMA capabilities information. Phase 2 FDMA only and Phase 2 FDMA/TDMA infrastructures interpret messages that do not contain FDMA and TDMA capability information as 12.5 kHz FDMA only radios.

Phase 1 FDMA only infrastructures do not recognize the messages containing the FDMA and TDMA capability information and assume all radios are 12.5 kHz FDMA only.

When call requests are received, the infrastructure determines the FDMA and TDMA capabilities of all radios and all RF sites involved in the call. This applies to all voice calls regardless of whether the call is a single site, multi site or multi system call. Phase 1 FDMA only infrastructures have no knowledge of Two-Slot TDMA capabilities and so all calls are assigned, by default, as 12.5 kHz FDMA.

Phase 2 (FDMA only and FDMA/TDMA) infrastructures have the knowledge of which radios have Two-Slot TDMA capabilities and which stations, sites and systems have Two-Slot TDMA capabilities. When a voice call involves a mixture of Phase 1 FDMA only, Phase 2 FDMA only, and Phase 2 FDMA/TDMA capable radios, the Phase 2 infrastructures choose between two methods for providing FDMA and Two-Slot TDMA interoperability during the call. The call may be assigned as FDMA at all participating RF sites to accommodate the 12.5 kHz FDMA only radios and sites. Alternatively, the call may be assigned as 12.5 kHz FDMA at some sites and Two-Slot TDMA at other sites taking into account radio capabilities. Since 12.5 kHz FDMA calls are expected to use a full-rate vocoder and Two-Slot TDMA calls are expected to use a half-rate vocoder, vocoder parametric rate conversion is used by the Phase 2 infrastructure to interconnect 12.5 kHz FDMA and Two-Slot TDMA sites. By these two methods, the Phase 2 infrastructure obtains interoperability between Phase 1 FDMA only, Phase 2 FDMA only, and Phase 2 FDMA/TDMA capable radios.

Both of the approaches described above to achieve interoperability of 12.5 kHz FDMA and Two-Slot TDMA radios use the same set of FDMA and TDMA capability information. Both methods are coordinated and controlled by the infrastructures participating in each call. The radios participating in each call follow the call assignment instructions provided by the infrastructure and are unaware of which method the infrastructure uses (with the exception of end-to-end encryption as described in Section 9). Therefore, Two-Slot TDMA Standards need only describe how the FDMA and TDMA capability information is provided and the choice of which interoperability method to use may remain outside the scope of the standard.

11. Options Associated with the P25 Two-Slot TDMA Standard

Standardized signaling allows optional synchronization of FDMA CCH and TDMA TCH for better access time. The 30 ms slots on the working channel may be synchronized with the control channel such that the subscriber radios may anticipate the slot time boundaries and the burst schedule directly from monitoring the control channel messages. Subscribers that maintain this synchronization when they switch from the control channel to the working channel may immediately transmit or receive on the first slot they encounter after the switch. Unsynchronized subscribers have to first decode the synchronization on the working channel before they may operate on the desired TDMA sub-channel.

Currently for future consideration as noted in Section 2, an optional proposed H-D8PSK modulation is an 8-level form of H-DQPSK modulation for improved simulcast delay spread. H-D8PSK modulation is an item for future work. H-DQPSK transmits information with 2 bits per symbol, so the symbols have 4 phase shift values, and the symbols are spaced 166.667 microseconds apart. H-D8PSK transmits 12 kb/s with 3 bits per symbol so the symbols are spaced 250.0 microseconds apart. The remaining filters of the modulator and demodulator remain unchanged, so the eye pattern is more open, and the simulcast delay spread is proportionately increased. H-D8PSK may be used for systems which demand larger simulcast delay spreads that may be obtained with H-DQPSK.

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