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Space data and information transfer systems — TC (telecommand) synchronization and channel coding

Systèmes de transfert des données et informations spatiales — Synchronisation TC (télécommande) et codage de canal

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22642 was prepared by the Consultative Committee for Space Data Systems (CCSDS) (as CCSDS 231.0-B-1, September 2003) and was adopted (without modifications except those stated in Clause 2 of this International Standard) by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 13, *Space data and information transfer systems*.

Space data and information transfer systems — TC (telecommand) synchronization and channel coding

1   Scope

This International Standard defines synchronization and channel coding schemes used with the telecommand (TC) space data link protocol as defined in ISO 22664. These schemes are to be used over ground-to-space or space-to-space communications links by space missions.

The scope and field of application are furthermore detailed in subclauses 1.1 and 1.2 of the enclosed CCSDS publication.

2   Requirements

Requirements are the technical recommendations made in the following publication (reproduced on the following pages), which is adopted as an International Standard:

CCSDS 231.0-B-1, September 2003, TC *synchronization and channel coding.*

For the purposes of international standardization, the modifications outlined below shall apply to the specific clauses and paragraphs of publication CCSDS 231.0-B-1.

Pages i to v

This part is information which is relevant to the CCSDS publication only.

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Add the following information to the reference indicated:

[1]   Document CCSDS 232.0-B-1, September 2003, is equivalent to ISO 22664:2005.

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Add the following information to the reference indicated:

[B2]   Document CCSDS 201.0-B-3, June 2000, is equivalent to ISO 12171:2002.

It has been agreed with the Consultative Committee for Space Data Systems that Subcommittee ISO/TC 20/SC 13 will be consulted in the event of any revision or amendment of publication CCSDS 231.0-B-1. To this end, NASA will act as a liaison body between CCSDS and ISO.

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Consultative Committee for Space Data Systems

**RECOMMENDATION FOR SPACE
DATA SYSTEM STANDARDS**

TC SYNCHRONIZATION

AND CHANNEL CODING

CCSDS 231.0-B-1

BLUE BOOK

September 2003

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CCSDS RECOMMENDATION FOR TC SYNCHRONIZATION AND CHANNEL CODING

AUTHORITY

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This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS Recommendations is detailed in reference [B1], and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This Recommendation is published and maintained by:

CCSDS Secretariat
Office of Space Communication (Code M-3)
National Aeronautics and Space Administration
Washington, DC 20546, USA

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space Agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommendations** and are not considered binding on any Agency.

This **Recommendation** is issued by, and represents the consensus of, the CCSDS Plenary body. Agency endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

– Whenever an Agency establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommendation**. Establishing such a **standard** does not preclude other provisions which an Agency may develop.

– Whenever an Agency establishes a CCSDS-related standard, the Agency will provide other CCSDS member Agencies with the following information:

  • The **standard** itself.

  • The anticipated date of initial operational capability.

  • The anticipated duration of operational service.

– Specific service arrangements are made via memoranda of agreement. Neither this Recommendation nor any ensuing standard is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this **Recommendation** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or, (3) be retired or canceled.

In those instances when a new version of a **Recommendation** is issued, existing CCSDS-related Agency standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each Agency to determine when such standards or implementations are to be modified. Each Agency is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommendation.

CCSDS RECOMMENDATION FOR TC SYNCHRONIZATION AND CHANNEL CODING

FOREWORD

This document is a technical Recommendation for use in developing synchronization and channel coding systems and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The synchronization and channel coding concept described herein is intended for missions that are cross-supported between Agencies of the CCSDS.

This Recommendation establishes a common framework and provides a common basis for the synchronization and channel coding schemes to be used by space missions with the TC Space Data Link Protocol (reference [1]) over ground-to-space and space-to-space communications links. This Recommendation was developed from an older CCSDS Recommendation [B2], which defines essentially the same schemes but in a slightly different context.

This Recommendation does not change the major technical content defined in [B2], but the presentation of the specification has been changed so that:

  a) these schemes can be used to transfer any data over any space link in either direction;

  b) all CCSDS space link protocols are specified in a unified manner;

  c) the layered model matches the Open Systems Interconnection (OSI) Basic Reference Model (reference [2]).

Together with the change in presentation, a few technical specifications in [B2] have been changed in order to define all Space Data Link Protocols in a unified way. Also, some technical terms in reference [B2] have been changed in order to unify the terminology used in all the CCSDS Recommendations that define space link protocols and to define these schemes as general communications schemes. These changes are listed in annex C of this Recommendation.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommendation is therefore subject to CCSDS document management and change control procedures, as defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

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CCSDS RECOMMENDATION FOR TC SYNCHRONIZATION AND CHANNEL CODING

At time of publication, the active Member and Observer Agencies of the CCSDS were:

<u>Member Agencies</u>

–   Agenzia Spaziale Italiana (ASI)/Italy.
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–   Swedish Space Corporation (SSC)/Sweden.
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DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 231.0-B-1	TC Synchronization and Channel Coding, Issue 1	September 2003	Original Issue

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CCSDS RECOMMENDATION FOR TC SYNCHRONIZATION AND CHANNEL CODING

1 INTRODUCTION

1.1 PURPOSE

The purpose of this Recommendation is to specify synchronization and channel coding schemes used with the Telecommand (TC) Space Data Link Protocol [1]. These schemes are to be used over ground-to-space or space-to-space communications links by space missions.

1.2 SCOPE

This Recommendation defines synchronization and channel coding schemes in terms of:

 a) the services provided to the users of this specification;

 b) data formats; and

 c) the procedures performed to generate and process the data formats.

It does not specify:

 a) individual implementations or products;

 b) the methods or technologies required to perform the procedures; or

 c) the management activities required to configure and control the system.

1.3 APPLICABILITY

This Recommendation applies to the creation of Agency standards and to the future data communications over space links between CCSDS Agencies in cross-support situations. This Recommendation includes comprehensive specification of the data formats and procedures for inter-Agency cross support. It is neither a specification of, nor a design for, real systems that may be implemented for existing or future missions.

The Recommendation specified in this document is to be invoked through the normal standards programs of each CCSDS Agency, and is applicable to those missions for which cross support, based on capabilities described in this Recommendation, is anticipated. Where mandatory capabilities are clearly indicated in sections of this Recommendation, they must be implemented when this document is used as a basis for cross support. Where options are allowed or implied, implementation of these options is subject to specific bilateral cross support agreements between the Agencies involved.

1.4 RATIONALE

The CCSDS believes it is important to document the rationale underlying the recommendations chosen, so that future evaluations of proposed changes or improvements will not lose sight of previous decisions.

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1.5 DOCUMENT STRUCTURE

This document is divided into seven numbered sections and four annexes:

a) section 1 presents the purpose, scope, applicability and rationale of this Recommendation and lists the conventions, definitions, and references used throughout the Recommendation;

b) section 2 provides an overview of synchronization and channel coding;

c) section 3 specifies the Bose-Chaudhuri-Hocquenghem (BCH) coding;

d) section 4 specifies the Communications Link Transmission Unit (CLTU);

e) section 5 specifies the randomizer;

f) section 6 specifies the Physical Layer Operations Procedures (PLOPs);

g) section 7 lists the managed parameters associated with synchronization and channel coding;

h) annex A lists acronyms and terms used within this document;

i) annex B provides a list of informative references;

j) annex C defines the service provided to the users;

k) annex D lists the changes from the older CCSDS Recommendation [B2].

1.6 CONVENTIONS AND DEFINITIONS

1.6.1 DEFINITIONS

1.6.1.1 Definitions from the Open Systems Interconnection (OSI) Basic Reference Model

This Recommendation makes use of a number of terms defined in reference [2]. The use of those terms in this Recommendation shall be understood in a generic sense; i.e., in the sense that those terms are generally applicable to any of a variety of technologies that provide for the exchange of information between real systems. Those terms are as follows:

a) Data Link Layer;

b) Physical Layer;

c) service;

d) service data unit.

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1.6.1.2 Definitions from OSI Service Definition Conventions

This Recommendation makes use of a number of terms defined in reference [3]. The use of those terms in this Recommendation shall be understood in a generic sense; i.e., in the sense that those terms are generally applicable to any of a variety of technologies that provide for the exchange of information between real systems. Those terms are as follows:

a) indication;

b) primitive;

c) request;

d) service provider;

e) service user.

1.6.1.3 Terms Defined in This Recommendation

For the purposes of this Recommendation, the following definitions apply. Many other terms that pertain to specific items are defined in the appropriate sections.

asynchronous: not *synchronous*.

Mission Phase: a period of a mission during which specified communications characteristics are fixed. The transition between two consecutive mission phases may cause an interruption of the communications services.

Physical Channel: a stream of bits transferred over a space link in a single direction.

space link: a communications link between a spacecraft and its associated ground system or between two spacecraft. A space link consists of one or more Physical Channels in one or both directions.

synchronous: a sequence of events occurring in a fixed time relationship (within specified tolerance) to another sequence of events.

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1.6.2   NOMENCLATURE

The following conventions apply throughout this Recommendation:

a)   the words 'shall' and 'must' imply a binding and verifiable specification;

b)   the word 'should' implies an optional, but desirable, specification;

c)   the word 'may' implies an optional specification;

d)   the words 'is', 'are', and 'will' imply statements of fact.

1.6.3   CONVENTIONS

In this document, the following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0'; the following bit is defined to be 'Bit 1' and so on up to 'Bit N-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 1-1).

BIT 0   BIT N-1

N-BIT DATA FIELD

FIRST BIT TRANSMITTED = MSB
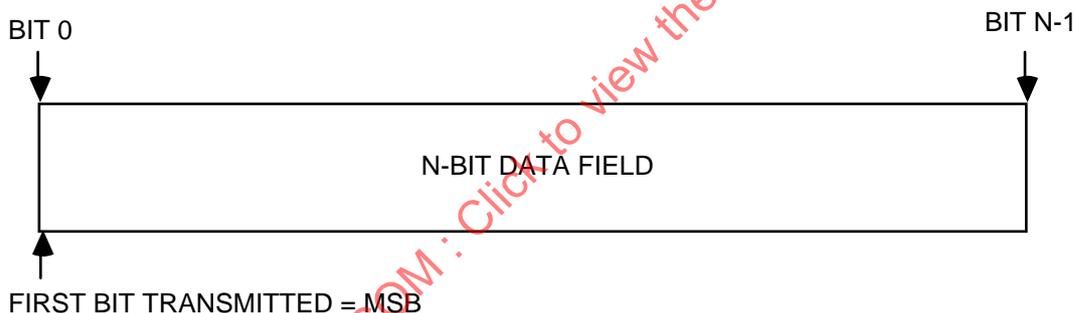
Figure 1-1:   Bit Numbering Convention

In accordance with standard data-communications practice, data fields are often grouped into 8-bit 'words' which conform to the above convention. Throughout this Recommendation, such an 8-bit word is called an 'octet'. The numbering for octets within a data structure starts with 0. By CCSDS convention, all 'spare' bits shall be permanently set to '0'.

1.7   REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommendation are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommendations.

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[1]   *TC Space Data Link Protocol.* Recommendation for Space Data Systems Standards, CCSDS 232.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[2]   *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model.* International Standard, ISO/IEC 7498-1. 2nd ed. Geneva: ISO, 1994.

[3]   *Information Technology—Open Systems Interconnection—Basic Reference Model— Conventions for the definition of OSI services.* International Standard, ISO/IEC 10731:1994. Geneva: ISO, 1994.

[4]   *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft.* Recommendation for Space Data Systems Standards, CCSDS 401.0-B. Blue Book. Washington, D.C.: CCSDS, March 2003.

NOTE   –   Informative references are listed in annex B.

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2 OVERVIEW

2.1 ARCHITECTURE

Figure 2-1 illustrates the relationship of this Recommendation to the Open Systems Interconnection (OSI) reference model (reference [2]). Two sublayers of the Data Link Layer are defined for CCSDS space link protocols. The TC Space Data Link Protocols specified in reference [1] corresponds to the Data Link Protocol Sublayer, and provides functions for transferring data using the protocol data unit called the Transfer Frame. The Synchronization and Channel Coding Sublayer provides additional functions necessary for transferring Transfer Frames over a space link. These functions are error-control coding/decoding, delimiting/synchronizing codeblocks, and bit transition generation/removal.

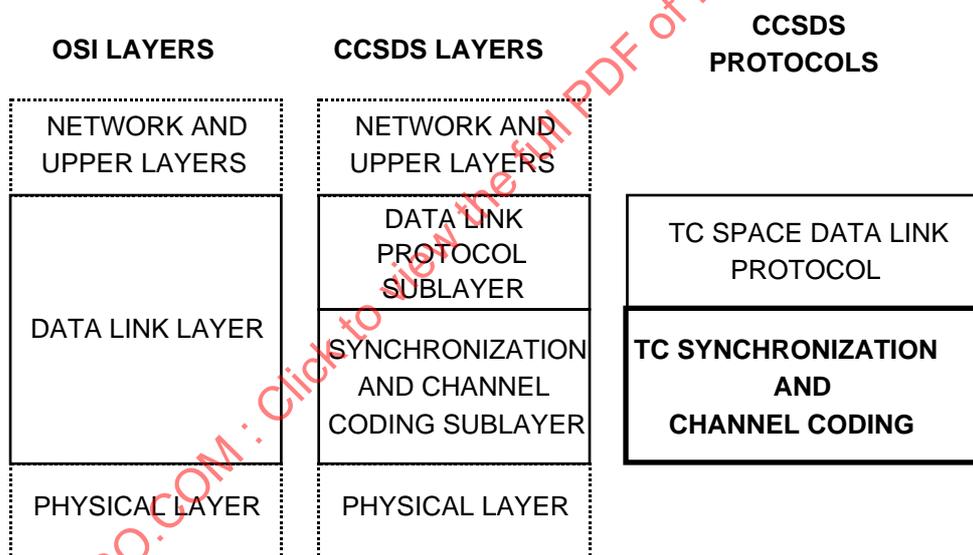| OSI LAYERS	CCSDS LAYERS	CCSDS PROTOCOLS
NETWORK AND UPPER LAYERS	NETWORK AND UPPER LAYERS	
DATA LINK LAYER	DATA LINK PROTOCOL SUBLAYER	TC SPACE DATA LINK PROTOCOL
	SYNCHRONIZATION AND CHANNEL CODING SUBLAYER	**TC SYNCHRONIZATION AND CHANNEL CODING**
PHYSICAL LAYER	PHYSICAL LAYER	

Figure 2-1: Relationship with OSI Layers

2.2 SUMMARY OF FUNCTIONS

2.2.1 FUNCTIONS

The Synchronization and Channel Coding Sublayer provides the following three functions for transferring Transfer Frames over a space link:

  a) error-control coding;

  b) synchronization; and

  c) pseudo-randomizing (optional).

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2.2.2   ERROR-CONTROL CODING

This Recommendation specifies an error-control coding method using a modified BCH code. This is described in section 3.

The modified BCH code specified in this Recommendation may be decoded either in an error-detecting mode or in an error-correcting mode, depending on mission requirements. If the modified BCH code is decoded in an error-detecting mode, the Frame Error Control Field (FECF) defined in reference [1] may be used to reduce the probability of undetected errors.

NOTE   –   In this Recommendation, the characteristics of the codes are specified only to the extent necessary to ensure interoperability and cross-support. The specification does not attempt to quantify the relative coding gain or the merits of each approach discussed, nor the design requirements for encoders or decoders.

2.2.3   SYNCHRONIZATION

This Recommendation specifies a method for synchronizing BCH Codeblocks using a data unit called the Communications Link Transmission Unit (CLTU), which consists of a Start Sequence, BCH Codeblocks, and a Tail Sequence. This is described in section 4.

The Start Sequence of the CLTU may also be used for resolution of data ambiguity (sense of '1' and '0') if data ambiguity is not resolved by the modulation method used in the Physical Layer.

This Recommendation also specifies a procedure called the Physical Layer Operations Procedure (PLOP) for activating and deactivating the physical communications channel so that the Physical Layer of the receiving end can achieve and maintain bit synchronization.

NOTE   –   Although PLOP belongs to the Physical Layer, it is included in this Recommendation because it must be used to transmit CLTUs specified in this document. The other specifications of the Physical Layer are contained in reference [4].

2.2.4   PSEUDO-RANDOMIZING

This Recommendation specifies an optional randomizer to improve bit transition density as an aid to bit synchronization. This is described in section 5.

NOTE   –   For brevity, the word 'random' is used in place of 'pseudo-random' throughout this document. See annex A.

2.3   INTERNAL ORGANIZATION OF SUBLAYER

2.3.1   SENDING END

Figure 2-2 shows the internal organization of the Synchronization and Channel Coding Sublayer of the sending end. This figure identifies functions performed by the sublayer and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system.

At the sending end, the Synchronization and Channel Coding Sublayer accepts Transfer Frames from the Data Link Protocol Sublayer (see figure 2-1), performs functions selected for the mission, and delivers CLTUs to the Physical Layer. If necessary, fill bits are added either before or after randomization to complete the integral number of BCH Codeblocks. The Physical Layer transmits CLTUs using the PLOP.
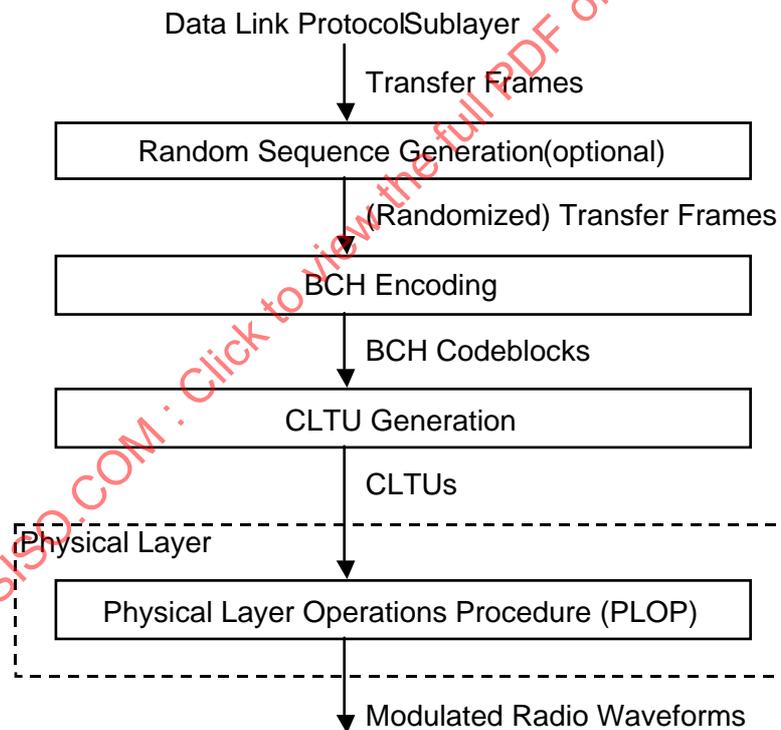
Figure 2-2: Internal Organization of the Sublayer at the Sending End

2.3.2   RECEIVING END

Figure 2-3 shows the internal organization of the Synchronization and Channel Coding Sublayer of the receiving end. This figures identifies functions performed by the sublayer and shows logical relationships among these functions. The figure is not intended to imply any hardware or software configuration in a real system.

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At the receiving end, the Synchronization and Channel Coding Sublayer accepts streams of channel bits together with information on the state of the physical communications channel from the Physical Layer, performs functions selected for the mission, and delivers Transfer Frames (possibly incomplete or with fill bits) to the Data Link Protocol Sublayer.

Data Link ProtocolSublayer

↑ Transfer Frames (+Fill)

| Random Sequence Removal (optional) |

↑ (Randomized) Transfer Frames (+Fill)

| BCH Decoding |

↑ BCH Codeblocks+Tail Sequence

| Search for Start Sequence |

↑ Channel Bits

Physical Layer

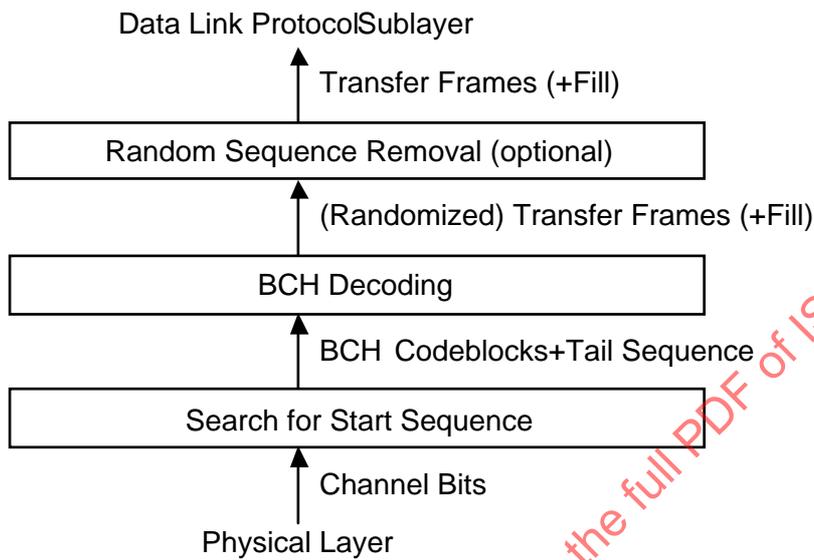**Figure 2-3: Internal Organization of the Sublayer at the Receiving End**

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3   BCH CODING

3.1   INTRODUCTION

The Synchronization and Channel Coding Sublayer establishes the reliable, error-controlled data channel through which user data bits may be transferred. The data are encoded to reduce the effects of noise in the Physical Layer on the user data. A modified Bose-Chaudhuri-Hocquenghem (BCH) code has been chosen to provide this protection.

3.2   CODEBLOCK FORMAT

3.2.1   The BCH Codeblock format is a fixed-length data entity shown in figure 3-1. The Codeblock is formulated using a systematic coding technique which contains 56 information bits in the leading octets, and the error control bits in the last octet. The BCH Codeblock contains an integer number of octets with an overall length of 8 octets (64 bits).
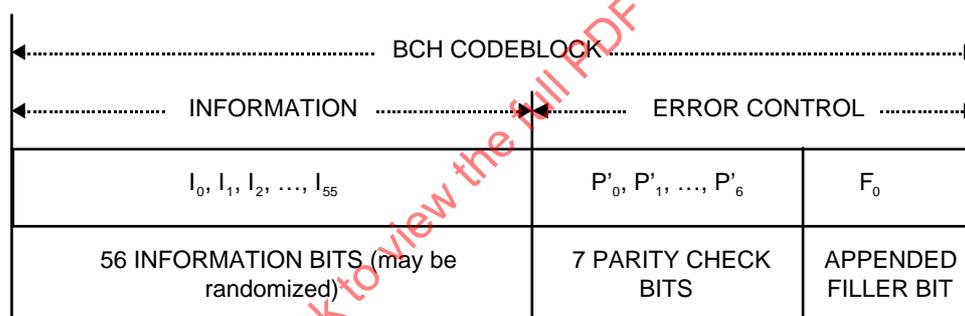

BCH CODEBLOCK		
INFORMATION	ERROR CONTROL	
$I_0, I_1, I_2, …, I_{55}$	$P'_0, P'_1, …, P'_6$	F_0
56 INFORMATION BITS (may be randomized)	7 PARITY CHECK BITS	APPENDED FILLER BIT

Figure 3-1: BCH Codeblock Format

3.2.2   The COMPLEMENTS of the seven parity check bits, P_0 through P_6, are located in the first seven bits of the last octet of the BCH Codeblock. The complements are used to aid in maintaining bit synchronization and detection of bit slippage. The encoding procedure for generating these parity bits is described in 3.3.

3.2.3   The last bit of the last octet, F_0, is a Filler Bit appended to provide an overall Codeblock length which is an integer number of octets. This Filler Bit shall always be a zero.

3.3   ENCODING PROCEDURE

3.3.1   A systematic block coding procedure shall be used which always generates 7 parity check bits per Codeblock and which shall always be computed from 56 information bits. The parity check bits are then COMPLEMENTED and placed into the Codeblock as shown in figure 3-1.

3.3.2   The code used is a (63,56) modified Bose-Chaudhuri-Hocquenghem (BCH) code which uses the following generator polynomial to produce the seven parity bits:

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$$g(x) = x^7 + x^6 + x^2 + 1$$

NOTE – The code generator implementation is shown in figure 3-2. The shift registers are initialized to zero. The ganged switch is in position 1 while the 56 information bits are being transmitted, in position 2 for the seven parity bits, and in position 3 for the appended Filler Bit.
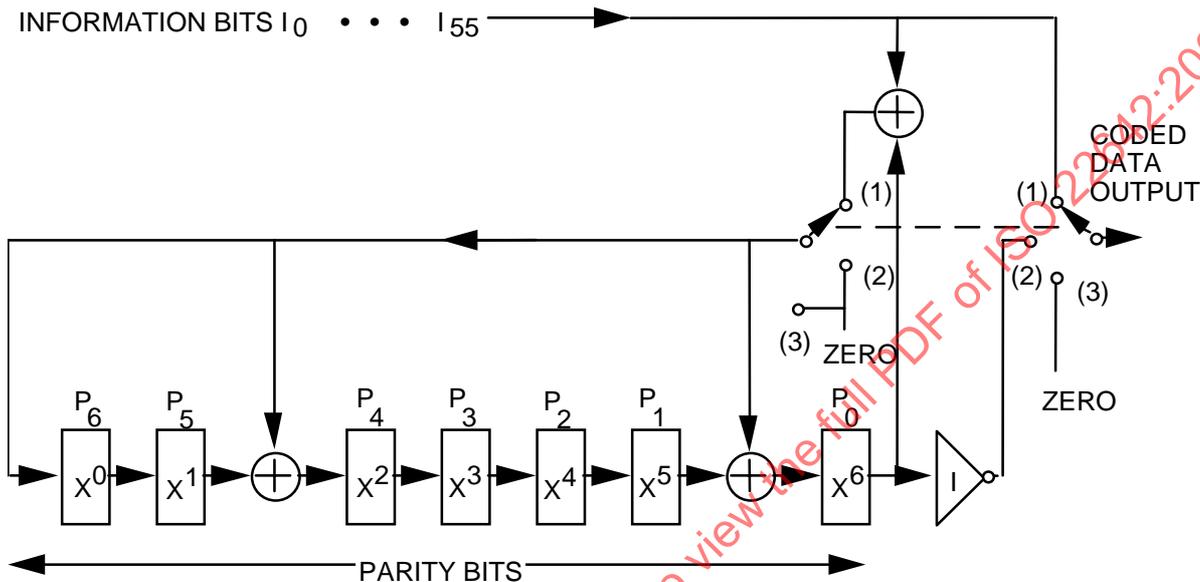

Figure 3-2: (63,56) Modified BCH Code Generator

3.4 FILL BITS

3.4.1 If the Transfer Frame(s) to be transmitted in a Communications Link Transmission Unit (CLTU) do not fit exactly within an integral number of BCH Codeblocks, then the last octet(s) and ONLY the last octet(s) of the information field of the last Codeblock within the CLTU may contain 'Fill' bits. The pattern of the fill shall consist of a sequence of alternating 'ones' and 'zeros', starting with a 'zero'.

3.4.2 The Synchronization and Channel Coding Sublayer may require the introduction of these fill bits in the encoding process; they are not removed by the decoding process. Removal of fill is the responsibility of the sublayer above, which delimits the end of the Transfer Frame(s) and discards extraneous bits (e.g., fill).

3.4.3 If randomization is used, the fill bits mentioned above shall be added either before or after randomization.

NOTE – If randomization is being used, any fill octets that were added to the last Codeblock of the CLTU will be derandomized even if they were not randomized.

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3.5   DECODING PROCEDURE

Codeblocks that have been encoded using the modified BCH code described in 3.3 may be decoded either in an error-detecting mode (Triple Error Detection, or TED) or in an error-correcting mode (Single Error Correction, or SEC), depending on mission requirements. When the error-detecting mode is chosen, one, two or three bits in error will be detected within the Codeblock (not counting the appended Filler Bit); when the error-correcting mode is chosen, one bit in error will be corrected and two bits in error will be detected.

NOTE – The decoding procedure described in 3.5 assumes the use of a hard-limiting detector before decoding, but the use of a soft-limiting detector is not intended to be precluded.

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4 COMMUNICATIONS LINK TRANSMISSION UNIT

4.1 INTRODUCTION

4.1.1 Synchronization for the Codeblock and delimiting of the beginning of user data are provided by the Communications Link Transmission Unit (CLTU) data structure.

4.1.2 Resolution of data ambiguity (sense of '1' and '0') when receiving the symbol stream shall be a service of the Synchronization and Channel Coding Sublayer if it is not performed by the Physical Layer (e.g., with a differential modulation technique). In the Synchronization and Channel Coding Sublayer, ambiguity resolution shall use inherent information in the CLTU Start Sequence.

4.2 CLTU UNIT FORMAT

4.2.1 STRUCTURE OF CLTU

The CLTU is the data structure which carries the data as a contiguous series of encoded BCH Codeblocks across the Synchronization and Channel Coding Sublayer. The data contained in the BCH Codeblocks in the CLTU consist of Transfer Frame(s) from the sublayer above (possibly with fill bits). The CLTU has the structural components shown in figure 4-1.
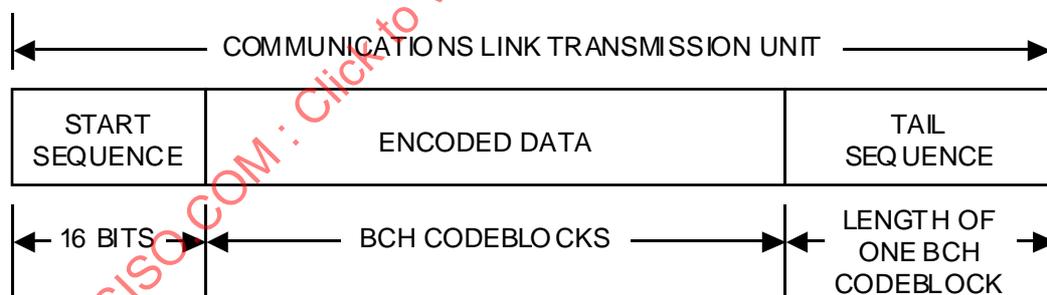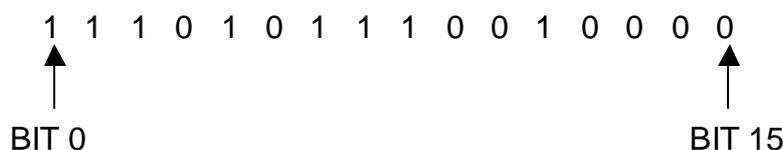

Figure 4-1: Components of the CLTU

4.2.2 START SEQUENCE

The CLTU Start Sequence field shall delimit the start of the encoded data within the CLTU. It consists of a 16-bit synchronization pattern with low autocorrelation side lobes and shall have the following pattern:

1 1 1 0 1 0 1 1 1 0 0 1 0 0 0 0

BIT 0   BIT 15

4.2.3 ENCODED DATA

The Encoded Data field shall consist of a set of BCH Codeblocks which have been encoded in accordance with the BCH Codeblock encoding procedure. In addition to error control bits, these Codeblocks contain the Transfer frame(s), plus any fill bits that were appended to meet codeblock length constraints. The Transfer Frames contained in the Encoded Data field may have been randomized before encoding, or not randomized, as selected for the mission.

4.2.4 TAIL SEQUENCE

The CLTU Tail Sequence field is a data structure which is constructed specifically to be a noncorrectable sequence which delimits the end of a CLTU by stopping the decoding process. The Tail Sequence shall have the same length as the BCH Codeblock that is being used. The Tail Sequence shall consist of leading octets having the pattern 11000101, repeated as necessary until the next-to-last octet of the Tail Sequence field is reached. The last octet completes the Tail Sequence field, and always has the pattern 01111001. Therefore, the bit pattern for the standard Tail Sequence may be described as follows:

<p align="center">Tail Sequence Pattern</p>

<p align="center">11000101 11000101 11000101 11000101 11000101 11000101 11000101 01111001</p>

NOTE – A pattern of alternating 'zeros' and 'ones' identical to the Idle Sequence throughout the length of a Codeblock was defined in the first issue of reference [B2]. The new pattern introduced later and specified above is preferred for new designs because of its improved performance.

4.3 CLTU RECEPTION LOGIC

The CLTU Reception Logic at the receiving end is presented in state diagram form (figure 4-2). To support the state diagrams, a list of 'states' and 'events' is given in tables 4-1 and 4-2. There are three states and four events.
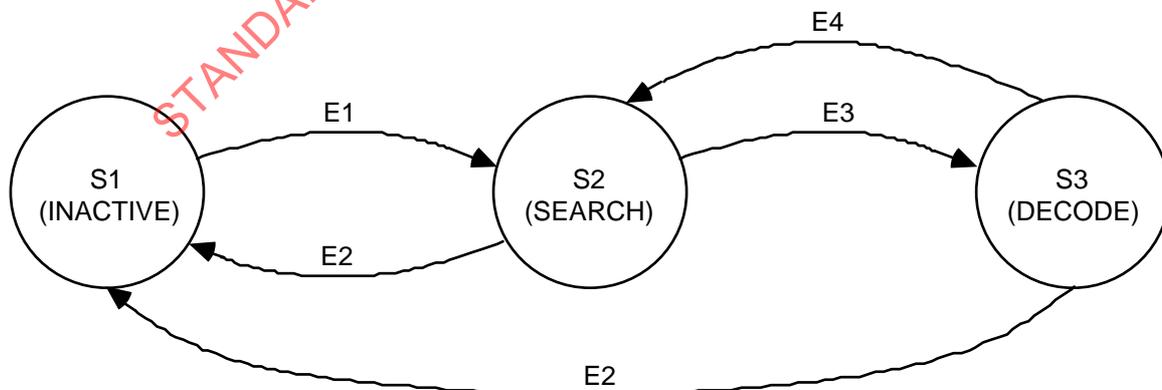
Figure 4-2: CLTU Reception State Diagram (Receiving End)

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Table 4-1: CLTU Reception States (Receiving End)

State Number	State Name	State Definition
S1	INACTIVE	The communications channel is INACTIVE (i.e., 'no bit lock is achieved', or, alternatively, 'no bit modulation is detected').
S2	SEARCH	The incoming bit stream is searched, bit by bit, for the Start Sequence pattern.
S3	DECODE	BCH Codeblocks, which are either free of error or which can be corrected, are received, decoded, and derandomized (if used), and their contents are transferred to the sublayer above.

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Table 4-2: CLTU Reception Events (Receiving End)

Event Number	Event Name	Event Definition
E1	CHANNEL ACTIVATION	Bit modulation is detected and bit lock is achieved: channel bit stream is present.
E2	CHANNEL DEACTIVATION	Bit lock is lost or communications signal is lost: channel bit stream is NOT present.
E3	START SEQUENCE FOUND	The Start Sequence pattern has been detected, signaling the beginning of the first Codeblock of the CLTU.
E4	CODEBLOCK REJECTION	The decoder has indicated uncorrected errors in a Codeblock. No data from this Codeblock are transferred to the sublayer above.

NOTE – In the search for the Start Sequence in State 2, no error in the Start Sequence is allowed if the modified BCH code is decoded in the error-detecting mode; one error in the Start Sequence is allowed if the modified BCH code is decoded in the error-correcting mode.

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5   RANDOMIZER

5.1   INTRODUCTION

5.1.1   In order to maintain bit (or symbol) synchronization with the received communications signal, every data capture system at the receiving end requires that the incoming signal must have a minimum bit transition density (see subsection 2.2.3 in reference [4]).

5.1.2   In order to ensure proper receiver operation, the data stream must be sufficiently random. The Pseudo-Randomizer defined in this section is the preferred method to ensure sufficient randomness for all combinations of CCSDS-recommended modulation and coding schemes. The Pseudo-Randomizer defined in this section is required unless the system designer verifies proper operation of the system if this Randomizer is not used.

5.1.3   The presence or absence of randomization is fixed for a Physical Channel and is managed (i.e., its presence or absence is not signaled but must be known a priori by the receiver). A random sequence is exclusively ORed with the **Transfer Frame(s)** to increase the frequency of bit transitions. On the receiving end, the same random sequence is exclusively ORed with the decoded data, restoring the original data form. The random sequence is generated by the Bit Transition Generator (BTG).

5.2   RANDOMIZER DESCRIPTION

The random sequence shall be generated using the following polynomial:

$$h(x) = x^8 + x^6 + x^4 + x^3 + x^2 + x + 1$$

This sequence repeats after 255 bits, continuing as needed. The first 40 bits of the sequence are

    1111   1111   0011   1001   1001   1110   0101   1010   0110   1000

    Increasing Time---------------------------------->

NOTE   –   Figure 5-1 depicts a basic logic diagram of the BTG.

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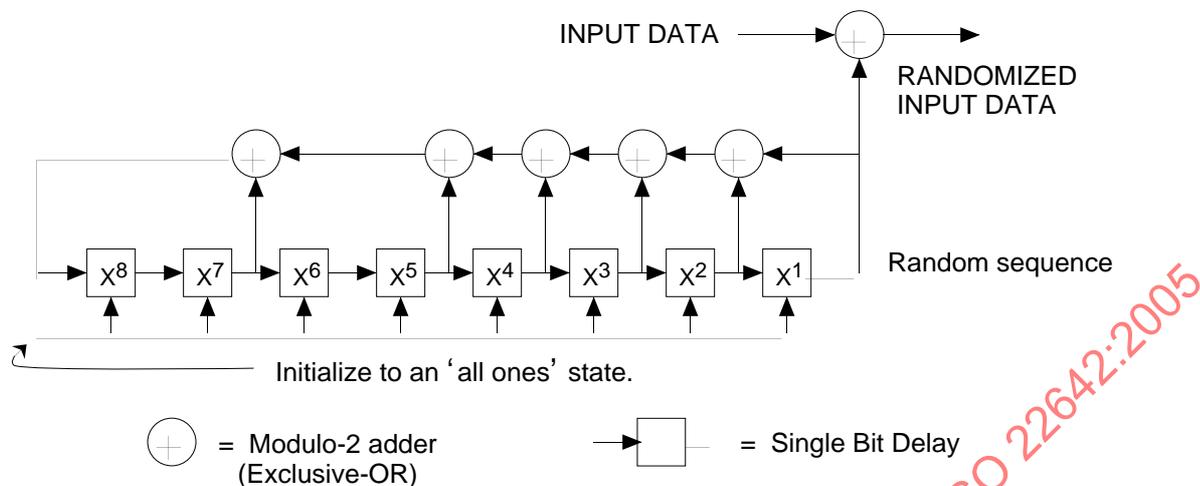CCSDS RECOMMENDATION FOR TC SYNCHRONIZATION AND CHANNEL CODING

Figure 5-1: Bit Transition Generator Logic Diagram

5.3   APPLICATION OF THE RANDOMIZER

5.3.1   The randomization shall be applied at the transmitting end, and it shall be applied only to the Transfer Frame(s). The BTG shall be preset to the 'all-ones' state at the start of Transfer Frame(s) and then shall be exclusively ORed, bit by bit, with the Transfer Frame(s) until the process ends with the last bit of the Transfer Frame(s) to be transmitted in a CLTU.

5.3.2   The randomization may also be applied to the fill bits added after the end of the Transfer Frame(s) to complete the last Codeblock of the CLTU, but doing so is optional.

5.3.3   At the receiving end, the derandomization shall be applied to the successfully decoded data. The BTG remains in the 'all-ones' state until the CLTU Start Sequence has been detected. The BTG pattern shall be exclusively ORed, bit by bit, to the successfully decoded data (after the Error Control Bits have been removed). The BTG shall be reset to the 'all-ones' state following a failure of the decoder to successfully decode a BCH Codeblock or other loss of data.

6 PHYSICAL LAYER OPERATIONS PROCEDURES

6.1 INTRODUCTION

6.1.1 Operations within the Physical Layer begin with the activation of the physical communications channel by invoking the radio frequency carrier and modulation techniques. These techniques include provision of any required subcarrier(s) and data modulation in order to establish the physical connection from the transmitter to the receiver. During a communications session, a series of CLTUs is transmitted to the receiver. The session ends with the removal of the carrier.

6.1.2 The Physical Layer Operations Procedures (PLOPs) specify the sequence of operations performed during a communications session. Two procedures, PLOP-1 and PLOP-2, are currently defined. The selection of PLOPs is mission-specific.

6.2 DATA FORMATS

6.2.1 GENERAL

The data formats used by the PLOPs are:

   a) the Acquisition Sequence;

   b) CLTU; and

   c) the Idle Sequence.

They are used to provide synchronization of the symbol stream, and are described in subsections 8.2.2 through 8.2.4.

6.2.2 ACQUISITION SEQUENCE

The Acquisition Sequence is a data structure forming a preamble which provides for initial symbol synchronization within the incoming stream of detected symbols. The length of the Acquisition Sequence shall be selected according to the communications link performance requirements of the mission, but the preferred minimum length is 16 octets. The length is not required to be an integral multiple of octets. The pattern of the Acquisition Sequence shall be alternating 'ones' and 'zeros', starting with either a 'one' or a 'zero'.

6.2.3 CLTU

The CLTU is the data structure (symbol sequence) furnished from the Synchronization and Channel Coding Sublayer, and defined in 4.2. It contains the data symbols that are to be transmitted to the receiving end. Each Codeblock within the CLTU, having the format specified in 3.2, shall provide at least 2 data transitions per Codeblock. If the receiver symbol synchronization design necessitates more frequent transitions, either the CLTU as

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delivered to the Physical Layer must have been randomized as described in section 5, or the Physical Layer must invoke a technique (modulation type, phase-coherent data and subcarrier, or other) to guarantee sufficiently frequent transitions for adequate symbol synchronization.

6.2.4   IDLE SEQUENCE

The Idle Sequence is the data structure which provides for maintenance of symbol synchronization in the absence of CLTUs. The bit pattern is a sequence of alternating 'ones' and 'zeros'. The length of the Idle Sequence is an unconstrained number of bits.

NOTE –   In the first issue of reference [B2], the Idle Sequence was constrained to begin with a 'zero' to be continuous with the CLTU Tail Sequence. Because of the improved performance of the Tail Sequence introduced later and specified in this Recommendation, the constraint is no longer necessary.

6.3   CARRIER MODULATION MODES

6.3.1   A PLOP consists of a sequential application of the various Carrier Modulation Modes (CMMs) in order to activate and deactivate the physical communications channel.

6.3.2   CMMs consist of different states of data modulation upon the RF carrier which creates the physical communications channel. The physical methods of modulating the carrier are described in reference [4]. The Carrier Modulation Modes are shown in table 6-1.

Table 6-1: Carrier Modulation Modes

Mode	State
CMM-1	Unmodulated CARRIER only
CMM-2	CARRIER modulated with ACQUISITION SEQUENCE
CMM-3	CARRIER modulated with CLTU
CMM-4	CARRIER modulated with IDLE SEQUENCE

6.4   PLOP-1

6.4.1   PLOP-1 is a procedure for individually radiating CLTUs, whereby the receiver is always forced into the INACTIVE state (S1) (see 4.3) by deactivating the physical communications channel after the end of transmission of each CLTU (or CLTU followed by an Idle Sequence).

6.4.2 PLOP-1 invokes the sequence of CMMs shown in figure 6-1.   Note that 'unmodulated' is defined as the state in which no *data* modulation is present.
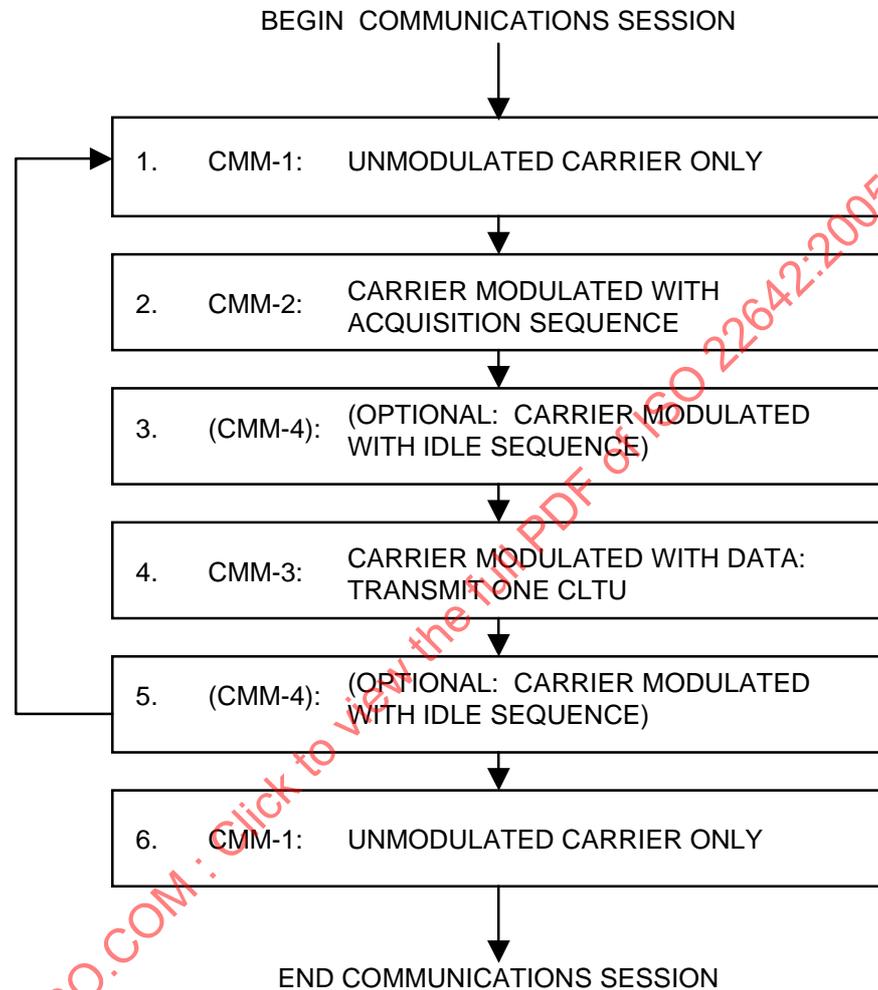
BEGIN COMMUNICATIONS SESSION

1.	CMM-1:	UNMODULATED CARRIER ONLY
2.	CMM-2:	CARRIER MODULATED WITH ACQUISITION SEQUENCE
3.	(CMM-4):	(OPTIONAL: CARRIER MODULATED WITH IDLE SEQUENCE)
4.	CMM-3:	CARRIER MODULATED WITH DATA: TRANSMIT ONE CLTU
5.	(CMM-4):	(OPTIONAL: CARRIER MODULATED WITH IDLE SEQUENCE)
6.	CMM-1:	UNMODULATED CARRIER ONLY

END COMMUNICATIONS SESSION

Figure 6-1: Sequence of CMMs Composing PLOP-1

6.5   PLOP-2

6.5.1 PLOP-2 is a procedure whereby the physical communications channel is not deactivated after each transmitted CLTU. The termination of an individual CLTU shall be provided only through the data path, using the CLTU Tail Sequence and, optionally, Idle Sequence. This places the receiver in the SEARCH state (S2) (see 4.3) after each CLTU. The receiver is forced into the INACTIVE state (S1) by deactivating the physical communications channel only at the end of transmission of a series of CLTUs, which may or may not be followed by an Idle Sequence.

6.5.2 It should be noted that when operating with PLOP-2, it is recommended that a minimum Idle Sequence of one octet be systematically inserted between each CLTU to eliminate the small but finite possibility of synchronization lockout. Such a lockout may

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occur if the start pattern of one CLTU is not detected (leaving the receiver in SEARCH state) and a start pattern exists over the last bits of the last Transfer Frame of that CLTU and the first bits of its Tail Sequence. This creates an erroneous but temporary CLTU start (DECODE state), causing the true start of the following CLTU to be missed. The added Idle Sequence prevents this from happening.

6.5.3 PLOP-2 invokes the sequence of CMMs shown in figure 6-2. Note that 'unmodulated' is defined as the state in which no *data* modulation is present.

BEGIN COMMUNICATIONS SESSION

1.	CMM-1:	UNMODULATED CARRIER ONLY
2.	CMM-2:	CARRIER MODULATED WITH ACQUISITION SEQUENCE
3.	(CMM-4):	(OPTIONAL: CARRIER MODULATED WITH IDLE SEQUENCE)
4.	CMM-3:	CARRIER MODULATED WITH DATA: TRANSMIT ONE CLTU
5.	(CMM-4):	(OPTIONAL: CARRIER MODULATED WITH IDLE SEQUENCE)
6.	REPEAT (4) AND (5) FOR EACH CLTU	
7.	CMM-1:	UNMODULATED CARRIER ONLY

END COMMUNICATIONS SESSION
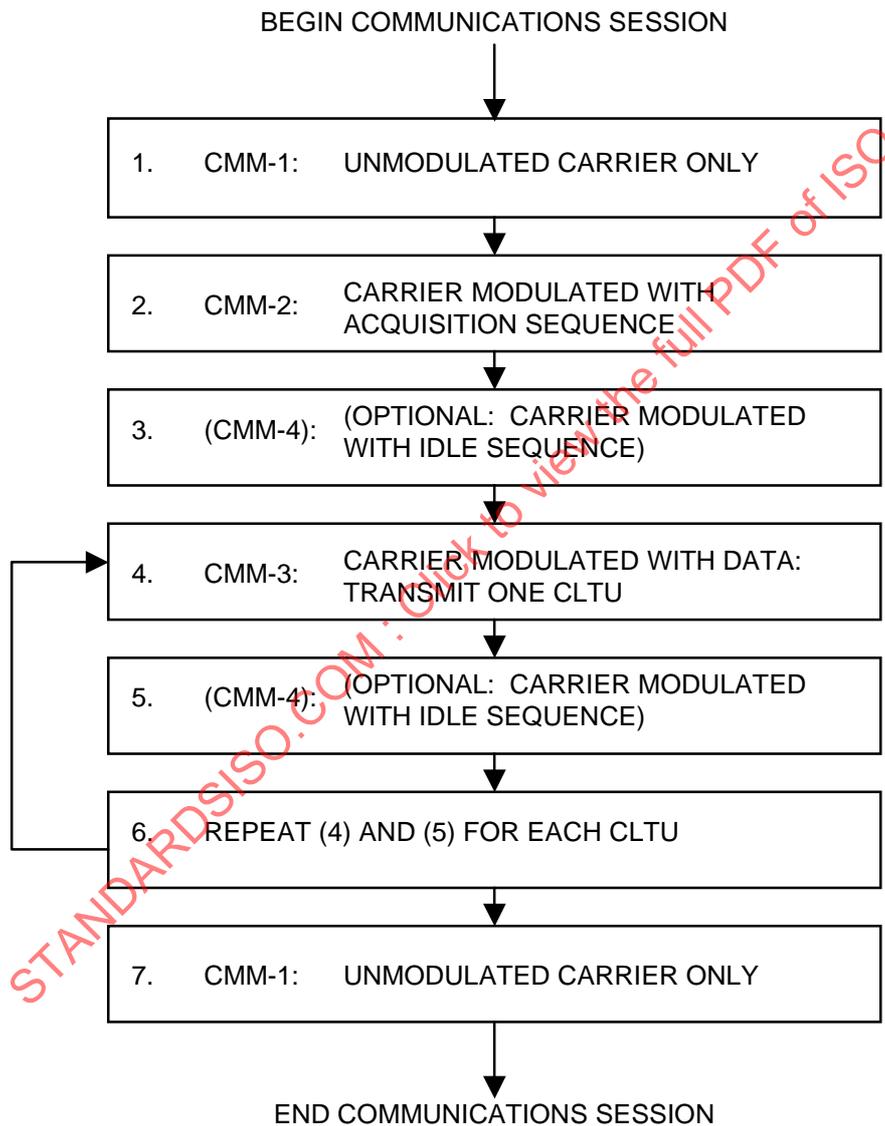
Figure 6-2: Sequence of CMMs Composing PLOP-2

7 MANAGED PARAMETERS

7.1 OVERVIEW OF MANAGED PARAMETERS

In order to conserve bandwidth on the space link, some parameters associated with synchronization and channel coding are handled by management rather than by inline communications protocol. The managed parameters are those which tend to be static for long periods of time, and whose change generally signifies a major reconfiguration of the synchronization and channel coding systems associated with a particular mission. Through the use of a management system, management conveys the required information to the synchronization and channel coding systems.

In this section, the managed parameters used by synchronization and channel coding systems are listed. These parameters are defined in an abstract sense and are not intended to imply any particular implementation of a management system.

7.2 MANAGED PARAMETERS FOR BCH CODING

Table 7-1 lists the managed parameters for BCH coding.

Table 7-1: Managed Parameters for BCH Coding

Managed Parameter	Allowed Values
Decoding Mode	Error-Detecting, Error-Correcting

7.3 MANAGED PARAMETERS FOR CLTU

Table 7-2 lists the managed parameters for CLTU.

Table 7-2: Managed Parameters for CLTU

Managed Parameter	Allowed Values
Maximum CLTU Length (octets)	Integer
Allowed Number of Errors in Start Sequence	0, 1

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7.4 MANAGED PARAMETERS FOR THE RANDOMIZER

Table 7-3 lists the managed parameters for the randomizer.

Table 7-3: Managed Parameters for Randomizer

Managed Parameter	Allowed Values
Randomizer	Used, Not used

7.5 MANAGED PARAMETERS FOR PLOPS

Table 7-4 lists the managed parameters for PLOPs.

Table 7-4: Managed Parameters for PLOPs

Managed Parameter	Allowed Values
Physical Layer Operations Procedure	PLOP-1, PLOP-2

ANNEX A

ACRONYMS AND TERMS

(This annex **is not** part of the Recommendation)

This annex lists key acronyms and terms that are used throughout this Recommendation to describe synchronization and channel coding.

A1   ACRONYMS

BCH   Bose-Chaudhuri-Hocquenghem

BTG   Bit Transition Generator

CCSDS   Consultative Committee For Space Data Systems

CLTU   Communications Link Transmission Unit

CMM   Carrier Modulation Mode

FECF   Frame Error Control Field

MSB   Most Significant Bit

NRZ-M   Non-Return-to-Zero-Mark

PLOP   Physical Layer Operations Procedure

A2   TERMS

Acquisition Sequence: A specific high transition density bit pattern transmitted to permit the receiving end to acquire symbol synchronization.

Bit Transition Generator: A generator that produces a specific random sequence of 255 bits to be ORed with the Transfer Frame(s) to increase the frequency of bit transitions (between '1' and '0'). No additional bits are added by this process.

Carrier Modulation Mode: The mode of modulation determined by the data type being used to modulate the RF carrier or subcarrier.

Synchronization and Channel Coding Sublayer: That sublayer of the Data Link Layer used by CCSDS space link protocols which uses a prescribed coding technique to reliably transfer Transfer Frames through the potentially noisy Physical Layer.

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Codeblock: A fixed-length data entity containing information and check bits that have been structured by an encoding algorithm.

Communications Link Transmission Unit: A Synchronization and Channel Coding Sublayer data entity which is used to synchronize and delimit the beginning of a continuum of bits consisting of a Start Sequence followed by an integral number of Codeblocks and a Tail Sequence.

Communications Session: A continuous period of time during which the signal path is established for the communications channel.

Data Link Layer: The layer which provides means for transferring data supplied by users (i.e., Network Layer entities) using the capability provided by the Physical Layer. It detects and possibly corrects error which may occur in the Physical Layer.

Decoding (Hard Decision): A Synchronization and Channel Coding Sublayer algorithmic process which utilizes the check bits contained in a Codeblock for detecting or correcting errors in the information bits. The check bits are then removed before the information bits are outputted.

Decoding (Soft Decision): A Synchronization and Channel Coding Sublayer algorithmic process which uses quantization of the detector output into *n* levels for each received bit to decide upon the most likely Codeblock and to estimate the reliability of that decision. The check bits are then removed before the best-estimate information bits and any reliability information is outputted.

Encoded Data: The data contained in a Codeblock.

Encoding: As used in this document, a Synchronization and Channel Coding Sublayer algorithmic process which adds check bits to a series of information bits to create a Codeblock.

Event: As used in this document, an action which causes the CLTU Reception Logic to change states.

Fill: Bits appended by the Synchronization and Channel Coding Sublayer to the Transfer Frame(s) to enable the data entity to exactly fit an integer number of Codeblocks. These fill bits ARE transmitted and must be removed by the sublayer above. The pattern of the Fill shall consist of a sequence of alternating 'ones' and 'zeros' starting with a 'zero'.

Filler Bit: The last bit of the last octet of a BCH Codeblock to provide an overall codeblock length which is an integer number of octets. The Filler Bit shall always be a zero.

Idle Sequence: A specific high transition density bit pattern transmitted during a communications session in the absence of a CLTU to maintain symbol synchronization in the channel.