International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.2047-0

(12/2013)

Detailed specifications of the satellite radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)

M Series

Mobile, radiodetermination, amateur and related satellite services

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Foreword

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RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2014

RECOMMENDATION ITU-R M.2047-0

Detailed specifications of the satellite radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)

(2013)

Scope

This Recommendation identifies the satellite radio interface technologies of International Mobile Telecommunications-Advanced (IMT-Advanced) and provides the detailed radio interface specifications.

These radio interface specifications detail the features and parameters of the satellite component of IMT-Advanced. This Recommendation includes the capability to ensure worldwide compatibility, international roaming and access to high-speed data services.

Keywords

Satellite; radio interface; IMT-Advanced; SAT-OFDM; BMSat.

Abbreviations/Glossary

3GPP	Third generation partnership project
ACK	Acknowledgement
AI	Acquisition indicator
AM	Acknowledge mode
AMC	Adaptive modulation and coding
ARQ	Automatic repeat request
AS	Access stratum
3GPP	3rd Generation partnership project
BCCH	Broadcast control channel
BCH	Broadcast channel
BPSK	Binary phase shift keying
BSR	Buffer status reporting
CCCH	Common control channel
CCE	Control channel element
CCSA	China communications standards association
CFI	Control format indicator
CGC	Complementary ground component
CoMT	Coordinated multi-point transmission
CP	Cyclic prefix
CQI	Channel quality information
CRC	Cyclic redundancy check
CRS	Cell-specific reference signals
C-RNTI	Control-radio network temporary identifier

CSI	Channel state information
DCCH	Dedicated control channel
DCI	Downlink control information
DFT	Discrete Fourier transform
DFTS-OFDM	Discrete Fourier transform-spread orthogonal frequency division multiplexing
DL	Downlink
DL-SCH	Downlink shared channel
DM-RS	Demodulation reference signals
DSAT-eNB	Donor satellite eNodeB
DTCH	Dedicated traffic channel
ECR	Efficient code rate
EF	Envelop fluctuation
EIRP	Equivalent isotropically radiated power
E-PPCH	Enhanced physical paging channel
E-USRA	Evolved universal satellite radio access
E-USRAN	Evolved universal satellite radio access network
FEC	Forward error correction
FDD	Frequency division duplexing
FDMA	Frequency division multiple access
FFR	Fractional frequency reuse
FSTD	Frequency switched transmit diversity
GBR	Guaranteed bit rate
GEO	Geostationary earth orbit
GNSS	Global navigation satellite system
GPS	Global positioning system
GSO	Geostationary-satellite orbit
G/T	Antenna gain-to-noise temperature
GTP	General packet radio service tunnelling protocol
HARQ	Hybrid ARQ
HEO	Highly elliptical orbit
HI	HARQ indicator
IBIC	Inter-beam interference coordination
ID	Identity
IFFT	Inverse fast Fourier transform
IMAP	Internet message access protocol
IMT	International Mobile Telecommunications

IP	Internet protocol
ITS	Intelligent transport systems
IU	Interleaving unit
L2	Layer 2
LCID	Logical channel identifier
LEO	Low earth orbit
LHCP	Left hand circular polarisation
LTE	Long term evolution
MAC	Medium access control
MBMS	Multimedia broadcast and multicast service
MBSFN	Multicast/broadcast over a single frequency network
MCCH	Multicast control channel
MCH	Multicast channel
MCS	Modulation and coding scheme
MEO	Medium earth orbit
MES	Mobile earth station
MIMO	Multiple input and multiple output antennas
MME	Mobility management entity
MMEC	Mobility management entity code
MSS	Mobile satellite service
MTCH	Multicast traffic channel
NACK	Negative-acknowledgement
N/A	Not applicable
NAS	Non-access stratum
NDI	New data indicator
OAM	Network operations and maintenance
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
OSC	Offset-modulated single-carrier
PAPR	Peak to average power ratio
PBCH	Physical broadcast channel
PCCC	Parallel concatenated convolutional code
PCCH	Paging control channel
PCFICH	Physical control format indicator channel
PCH	Paging channel
PDCCH	Physical downlink control channel

PDCP	Packet data convergence protocol
PDSCH	Physical downlink shared channel
PDU	Protocol data unit
PHICH	Physical hybrid ARQ indicator channel
PMCH	Physical multicast channel
PMI	Precoding matric indicator
POP	Post office protocol
PRACH	Physical random access channel
PRB	Physical resource block
PRS	Positioning reference signals
PSD	Power spectral density
PSRACH	Physical satellite random access channel
PSS	Primary synchronization channel
PUCCH	Physical uplink control channel
PUSCH	Physical uplink shared channel
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quadrature phase shift keying
RA	Random access
RACH	Random access channel
RAN	Radio access network
RB	Resource block
RBG	Resource block group
RE	Resource element
RF	Radio frequency
RHCP	Right hand circular polarisation
RI	Rank indicator
RIT	Radio Interface Technology
RLC	Radio link control
RM	Receiver memory
ROHC	Robust header compression
RRC	Radio resource control
RRM	Radio resource management
RS	Reference signal
RTD	Round trip delay
Rx	Receiver

S-eNodeB	Satellite eNodeB in the SAT-OFDM
S1AP	S1 application protocol
SAT-eNB	Satellite eNodeB
SDU	Service data unit
S-GW	Serving gateway
SC-FDMA	Single carrier frequency division multiple access
SCH	Synchronization signal
SFBC	Space-frequency block coding
SI	System information
SIR	Signal to interference ratio
SN	Sequence number
SNR	Signal to noise ratio
SRS	Sounding reference symbol
SSS	Secondary synchronization channel
STC	Space-time coding
TA	Time advance
TB	Transport block
TDM	Time division multiplexing
TF	Transport format
TM	Transparent mode
TMSI	Temporary mobile subscriber identity
TS	Technical specification
TTA	Korean telecommunication technology association
TTI	Transmission time interval
Tx	Transmitter
UCI	Uplink control information
UE	User equipment
UL	Uplink
UL-SCH	Uplink shared channel
UM	Unacknowledged mode
UTC	Coordinated universal time
VARQ	Virtual HARQ
VoIP	Voice over Internet protocol
X2AP	X2 Application Protocol

Related ITU Recommendations, Reports and Resolutions

Recommendation ITU-R M.1224-1	Vocabulary of Terms for International Mobile Telecommunications (IMT)
Recommendation ITU-R M.1645	Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000
Recommendation ITU-R M.1822	Framework for services supported by IMT
Recommendation ITU-R M.1850-1	Detailed specifications of the radio interfaces for the satellite component of International Mobile Telecommunications-2000 (IMT-2000)
Report ITU-R M.2176-1	Vision and requirements for the satellite radio interface(s) of IMT-Advanced
Report ITU-R M.2279	Outcome of the evaluation, consensus building and decision of the IMT-Advanced satellite process (Steps 4 to 7), including characteristics of IMT-Advanced satellite radio interfaces
Resolution ITU-R 56-1	Naming for International Mobile Telecommunications
Resolution ITU-R 57-1	Principles for the process of development of IMT-Advanced.

The ITU Radiocommunication Assembly,

considering

a) that International Mobile Telecommunications (IMT) systems are mobile broadband systems including both IMT-2000 and IMT-Advanced;

b) that IMT-Advanced systems include the new capabilities of IMT that go beyond those of IMT-2000;

c) that such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based;

d) that IMT-Advanced systems support low to high mobility applications and a wide range of data rates in accordance with user and service demands in multiple user environments;

e) that IMT-Advanced also has capabilities for high-quality multimedia applications within a wide range of services and platforms providing a significant improvement in performance and quality of service;

f) that the key features of IMT-Advanced are:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost-efficient manner;
- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- high-quality mobile services;
- user equipment suitable for worldwide use;
- user-friendly applications, services and equipment;
- worldwide roaming capability;
- enhanced peak data rates (i.e. wideband) to support advanced services and applications;

g) that these features enable IMT-Advanced to address evolving user needs;

h) that the capabilities of IMT-Advanced systems are being continuously enhanced in line with user trends and technology developments;

j) that the satellite component of IMT-Advanced will be an integral part of future IMT infrastructure with the optimized service delivery;

k) that it is desirable to achieve as much commonality as possible with the terrestrial component when designing and developing an IMT-Advanced satellite system,

recognizing

a) that Resolution ITU-R 57-1 – Principles for the process of development of IMT-Advanced, outlines the essential criteria and principles used in the process of developing the Recommendations and Reports for IMT-Advanced, including Recommendation(s) for the radio interface specification;

b) that Report ITU-R M.2279 contains the outcome and conclusion of Steps 4 through 7 of the evaluation, consensus building and decision of the IMT-Advanced satellite process, including characteristics of IMT-Advanced satellite radio interfaces,

recommends

1 that the satellite radio interfaces for IMT-Advanced should be:

– “BMSat” (Broadband Mobile Satellite); and

– “SAT-OFDM” (Satellite-Orthogonal Frequency Division Multiplexing);

2 that the information provided or referenced in Annexes 1 and 2 should be used as the complete set of standards for the detailed specifications of the satellite radio interfaces of IMT-Advanced.

Annex 1

Specification of the BMSat radio interface technology

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1.1 Overview of the radio interface technology

1.1.1 Overview of the radio interface technology

The IMT-Advanced satellite radio interface specifications known as BMSat is developed by China. BMSat is designed based on terrestrial long term evolution-Advanced (LTE-Advanced) specifications (also known as LTE Release 10 and beyond developed by the Third generation partnership project (3GPP)) and the satellite requirements. A number of modifications to LTE-Advanced are made to adapt to the satellite radio transmission environment.

BMSat is a FDD RIT designed for operation in paired spectrum. Both full-duplex and half-duplex FDD are supported. BMSat meets all the ITU IMT-Advanced minimum requirements in the mandatory open area environment defined in all aspects of services, spectrum and technical performance.

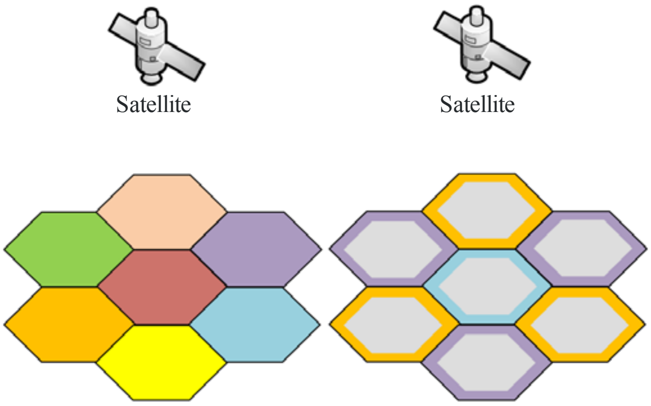
The complete set of standards for the satellite radio interface of IMT-Advanced identified as BMSat includes not only the key characteristics of IMT-Advanced but also the additional capabilities of BMSat both of which are continuing to be enhanced.

1.1.2 Overview of the system aspects of the RIT

BMSat is designed mainly for geostationary earth orbit (GEO) satellite. It is assumed that each satellite is deployed with large aperture reflector antenna systems and could provide multiple spot-beams. The frequency is reused in different beams. Flexible frequency reuse schemes could be supported in BMSat, including integer frequency reuse and fractional frequency reuse, as shown in Fig. 1.1.

FIGURE 1.1

Frequency reuse schemes for BMSat



a) Frequency reuse factor: 7 b) Fractional frequency reuse

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The transmission scheme is based on conventional OFDM. Depending on the deployed satellite/terminal power amplifier performance, two low envelope fluctuation transmission modes within the OFDM framework, DFT-spread OFDM (DFTS-OFDM) and offset-modulated single-carrier (OSC), could be used in both uplink and downlink. The use of DFTS-OFDM transmission and OSC transmission is motivated by the lower peak-to-average power ratio (PAPR) of the transmitted signal compared to conventional OFDM. This allows for more efficient usage of the power amplifier at the satellite/terminal, which translates into an increased coverage and/or reduced power consumption.

Channel coding is based on rate –1/3 Turbo coding. Data modulation supports QPSK, 16QAM, and 16APSK for both the downlink and the uplink.

BMSat supports bandwidths from approximately 1.4 MHz to 100 MHz. Carrier aggregation, i.e. the simultaneous transmission of multiple component carriers in parallel to/from the same terminal, is used to support bandwidths larger than 20 MHz. Component carriers do not have to be contiguous in frequency and can even be located in different frequency bands in order to enable exploitation of fragmented spectrum allocations by means of spectrum aggregation.

BMSat supports three scheduling types: channel-dependent scheduling (dynamic), semi-persistent scheduling, and fixed scheduling. Channel-dependent scheduling in both the time and frequency domains is supported for both downlink and uplink with the base-station scheduler being responsible for (dynamically) selecting the transmission resource as well as the data rate. Semi-persistent/fixed scheduling enables transmission resources and data rates to be semi-statically/fixedly allocated to a given User Equipment (UE) to guarantee QoS of time-sensitive service and reduce the control-signalling overhead. The basic scheduling unit is 1 ms Transmission Time Interval (TTI). TTI bundling which allows transmission for a longer time period than one TTI (up to 20 TTIs) is supported in BMSat to improve coverage.

Multi-antenna transmission schemes are part of BMSat. Spatial multiplexing with up to two layers in the downlink and uplink is supported. Transmit diversity based on space-frequency block coding (SFBC) or a combination of SFBC and frequency switched transmit diversity (FSTD) in the downlink or autonomous antenna selection diversity in the uplink is supported.

Inter-beam interference coordination (IBIC), where neighbour beams exchange information aiding the scheduling in order to reduce interference, is supported for the RITs. IBIC can be used for homogenous deployments with non-overlapping beams of similar transmission power.

1.1.2.1 Network architecture

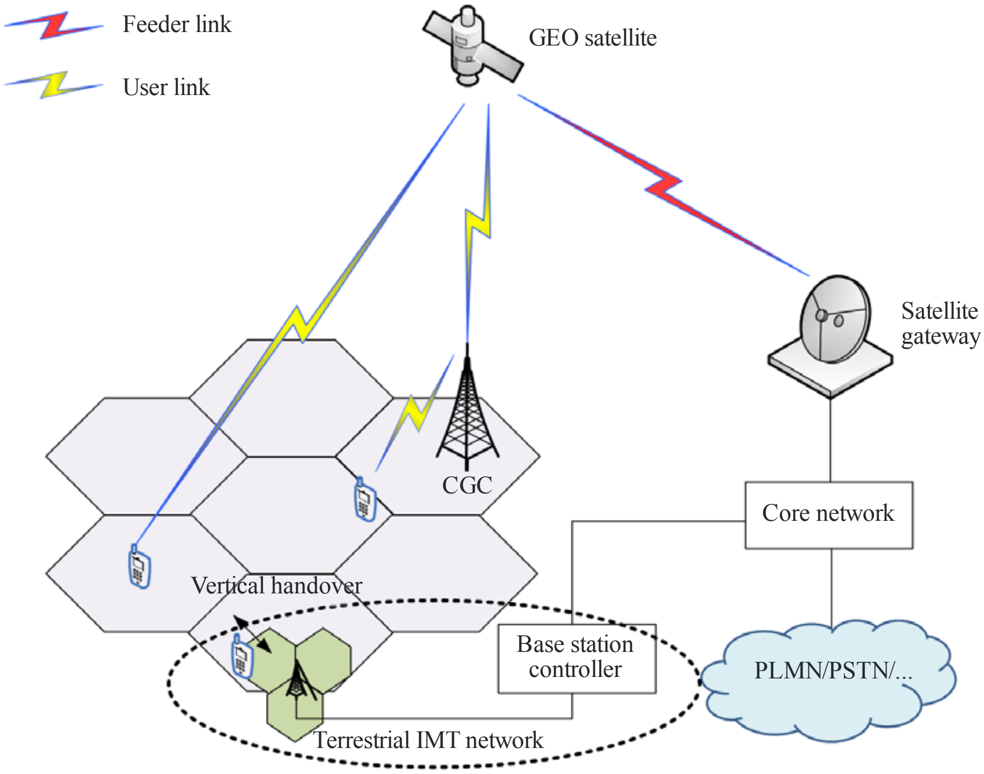
The architecture of BMSat shown in Fig. 1.2 consists of GEO satellites with or without on board processing and switching system, satellite gateway, satellite core network and complementary ground component (CGC). Satellite gateway is a physical entity, and may include multiple logical entity: satellite eNodeB (STA-eNB). One SAT-eNB logically controls one beam or several beams, and one beam is logically controlled by one SAT-eNB. Complementary ground component (CGC) plays a role of relaying functionality in BMSat to fill the gaps that cannot be covered by satellite signals (e.g. indoor scenario) or to provide better traffic quality. CGC is not a simple repeater, but has its own beam ID, synchronization channels, reference symbols, and could create its own beam. It demodulates and decodes the signal in the forward link, then transmits information to UE by new modulation and coding types based on the link quality between CGC and UE. CGC is a fixed node and could use more advanced antenna and other techniques to improve the transmission efficiency in CGC-Satellite link. CGC appears as a SAT-eNB to terminals, and a UE to SAT-eNB.

BMSat radio interface includes two links: UE-CGC link and UE-Satellite link. UE-Satellite link is specified based on terrestrial LTE-Advanced standards and modified to adapt to satellite radio transmission environment. UE-CGC link could reuse the terrestrial LTE-Advanced specifications. In this case, the terminal needs to support both BMSat mode and LTE-Advanced mode.

NOTE – CGC-Satellite link is the same as the UE-Satellite link.

FIGURE 1.2

Architecture of BMSat



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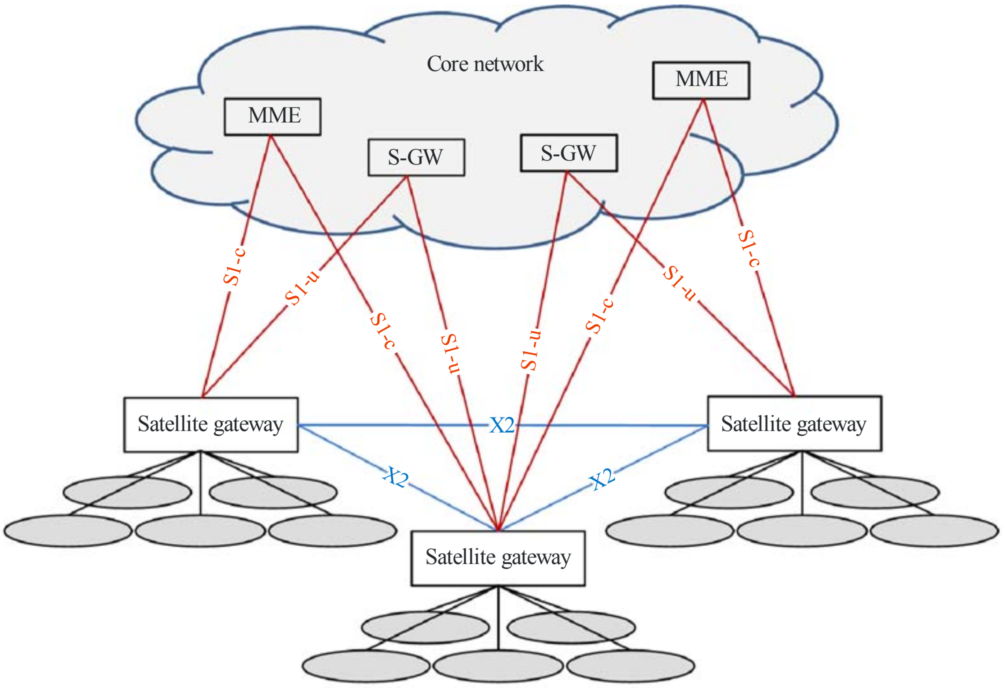
The BMSat radio-access network has a flat architecture with a single type of node, the satellite gateway (SAT-eNB), which is responsible for all radio-related functions in one or several beams. The SAT-eNB is connected to the core network by means of the S1 interface, more specifically to the serving gateway (S-GW) by means of the user-plane part, S1-u, and to the Mobility Management Entity (MME) by means of the control-plane part, S1-c. One SAT-eNB can interface to multiple MMEs/S-GWs for the purpose of load sharing and redundancy.

The X2 interface, connecting SAT-eNBs to each other, is mainly used to support active-mode mobility. This interface may also be used for multi-beam Radio Resource Management (RRM) functions such as IBIC. The X2 interface is also used to support lossless mobility between neighbouring beams by means of packet forwarding.

FIGURE 1.3

Radio-access network interfaces of BMSat



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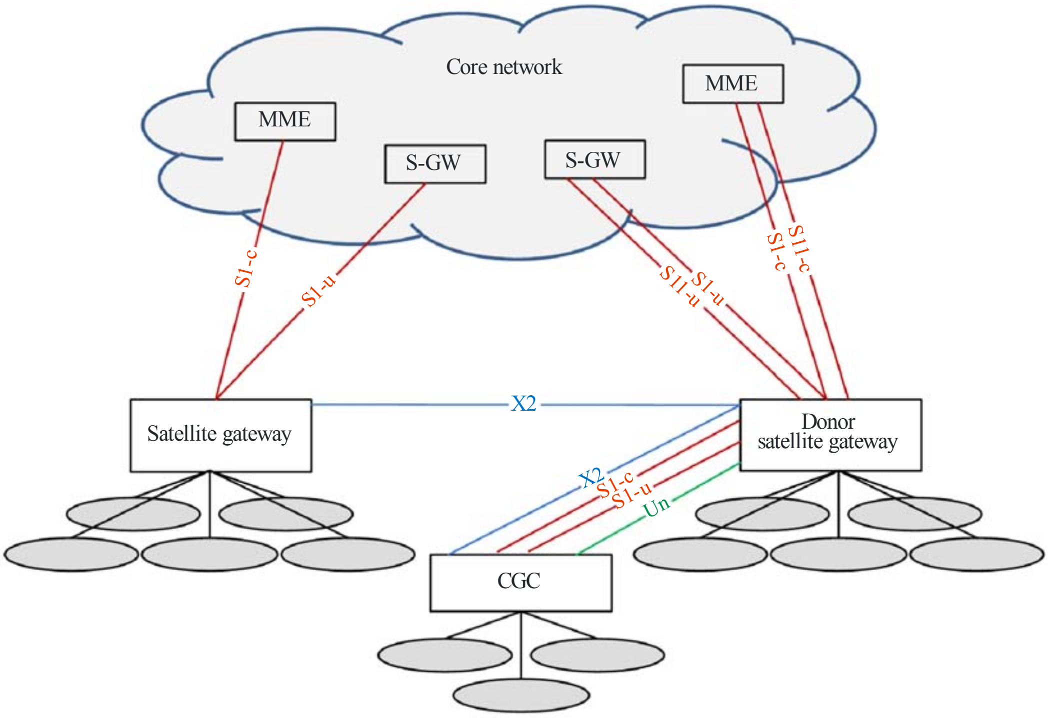
The radio-access network interfaces for BMSat supporting CGCs are shown in Fig.1.4. The CGC terminates the S1, X2 and Un interfaces. The Donor SAT-eNB (DSAT-eNB) provides S1 and X2 proxy functionality between the CGC and other network nodes (other SAT-eNBs, MMEs and S-GWs). The S1 and X2 proxy functionality includes passing UE-dedicated S1 and X2 signalling messages as well as GTP data packets between the S1 and X2 interfaces associated with the CGC and the S1 and X2 interfaces associated with other network nodes. Due to the proxy functionality, the DSAT-eNB appears as an MME (for S1-c), an SAT-eNB (for X2) and an S-GW (for S1-u) to the CGC.

FIGURE 1.4

Radio-access network interfaces of BMSat supporting CGC



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1.1.2.2 Layer 2 protocol architecture

Layer 2 (L2) consists of several sub-layers: packet data convergence protocol (PDCP), radio link control (RLC) and medium access control (MAC). The downlink and uplink protocol structures are illustrated in Figs 1.5 and 1.6, respectively. Layer 2 provides one or more radio bearers to higher layers to which IP packets are mapped according to their quality-of-service (QoS) requirements. L2/MAC PDUs, also referred to as transport blocks, are created according to instantaneous scheduling decisions and delivered to the physical layer on one or several transport channels (one transport channel of the same type per component carrier).

FIGURE 1.5

Downlink L2 protocol structure

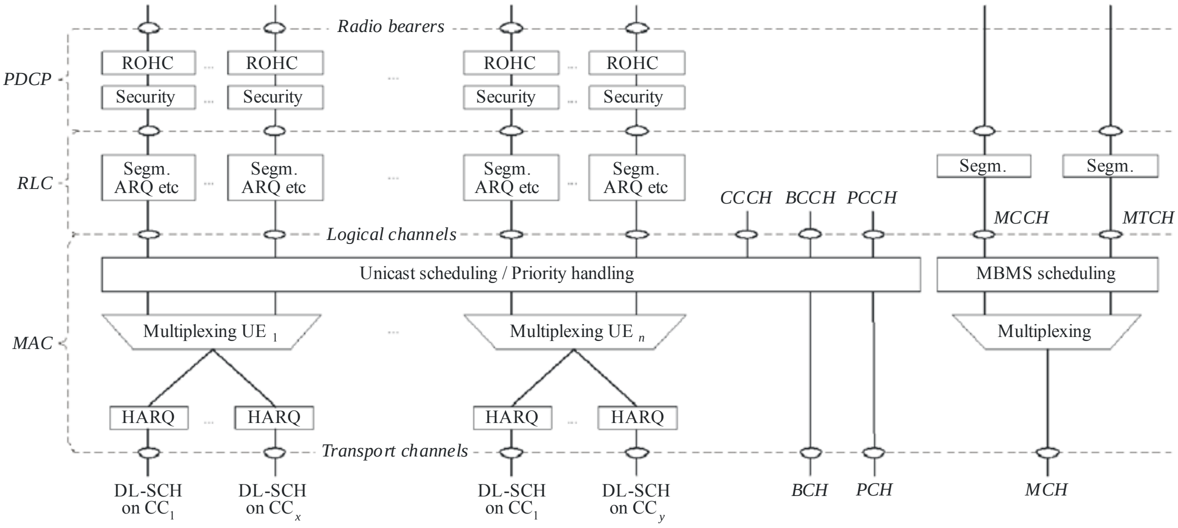

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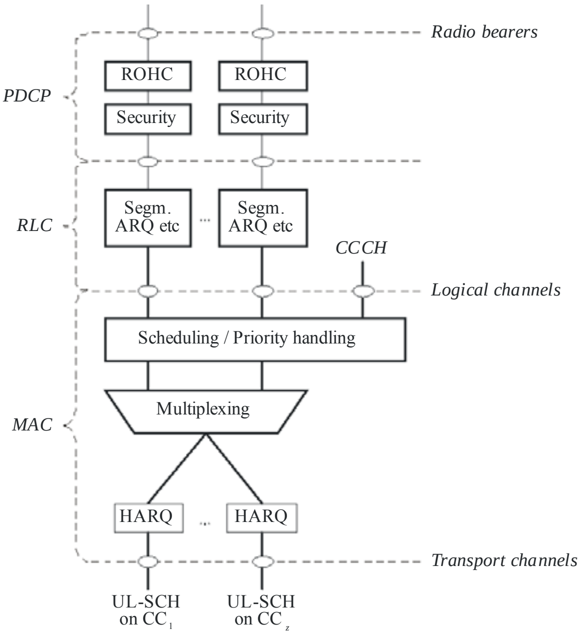
FIGURE 1.6

Uplink L2 protocol structure



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1.1.2.2.1 Packet data convergence protocol

Packet data convergence protocol (PDCP) is responsible for:

- User plane:
  - Header compression and decompression of IP data flows using ROHC.
  - Transfer of user data.
  - Maintenance of PDCP Sequence Numbers (SNs).
  - In-sequence delivery of upper layer PDUs at PDCP re-establishment procedure for RLC AM.

  - Duplicate detection of lower layer SDUs at PDCP re-establishment procedure for RLC AM.
  - Retransmission of PDCP SDUs at handover for RLC AM.
  - Ciphering and deciphering.
  - Timer-based SDU discard in uplink.
- Control plane:
  - Maintenance of PDCP Sequence Numbers (SNs).
  - Ciphering and Integrity Protection and Verification.
  - Transfer of control plane data.

PDCP uses the services provided by the RLC sub-layer. There is one PDCP entity per radio bearer configured for a UE.

1.1.2.2.2 Radio link control

Radio link control (RLC) is responsible for:

- Transfer of upper layer PDUs.
- Error correction through automatic repeat request (ARQ) (only for AM data transfer).
- Concatenation, segmentation and reassembly of RLC SDUs (only for UM and AM data transfer).
- Resegmentation of RLC data PDUs (only for AM data transfer).
- Reordering of RLC data PDUs (only for UM and AM data transfer).
- Duplicate detection (only for UM and AM data transfer).
- Protocol error detection (only for AM data transfer).
- RLC SDU discard (only for UM and AM data transfer).
- RLC re-establishment.

Depending on the mode of operation, an RLC entity may provide all, a subset of, or none of the services above. The RLC can operate in three different modes:

- Transparent mode I, where the RLC is completely transparent and is in essence bypassed. This configuration is used for control-plane broadcast channels such as broadcast control channel (BCCH), common control channel (CCCH) and paging control channel (PCCH) only where the information should reach multiple users.
- Unacknowledged mode (UM), where the RLC provides all the functionality above except error correction, is used when error-free delivery is not required, for example for multicast control channel (MCCH) and multicast traffic channel (MTCH) using multimedia broadcast over a single frequency network (MBSFN) and for voice-over-IP (VoIP).
- Acknowledged mode (AM), where the RLC provides all the services above, is the main mode of operation for TCP/IP packet data transmission on the downlink shared channel (DL-SCH). Segmentation/reassembly, in-sequence delivery and retransmissions of erroneous data are all supported.

The RLC offers services to the PDCP in the form of radio bearers and uses services from the MAC layer in the form of logical channels. There is one RLC entity per radio bearer configured for a terminal.

1.1.2.2.3 Medium access control

The Medium access control (MAC) layer is responsible for:

- Mapping between logical channels and transport channels.
- Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks delivered to/from the physical layer on transport channels.
- Scheduling information reporting.
- UE-CGC link: Error correction through N-process stop-and-wait hybrid-ARQ (HARQ) with synchronous (for the uplink) and asynchronous (for the downlink) retransmissions.
- UE-Satellite link: Error correction through virtual hybrid-ARQ (V-HARQ) with synchronous (for the uplink) and asynchronous (for the downlink) retransmissions.
- Priority handling between logical channels of one UE.
- Priority handling between UEs by means of dynamic scheduling.
- Logical channel prioritization.
- Multimedia broadcast/Multicast service (MBMS) identification.
- Transport format selection.
- Padding.

The MAC offers services to the RLC in the form of logical channels. A logical channel is defined by the type of information it carries and is generally classified as a control channel, used for transmission of control and configuration information necessary for operating a BMSat system, or as a traffic channel, used for the user data. The set of logical-channel types specified for BMSat includes:

- Broadcast control channel (BCCH), used for broadcasting system control information.
- Paging control channel (PCCH), a downlink channel used for paging when the network is not aware of the location of the UE and for system information change notifications.
- Common control channel (CCCH), used for transmission of control information between UEs and network when the UE has no RRC connection.
- Dedicated control channel (DCCH), used for transmission of control information to/from a mobile terminal when the UE has a RRC connection.
- Multicast control channel (MCCH), used for transmission of control information required for reception of the MTCH.
- Dedicated traffic channel (DTCH), used for transmission of user data to/from a mobile terminal. This is the logical channel type used for transmission of all uplink and non-MBSFN downlink user data.
- Multicast traffic channel (MTCH), used for downlink transmission of MBMS services.

From the physical layer, the MAC layer uses services in the form of transport channels. A transport channel is defined by how and with what characteristics the information is transmitted over the radio interface. Data on a transport channel is organized into transport blocks. In each transmission time interval (TTI), at most one or two (in case of spatial multiplexing) transport blocks are transmitted per component carrier.

Associated with each transport block is a transport format (TF), specifying how the transport block is to be transmitted over the radio interface. The transport format includes information about the transport-block size, the modulation scheme, and the antenna mapping. The scheduler is responsible for (dynamically) determining the uplink as well as downlink transport format in each TTI.

The following transport-channel types are defined:

– Broadcast channel (BCH) has a fixed transport format, provided by the specifications. It is used for transmission of parts of the BCCH system information, more specifically the so-called master information block (MIB).

– Paging channel (PCH) is used for transmission of paging information from the PCCH logical channel. The PCH supports discontinuous reception (DRX) to allow the mobile terminal to save battery power by waking up to receive the PCH only at predefined time instants.

– Downlink shared channel (DL-SCH) is the main transport-channel type used for transmission of downlink data in BMSat. It supports dynamic rate adaptation and channel-dependent scheduling, HARQ/V-HARQ with soft combining, and spatial multiplexing. It also supports DRX to reduce mobile-terminal power consumption while still providing an always-on experience. The DL-SCH is also used for transmission of the parts of the BCCH system information not mapped to the BCH. In case of transmission to a terminal using multiple component carriers the UE receives one DL-SCH per component carrier.

– Multicast channel (MCH) is used to support MBMS. It is characterized by a semi-static transport format and semi-persistent scheduling. In case of multi-beam transmission using MBSFN, the scheduling and transport format configuration is coordinated among the beams involved in the MBSFN transmission.

– Uplink shared channel (UL-SCH) is the uplink counterpart to the DL-SCH, i.e. it is the uplink transport channel used for transmission of uplink data.

In addition, the random access channel (RACH) is also defined as an uplink transport channel although it does not carry transport blocks. The RACH is used in the uplink to respond to the paging message or to initiate the move to the RRC_CONNECTED state according to terminal data transmission needs.

The mapping between logical channels, transport channels and physical channels (described in § 1.1.3.3) is illustrated in Fig. 1.7 for the downlink and Fig. 1.8 for the uplink.

FIGURE 1.7

Downlink channel mapping

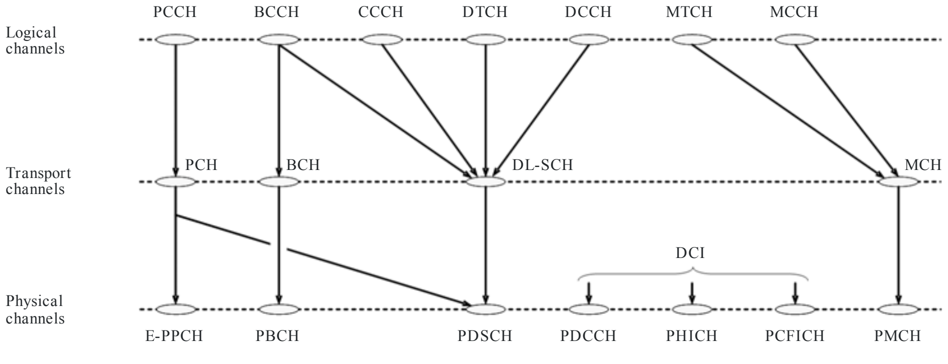

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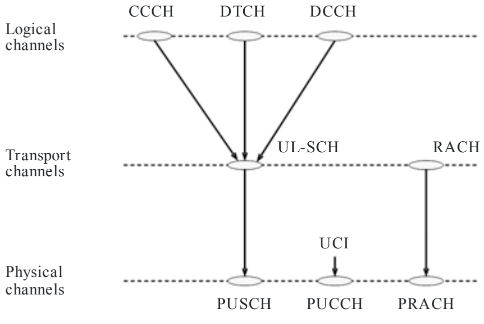
FIGURE 1.8

Uplink channel mapping



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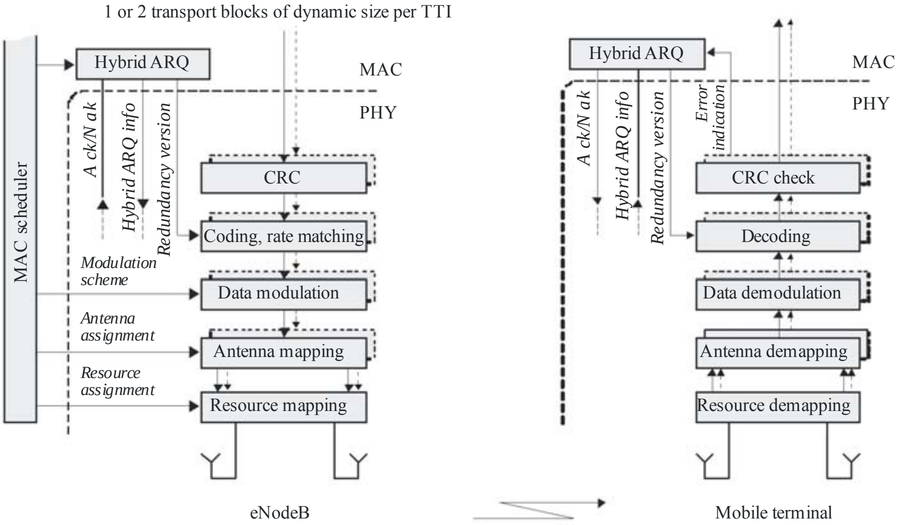
1.1.2.3 Physical layer

For UE-CGC link, the physical layer is responsible for:

- Modulation and demodulation of physical channels.
- Error detection on the transport channel and indication to higher layers.
- Forward error correction (FEC) encoding and decoding of transport channels.
- Rate matching of the coded transport channel to physical channels.
- Mapping of the coded transport channel onto physical channels according to Fig. 1.7 (downlink) and Fig. 1.8 (uplink).
- Hybrid ARQ (HARQ) soft-combining.
- Frequency and time synchronization.
- Power weighting of physical channels.
- Multi-antenna processing and beamforming.
- Characteristic measurements and indication to higher layers.
- RF processing.
- A simplified overview of the processing for the DL-SCH is given in Fig. 1.9.

FIGURE 1.9

Simplified physical-layer processing for DL-SCH on one component carrier



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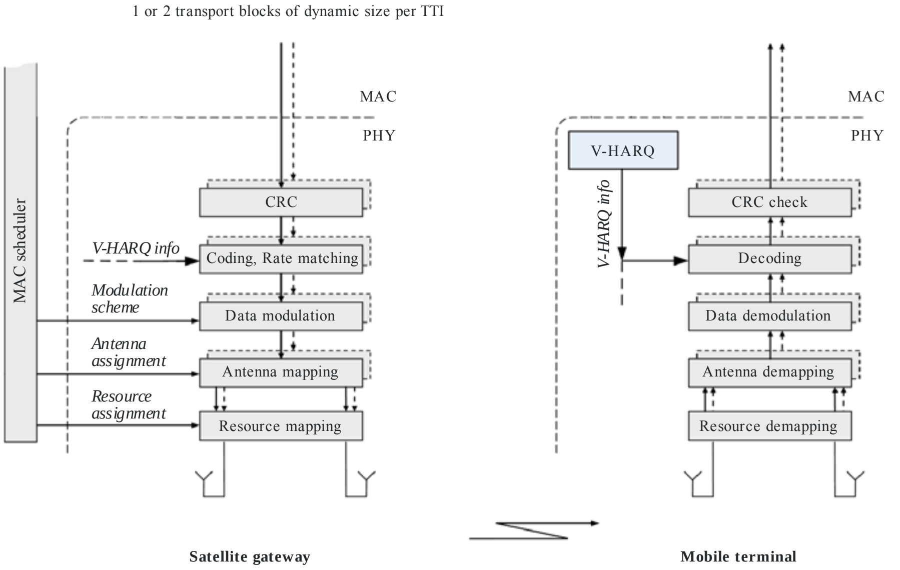
For UE-Satellite link, three items of the physical layer as below are different to UE-CGC link:

- Virtual hybrid ARQ combining.
- A simplified overview of the processing for the DL-SCH is given in Fig. 1.10.
- Multi-antenna processing (beamforming is not supported).

FIGURE 1.10

Simplified physical-layer processing for DL-SCH on one component carrier with virtual HARQ



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1.1.2.3.1 Physical channels

Seven different types of physical channels are defined for the downlink:

- Physical downlink shared channel (PDSCH): Used for transmission of user and control plane data services.

- Physical multicast channel (PMCH): Used for transmission of control and user-plane broadcast services during MBSFN subframes.
- Physical downlink control channel (PDCCH): Used for transmission of control information such as resource allocation, transport format and HARQ/V-HARQ related information.
- Physical broadcast channel (PBCH): Used for conveying beam and/or system specific information.
- Physical control format indicator channel (PCFICH): It indicates to the UE the control format (number of symbols comprising PDCCH, PHICH) of the current subframe.
- Physical hybrid ARQ indicator channel (PHICH): It conveys the ACK/NAK information for UL (PUSCH) transmissions received at CGC for UE-CGC link.
- Enhanced physical paging channel (E-PPCH): It conveys the enhanced paging information to page users in deep fading environment.

Three different types of physical channels are defined for the uplink:

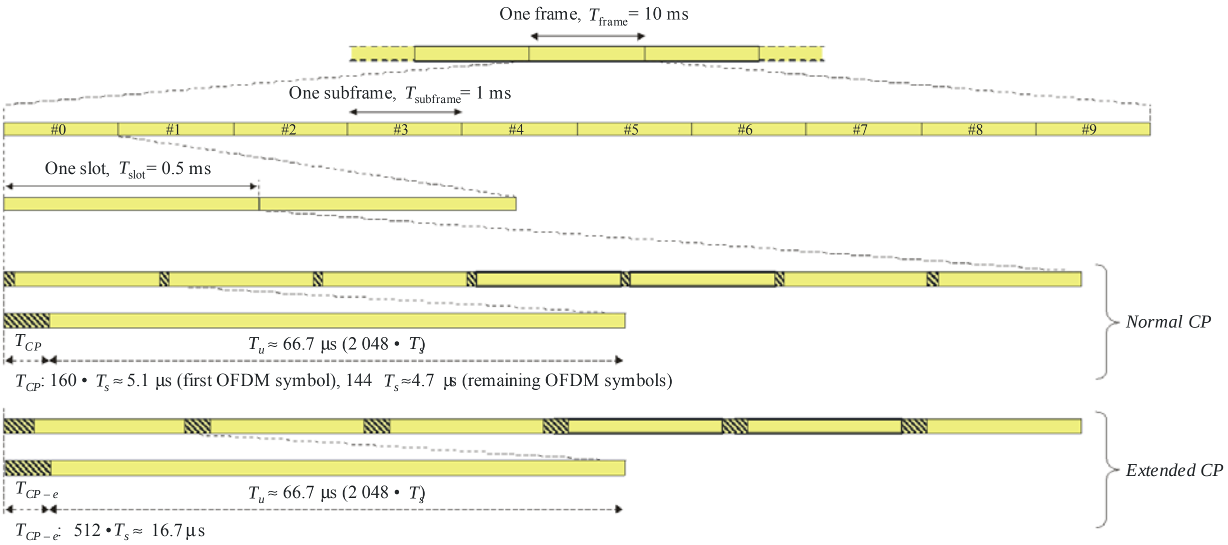
- Physical random access channel (PRACH): It conveys a preamble which is used to trigger a random-access procedure in the SAT-eNB.
- Physical uplink shared channel (PUSCH): It conveys both user data and upper layer control information.
- Physical uplink control channel (PUCCH): It conveys control information (scheduling requests, CQI, PMI, RI, and HARQ/V-HARQ information for PDSCH, etc.).

1.1.2.3.2 Time-domain structure and duplex schemes

Figure 1.11 illustrates the high-level time-domain structure for transmission, with each (radio) frame of length 10 ms consisting of ten equally sized subframes of length 1 ms. Each subframe consists of two equally sized slots of length Tslot = 0.5 ms with each slot consisting of a number of OFDM symbols including cyclic prefix.

FIGURE 1.11

BMSat time-domain structure



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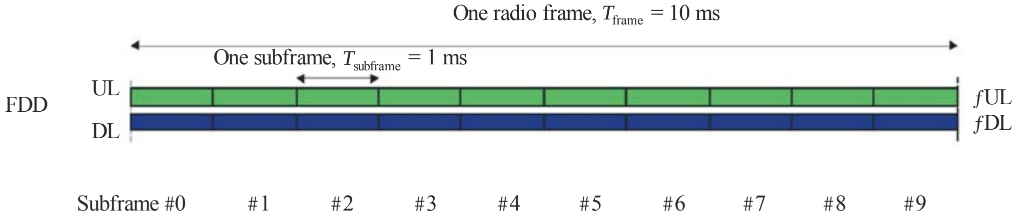
BMSat can operate in FDD as illustrated in Fig. 1.12.

FIGURE 1.12

Uplink/downlink time/frequency structure in case of FDD



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There are two carrier frequencies for each component carrier, one for uplink transmission (f_{UL}) and one for downlink transmission (f_{DL}). During each frame, there are thus ten uplink subframes and ten downlink subframes and uplink and downlink transmission can occur simultaneously within a beam. Half-duplex operation at the UE side is supported by the scheduler ensuring non-simultaneous reception and transmission at the UE.

1.1.2.3.3 Physical layer processing

To the transport block(s) to be transmitted on a DL-SCH or UL-SCH, a CRC is attached, followed by rate-1/3 Turbo coding for error correction. Rate matching is used not only to match the number of coded bits to the amount of resources allocated for the DL-SCH/UL-SCH transmission, but also to generate the different redundancy versions as controlled by the HARQ/V-HARQ protocol. In case of spatial multiplexing, the processing is duplicated for the two transport blocks. After rate matching, the coded bits are modulated (QPSK, 16QAM, 64QAM for UE-CGC link; QPSK, 16QAM/16APSK for UE-Satellite link). In case of multi-antenna transmission, the modulation symbols are mapped to multiple layers and precoded before being mapped to the different antenna ports. Alternatively, transmit diversity can be applied. Finally, the (precoded) modulation symbols are mapped to the time-frequency resources allocated for the transmission.

Downlink transmission is based on conventional OFDM with a cyclic prefix. The subcarrier spacing is $\Delta f = 15$ kHz and two cyclic prefix lengths are supported: normal cyclic prefix ≈4.7 µs and extended cyclic prefix ≈16.7 µs. In the frequency domain, the number of resource blocks can range from 6 to 110 per component carrier (for channel bandwidths ranging from 1.4 to 20 MHz respectively), where a resource block is 180 kHz in the frequency domain. There can be up to five component carriers transmitted in parallel implying an overall bandwidth up to 100 MHz.

Uplink transmission is based on DFT-spread OFDM (DFTS-OFDM). DFTS-OFDM can be seen as a DFT precoder, followed by conventional OFDM with the same numerology as in the downlink. Multiple DFT precoding sizes, corresponding to transmission with different scheduled bandwidths, can be used.

Depending on the deployed satellite/UE power amplifier performance, DFTS-OFDM and Offset-modulated Single-Carrier (OSC) could be used in both uplink and downlink of UE-Satellite link.

The remaining downlink transport channels (PCH, BCH, MCH) are based on the same general physical-layer processing as DL-SCH, although with some restrictions in the set of features used.

1.1.2.3.4 Multi-antenna transmission

A wide range of multi-antenna transmission schemes are supported in the downlink of UE-CGC link:

– Single-antenna transmission using a single cell-specific reference signal.

- Closed-loop spatial multiplexing, also known as codebook-based beam-forming or precoding, of up to four layers using cell-specific reference signals. Feedback reports from the terminal are used to assist CGC in selecting a suitable precoding matrix.
- Open-loop spatial multiplexing, also known as large-delay cyclic delay diversity, of up to four layers using cell-specific reference signals.
- Spatial multiplexing of up to eight layers using UE-specific reference signals. CGC may use feedback reports or exploit channel reciprocity to set the beam-forming weights.
- Transmit diversity based on space-frequency block coding (SFBC) or a combination of SFBC and frequency switched transmit diversity (FSTD).
- Multi-user MIMO where multiple terminals are assigned overlapping time-frequency resources.

For downlink of UE-Satellite link:

- Transmit diversity based on SFBC (space-frequency block coding) with maximum 2 antenna ports is supported.
- Open-loop spatial multiplexing of up to two layers using cell-specific reference signals is supported.

The following multi-antenna transmission schemes are supported in the uplink of UE-CGC link:

- Single-antenna transmission.
- Precoding supporting rank-adaptive spatial multiplexing with one up to four layers.

For uplink of UE-Satellite link:

- Open-loop spatial multiplexing with up to 2 layers is supported.
- Open-loop and UE autonomous antenna selection diversity is supported.

1.1.2.3.5 Link adaptation and power control

According to the radio channel conditions, the modulation and coding scheme (MCS) can be adapted flexibly. The same modulation and coding is applied to all resource units assigned to the same transport block within a TTI. Uplink power control determines the average power over a DFTS-OFDM symbol in which the physical channel is transmitted.

1.1.2.3.6 L1/L2 control signalling

Downlink control information (DCI) is transmitted in the first one to three OFDM symbols of each downlink subframe in each component carrier with the number of OFDM symbols being indicated on the PCFICH. Downlink and uplink scheduling grants (consisting of UE identity, time-frequency resources and transport format) and virtual hybrid-ARQ information are transmitted on the PDCCH and PHICH, respectively. Each grant is transmitted on a separate PDCCH using QPSK modulation.

Uplink control information (UCI), consisting of channel-status information, scheduling requests and HARQ/V-HARQ information, is transmitted at the band edges of the primary uplink component carrier. Alternatively, parts of the control signaling can be multiplexed with data on PUSCH.

1.1.2.3.7 Multicast/Broadcast over single frequency network operation

Multicast/Broadcast over single frequency network (MBSFN) transmission, where the same signal is transmitted from multiple, time-synchronized beams, is supported by the MCH transport channel. One component carrier can support simultaneous unicast and broadcast support through time-domain multiplexing of MCH and DL-SCH transmissions.

1.1.3 Overview of the specific characteristics of the RIT

1.1.3.1 Low-EF transmission mode

Satellite communication system is typically power limited. In order to increase the power efficiency, two low envelope fluctuation (EF) transmission modes within the OFDM framework, DFT-spread OFDM used in terrestrial LTE uplink and offset-modulated single-carrier (OSC), could be used in both uplink and downlink.

1.1.3.1.1 OSC mode

The frequency domain transmission signal mapped to a set of subcarriers is generated by:

$$y_m = \sqrt{\frac{2}{N}} \sin \frac{\pi(m+0.5)}{N} \sum_{n=0}^{N-1} e^{-j2\pi(m+0.5)n/N} \underline{x}_n$$

where:

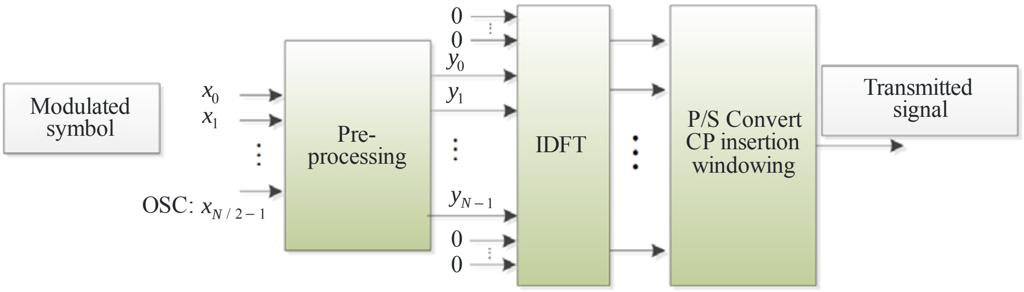
$$\underline{x}_{2k} = \mathrm{Re}\{x_k\} \text{ and } \underline{x}_{2k+1} = \mathrm{Im}\{x_k\},\ k = 0,1,\ldots,N/2-1$$

$$x_n,\ n = 0,1,\ldots,N/2-1,$$

are complex-valued modulation symbols, *N* is the set size of sub-carriers.

FIGURE 1.13

Signal generation for OSC transmission mode



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1.1.3.2 Virtual Hybrid ARQ

The Hybrid ARQ (HARQ) scheme used in terrestrial LTE systems cannot work effectively because of long radio transmission delay in satellite communication systems. However, by utilizing the terrestrial LTE HARQ process, a new scheme, virtual HARQ without ACK/NACK feedback, is designed to support a wider range of channel conditions as well as transmission rates.

In order to support effective transmission in low SINR region, low rate MCS levels should be supported. The MCS levels can be equivalently extended by using the LTE HARQ process. In virtual HARQ scheme, based on the reported CQI from the receiver, the transmitter adaptively selects both the MCS level and the number of transmitted redundancy versions. This scheme can support data transmission in very low SINR channel condition by selecting maximum 4 redundancy versions.

A Transmit processing for virtual HARQ

Based on the feedback CQI, the transmitter selects at the same time both the MCS level and the number of simultaneously transmitted redundancy versions for a given number of TTI, typically a single TTI. By this way the transmission rate has a more flexible choice in contrast to AMC in LTE.

Each MCS corresponds to an efficient code rate (ECR) in LTE, and 29 ECRs are supported in LTE. For 64QAM is not supported in BMSat, the number of other remaining MCS/ECR is 17. When the selections of MCS and the number of simultaneously transmitted redundancy versions are combined, the 17 ECRs will be extended to 68 ECRs in BMSat. Among all possible ECRs or its subset, the maximum transmission rate that is less than the channel capacity will be selected.

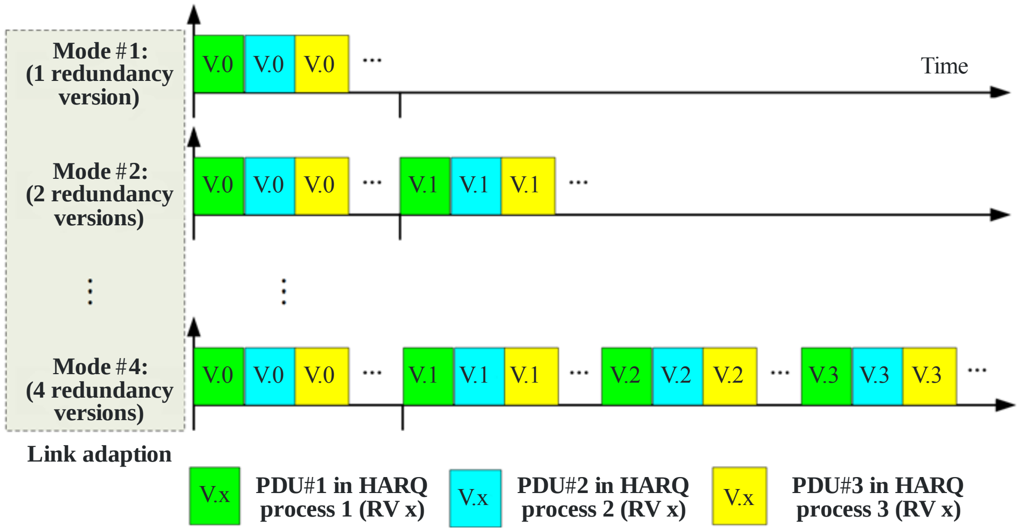
Once the transmission rate, i.e. the MCS level and the number of simultaneously transmitted redundancy versions, is determined, the transmitter calculates the data size to match the determined rate. After rate matching, each redundancy version goes through symbols modulation, concatenation, resource mapping and OFDM modulation. If multiple redundancy versions are selected to be transmitted in one TTI, they will be concatenated in time or space dimension.

B Virtual HARQ receiver

The receiver first de-concatenates the received signal corresponding to multiple redundancy versions in one TTI if needed. Then, the HARQ decoding method in LTE is used in BMSat by viewing multiple redundancy versions simultaneously transmitted in one TTI as retransmitted ones.

FIGURE 1.14

Virtual hybrid ARQ



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1.1.3.3 Long TTI bundling

Due to the large path loss of satellite link and UE/satellite transmission power limitation, UL/DL transmission may be power limited for some classes of UE. In order to improve coverage of PDSCH/PUSCH transmission, a long period TTI bundling (up to 20 ms) approach can be configured. By TTI bundling, one transport block will be transmitted in multiple successive subframes. The total transmission power of the packet is boosted. Transmission of a transport block in case of long TTI bundling is defined in terms of the following steps (Fig. 1.15):

- encoding of source bits in each of the codewords to be transmitted;
- scrambling of coded bits in each of the codewords to be transmitted;
- modulation of scrambled bits to generate complex-valued modulation symbols;
- mapping of the complex-valued modulation symbols of the transport block on an antenna port into each TTI bundling subframe: $x^q(n) = d(q \times M_{sym}^{SF} + n)$, $q = 0,1,...,Q-1$, $n = 0,1,...,M_{sym}^{SF} - 1$,

where Q is the number of bundled subframes, M_{sym}^{SF} is the number of modulation symbols that mapped into each subframe, $x^q(n)$ is the n^{th} modulation symbol mapped into the q^{th} subframe, $d(\cdot)$ is the complex-valued modulation symbols of the transport block;

- generating time-domain signal to be transmitted in each subframe.

To improve spectrum efficiency, code-division multiple access on top of OFDMA (SC-FDMA) can be used when generating time-domain signal in each subframe. To be specific, the procedure includes the following steps:

- spreading of the complex-valued modulation symbols in each subframe, an example can be found in Fig. 1.16, the n^{th} modulation symbol of subframe q is spread by $\lfloor w_0, w_1, \ldots, w_{N_{SF}-1} \rfloor$, where NSF is the length of spreading code;
- mapping of the spread symbols to resource elements, for example in Fig. 1.16, the spread symbols of the n^{th} modulation symbols are mapped to the n^{th} subcarrier of all SC-FDMA symbols except the symbols for reference signal;
- generating time-domain signal for each subframe.

FIGURE 1.15

Long TTI bundling transmission

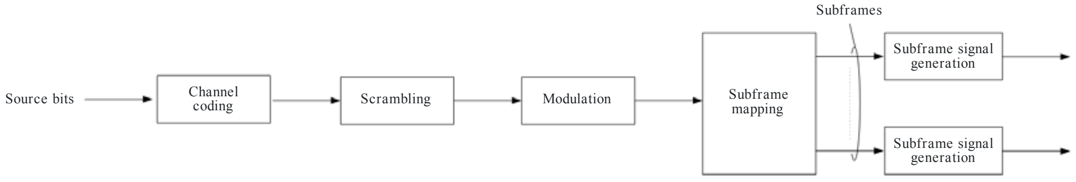

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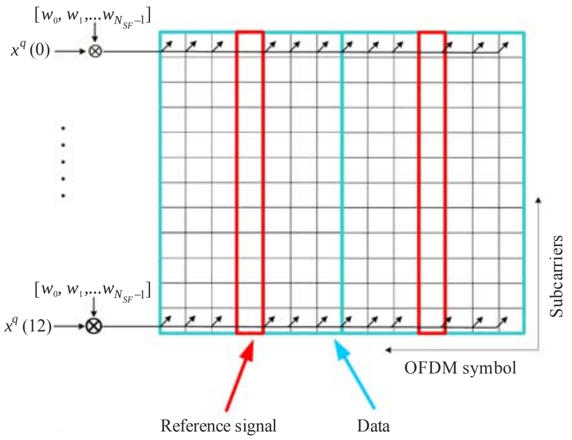
FIGURE 1.16

Mapping of spread symbols to resource elements (UL) (Example)



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1.1.3.4 Random access optimization

The propagation delay of satellite system is much longer than terrestrial LTE system. The terrestrial LTE access procedure needs to be optimized to adapt the long delay.

Depending on whether UE can obtain time advance (TA) in advance, two access schemes can be used in BMSat:

- RACH-less Access: for UE can obtain the accurate TA in advance;
- RACH: for UE cannot obtain TA in advance.

1.1.3.4.1 RACH-less access

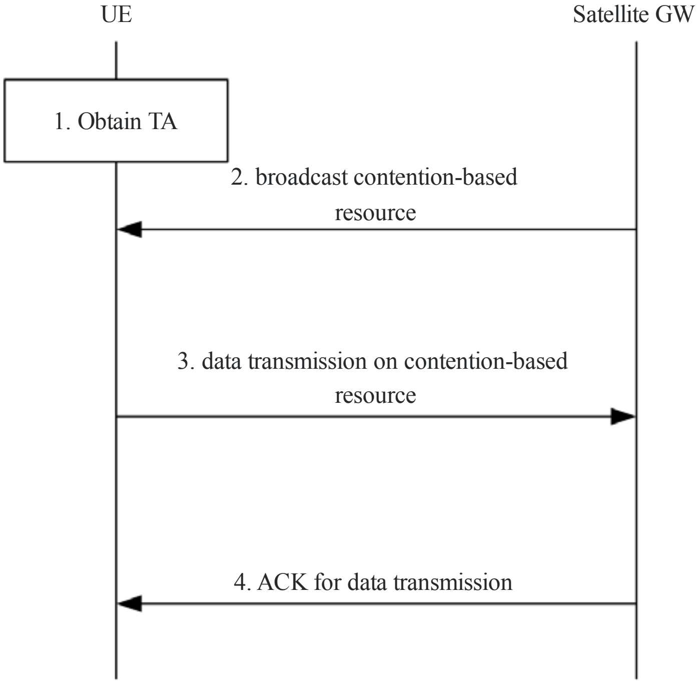
In case the UE can obtain the accurate TA value in advance, the random access procedure can be avoided and the RACH-less access procedure can be used. The RACH-less access procedure is performed for the following three example cases:

1) The UE has accessed the satellite and obtained the TA value before. And the TA value stored by UE in still valid for the time span between the last access and current access is short.
2) The UE deduces the TA value between itself and the satellite through the implementation method, e.g. the UE can obtain the distance between itself and the satellite using the global navigation satellite system (GNSS).
3) A satellite broadcasts a reference time in UTC, a UE equipped with GNSS can deduce the TA value according to the time difference between the time it receives the broadcast message and the reference time value from the satellite.

In the RACH-less access procedure, the satellite gateway broadcasts a set of contention-based PRBs, the access UE chooses one contention-based PRB to send data with its identifier. If the data transmission is successful, the satellite gateway should send UE a response. Otherwise, an access collision may occur, UE may retry the access procedure after a random back-off time.

FIGURE 1.17

RACH-less access



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NOTE – If the calculated TA is larger than the cycle time *T* of contention-based PRBs, TA = TA mod *T*.

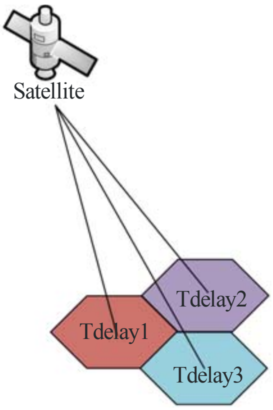
1.1.3.4.2 RACH optimization

In case UE cannot obtain the TA value in advance, the LTE RACH procedure can be reused. Two points of optimization can be adopted.

1) For the diameter of a satellite beam ranging from 100 to 500 km, the time difference of the satellite receiving the uplink synchronization codes from different UEs in the same beam may exceed the synchronization detection window. Therefore, the length of CP and GT needs to be adjusted according to the beam range (see § 1.1.3.7).
2) For the satellite having a number of beams, the transmission delay from the satellite to each beam is different. To ensure the RACH preambles from different beams to arrive the satellite in the detection window, the satellite broadcasts the propagation delay (i.e. T delay) from satellite to reference location of a beam (e.g. the centre of a beam) in each satellite beam. The UEs in the beam then set RACH preamble transmission time according to the T delay to make sure the preamble can be received by satellite in the detection window.

FIGURE 1.18

Broadcasting of the propagation delay from satellite to reference location of a beam (Example)



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1.1.3.5 Handover optimization

Compared with the terrestrial LTE system, the handover procedure in satellite communication system is more complex. Three handover scenarios are introduced: intra-satellite inter-beam handover, satellite to terrestrial handover and terrestrial to satellite handover. Some enhancements to optimize the handover procedure should be considered to reduce the handover interruption time caused by the long propagation delay.

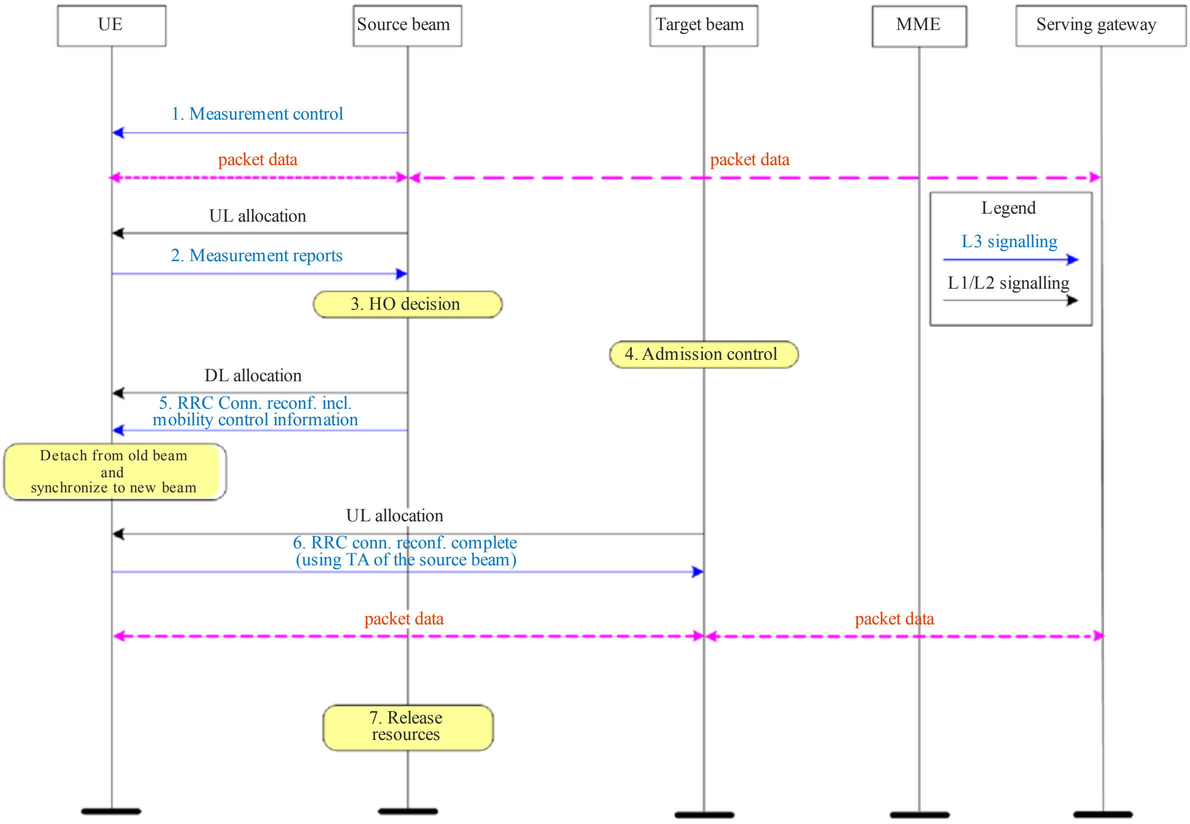
Handover is based on UE assisted network control, i.e. the handover decision for a UE in connected mode is made by the network, based on possible measurement reports from the UE. The UE measurements are based on the reference symbol strength or quality, and various measurement reporting conditions are configurable by the network.

1.1.3.5.1 Intra-satellite inter-beam handover

Inter-beam tight synchronization usually can be achieved, and the uplink time advances of source beam and target beam are the same. Based on this tight synchronization, the handover UE can avoid performing the RACH procedure in the target beam to accelerate the handover procedure. After the handover command is sent from the source beam, the target beam can directly schedule the handover UE in the target beam. When UE receives the handover command, it immediately hands over to the target beam to listen to the schedule. It can be expected that the handover interruption time is very short, e.g. several ms.

FIGURE 1.19

Intra-satellite inter-beam handover



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1.1.3.5.2 Satellite to terrestrial handover

In this case, the existing LTE handover procedure can be re-used directly. It can be expected that the interruption time is the same as the terrestrial LTE system, i.e. about 10 ms.

1.1.3.5.3 Terrestrial to satellite handover

In this case, the handover interruption time can be optimized with pre-synchronization procedure. To shorten the handover interruption time, the terrestrial eNodeB can indicate the handover UE to establish the uplink synchronization with the target satellite beam before sending the handover command. This implies that the UE should support the communication with both terrestrial and satellite simultaneously to establish the uplink synchronization with the target satellite beam before leaving the source cell, or the UE should be equipped with GNSS to deduce TA. After receiving the handover command, UE immediately sends the handover complete message to the target satellite beam (NOTE – The RB resources to send the handover complete message and relating information can be provided in handover command). When the satellite gateway receives the handover complete message, the handover procedure is completed successfully and the data transmission can be continued. In this way, the interruption time caused by the uplink synchronization procedure is avoided. However, there is still about 480 ms (GEO as an example) handover interruption time: 240 ms (the time of handover complete message from the UE to the satellite gateway) + 240 ms (the time of data from the satellite to the UE).

1.1.3.6 Paging enhancement

The terminal of satellite mobile communication systems sometimes works in very low SNR regions such as indoor environments or strong shadowed environments. In these scenarios, the signal strength will be much lower than the SNR threshold of normal paging decoding, which means a coming call cannot reach the user.

This problem is solved by means of enhanced paging in BMSat. The enhanced paging can inform the users who are in strong shadowed environment, that a call is coming, and the user can choose to move outdoor or out of the shadowing to receive the call. For this purpose, the decoding threshold for enhanced paging should be much lower than that of the normal paging.

For enhanced paging, a new physical channel E-PPCH within the LTE frame structure is designed in BMSat.

1.1.3.6.1 Payload on E-PPCH

For normal paging in LTE, an S-TMSI (temporary mobile subscriber identity) is used for searching a user in the tracking area. The S-TMSI is composed of 8 bits MMEC (mobility management entity code) and 32 bits M-TMSI. MME is an entity for control message processing in the core networks of LTE. Several MMEs compose a MME pool, and the MMEC is used to uniquely identify a MME within an MME pool. The M-TMSI is a temporary identity for a subscriber in one MME.

Generally, one MME is enough for one satellite gateway, thus, M-TMSI is enough for normal paging and enhanced paging in BMSat, and MMEC is not necessary for BMSat.

1.1.3.6.2 Resource allocation for E-PPCH

Since E-PPCH is a new physical channel designed for enhanced paging, the mapping of the message to resource elements in BMSat should be arranged carefully to avoid superposition with control channels and synchronization channels.

Figure 1.20 shows the frequency-time resources in BMSat for slot 0/slot 10 and slot 1/ slot 11. The basic unit for resource allocation in BMSat is a PRB (physical resource block), which is composed of 12 subcarriers (180 kHz) during one slot (7 OFDM symbols). The first three OFDM symbols in each TTI (composed of two slots) are usually used for control information, and the 6th and 7th OFDM symbols of the central 6 PRBs (72 subcarriers) in slot 0 and slot 10 are used for SSS (secondary synchronization signal) and PSS (primary synchronization signal), respectively.

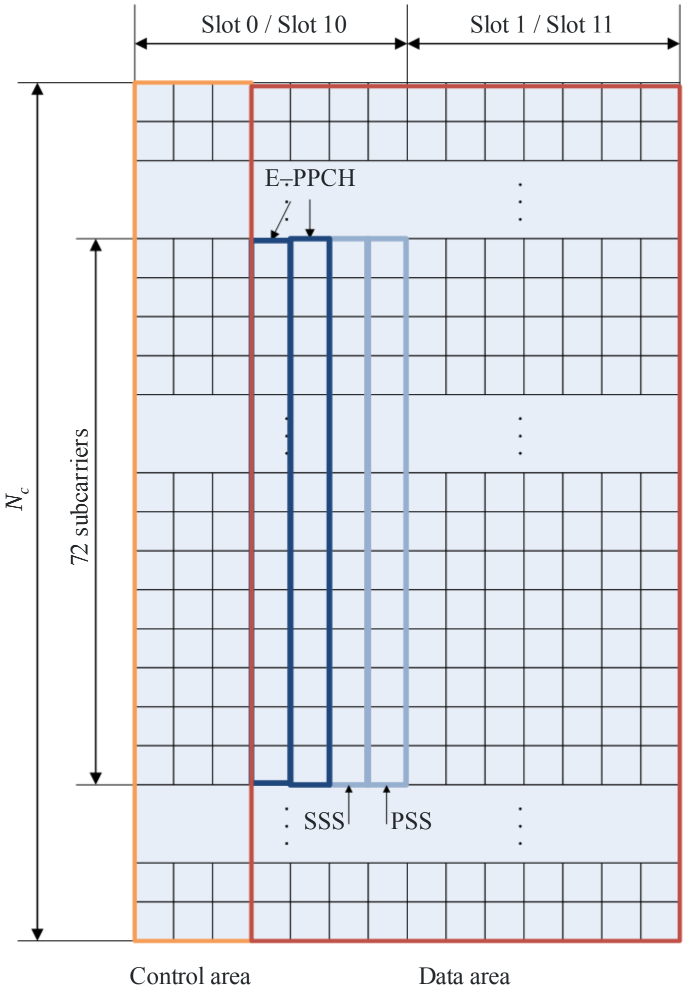
Based on the above considerations, the 4th and the 5th OFDM symbols of the central 6 PRBs in slot 0 and slot 10 are assigned as E-PPCH as shown in Fig. 1.20.

1.1.3.6.3 Reliable transmission of enhanced paging

To increase the SNR for enhanced paging decoding, two approaches are considered. The first is to apply “time spread” to decrease the decoding SNR threshold. By “time spread”, the short message is extended by dozens of times, so that spread gain can be obtained at the receiver by “time de-spread”. For further performance improvement, the time spread message can be repeated several times as required. The second approach is to increase the transmit power of the E-PPCH signal.

FIGURE 1.20

Resource allocation for E-PPCH



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1.1.3.6.4 Energy saving for un-targeted users

By time spread, the 32 bits M-TMSI may be extended by dozens of times. If the extended sequence is transmitted as a whole, the recovery of the M-TMSI message at the receiver will take a long time. In this case, the un-targeted users will waste a lot of energy before knowing that the M-TMSI in the message does not match their own M-TMSI.

To solve this problem, the 32 bits M-TMSI is divided into S segments with 32/S bits in each segment. All users will decode the message segment by segment, and do the comparison of the current decoded segment to the corresponding part of their own M-TMSI.

The decoding of the following segments of the message will go on only when the previous received segments all match the local M-TMSI. In this way, the un-targeted users can stop the detection as soon as possible, so that much of the energy is saved.

1.1.3.6.5 Procedure for the enhanced paging

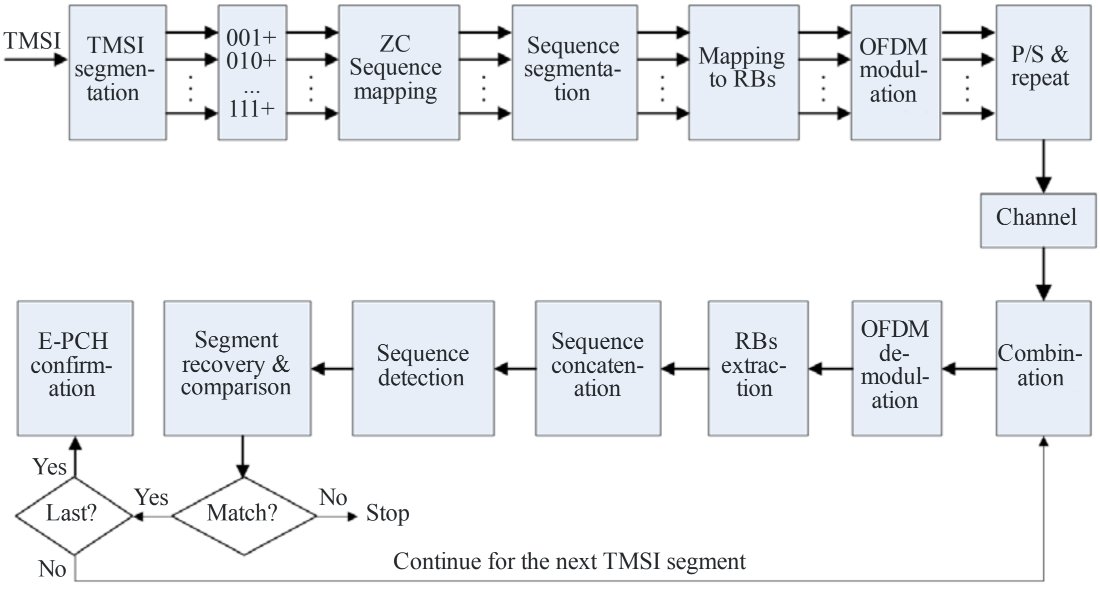
The whole procedure is shown in Fig. 1.21. At the transmitter, the 32 bits M-TMSI message is firstly divided into several segments. Each segment is then attached a segment ID, which is used for the segment comparison at the receiver. Each M-TMSI segment with ID is then mapped to a Zadoff-Chu sequence, which is actually the time spread process. Since the Zadoff-Chu sequence for each M-TMSI segment is usually longer than 72, it should be divided into several segments firstly, and then mapped to the allocated resource blocks. After OFDM modulation, the whole message is repeated as required.

At the receiver, the repeated message is firstly combined for current M-TMSI segment. After OFDM demodulation and resource blocks extraction, the segments of sequence for current M-TMSI are concatenated. The ML method can then be used for sequence detection, and the current M-TMSI segment with its segment ID is recovered according to the sequence mapping rules. With the help of the segment ID, the receiver compares the received M-TMSI segment with the corresponding part of the local M-TMSI. If current M-TMSI segment matches, the receiver will continue to detect the next M-TMSI segment. Otherwise, the receiver will stop for the E-PPCH detection. When the whole received M-TMSI matches the local M-TMSI, the receiver can inform the user that an E-PPCH is received.

E-PPCH configurations are broadcasted in system information blocks.

FIGURE 1.21

A complete design for enhanced paging



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1.1.3.7 Specific modification for long delay

1.1.3.7.1 PRACH configuration

In the terrestrial LTE system, several PRACH configurations are defined to support a maximum of 100 km coverage range. Satellite beam coverage targets to support much wider area with diameter from 100 km to 500 km. One PRACH configuration “sat1” is added in BMSat in Table 1.1.

TABLE 1.1

PRACH configuration

Preamble format	**TCP**	**TSEQ**	**Sequence Length**	**GT**
0	$3168T_s$	$24576T_s$	839	≈97.4 us
1	$21024T_s$	$24576T_s$	839	≈516 us
2	$6240T_s$	$2*24576T_s$	839	≈197.4 us
3	$21024T_s$	$2*24576T_s$	839	≈716 us
4 (frame structure type 2 only)	$448T_s$	$4096T_s$	139	≈9.4 us
Sat1	$41024T_s$	$2*24576T_s$	839	≈1280 us

1.1.3.7.2 Period CQI feedback configuration

The maximal CQI feedback period of terrestrial LTE system is 160 ms. It is extended to support a maximum of 2 048 ms in BMSat.

TABLE 1.2

CQI feedback configuration

$I_{CQI/PMI}$	**Value of** N_{pd}	**Value of** $N_{OFFSET,CQI}$
$0 \leq I_{CQI/PMI} \leq 1$	2	$I_{CQI/PMI}$
$2 \leq I_{CQI/PMI} \leq 6$	5	$I_{CQI/PMI} - 2$
$7 \leq I_{CQI/PMI} \leq 16$	10	$I_{CQI/PMI} - 7$
$17 \leq I_{CQI/PMI} \leq 36$	20	$I_{CQI/PMI} - 17$
$37 \leq I_{CQI/PMI} \leq 76$	40	$I_{CQI/PMI} - 37$
$77 \leq I_{CQI/PMI} \leq 156$	80	$I_{CQI/PMI} - 77$
$157 \leq I_{CQI/PMI} \leq 316$	160	$I_{CQI/PMI} - 157$
$I_{CQI/PMI} = 317$	Reserved	
$318 \leq I_{CQI/PMI} \leq 349$	32	$I_{CQI/PMI} - 318$
$350 \leq I_{CQI/PMI} \leq 413$	64	$I_{CQI/PMI} - 350$
$414 \leq I_{CQI/PMI} \leq 541$	128	$I_{CQI/PMI} - 414$
$542 \leq I_{CQI/PMI} \leq 641$*	256	$I_{CQI/PMI} - 542$
$642 \leq I_{CQI/PMI} \leq 741$*	512	$I_{CQI/PMI} - 642$

TABLE 1.2 (*end*)

$I_{CQI/PMI}$	**Value of** N_{pd}	**Value of** $N_{OFFSET,CQI}$
$742 \leq I_{CQI/PMI} \leq 841$*	1024	$I_{CQI/PMI} - 742$
$842 \leq I_{CQI/PMI} \leq 941$*	2048	$I_{CQI/PMI} - 842$
$942 \leq I_{CQI/PMI} \leq 1023$	Reserved	

1.1.3.7.3 QCI table

There are 9 standardized classes of QCI level pre-defined in LTE system to support a wide range of services. The services with very short delay like real-time gaming cannot be supported by satellite communication. Therefore, the original LTE QCI 3 is deleted in BMSat and other eight standardized QCI classes are left in BMSat. In addition, the packet delay budget is optimized to support satellite long delay.

TABLE 1.3

QCI configuration

QCI	**Resource type**	**Priority**	**Packet delay budget**	**Packet error loss rate**	**Example services**
1	GBR	2	100 ms + x	10^{-2}	Conversational voice
2		3	150 ms + x	10^{-3}	Conversational video (live streaming)
3		4	300 ms + 2x	10^{-6}	Non-conversational video (buffered streaming)
4	Non-GBR	1	100 ms + 2x	10^{-6}	IMS signalling
5		5	300 ms + 2x	10^{-6}	Video (buffered streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
6		6	100 ms + 2x	10^{-3}	Voice, Video (live streaming) Interactive gaming
7		7	300 ms + 2x	10^{-6}	Video (buffered streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file)
8		8			sharing, progressive video, etc.

NOTE – x is the average transmission delay between UE and satellite gateway.

"+x", service is assumed to be transmitted with RLC UM;

"+2x", service is assumed to be transmitted with RLC AM.

1.1.3.8 Network coding

In mobile-satellite communication systems, a simple XOR-based network coding technology is used to improve the downlink frequency efficiency.

First, the connected two users transmit messages in different uplink channels. Second, the ground station (or the on-board processor) decodes the messages from two uplink channels, and transmits the XOR of the two decoded messages in the same downlink channel. Third, the two users decode the XOR message and recover the message from the other user by XOR the received message with the uplink message of itself. The mobile satellite communication system is power limited, especially for downlink transmission, so using one downlink channel to serve two users, the system capacity improves significantly.

1.2 Detailed specification of the radio interface technology

The detailed specifications of IMT-Advanced satellite radio interface technology entitled BMSat were uploaded in the web site of China Communications Standards Association (CCSA).

The BMSat specifications are based upon the LTE-Advanced specifications, and their relationship is defined in Table 1.4.

TABLE 1.4

Relationship between BMSat specifications and LTE-Advanced specifications

Terminology	Definition
LTE-Advanced applies	The feature of this BMSat specification is identical to that of LTE-Advanced, and hence the associated LTE-Advanced specification applies.
BMSat specific	This BMSat specification describes a new BMSat feature that has no equivalent feature in LTE-Advanced.
Replaces LTE-Advanced	The BMSat specification is a replacement for the associated LTE-Advanced specification. The BMSat specification may make reference to the associated LTE-Advanced specification.

The BMSat family of specifications are organized in document series that correspond to the LTE-Advanced document structure as shown in Table 1.5.

TABLE 1.5

Structure of the BMSat family of specifications

	BMSat	LTE-Advanced
BMSat Specific	TS 36.0xx.2 series	
Radio Layer 1	TS 36.2xx.0/2 series	TS 36.2xx series
Radio Layers 2&3	TS 36.3xx.0/2 series	TS 36.3xx series
Architecture	TS 36.4xx.0/2 series	TS 36.4xx series

where:

- TS xx.yyy.0 is used for BMSat specifications that have a corresponding LTE-Advanced specification. In this case, the numbers xx and yyy correspond to the LTE-Advanced numbering scheme.
- TS xx.yyy.2 is used for BMSat specifications that do not correspond to an LTE-Advanced specification. In this case, only the number xx corresponds to the LTE-Advanced numbering scheme and the number yyy is allocated by BMSat.

The complete contents of the BMSat family of specifications are given in TS BMSat 36.001.2. This section only briefly introduces the specifications that define the differences (i.e. the modifications) relative to the terrestrial LTE-Advanced specifications, i.e. the specifications that are "BMSat specific" and "Replaces LTE-Advanced".

1.2.1 BMSat Specific

1.2.1.1 TS BMSat 36.001.2

Introduction to the BMSat family

This document gives a general introduction to the specifications in the BMSat family.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.1.2 TS BMSat 36.002.2

BMSat; General Description

This document is a general description to the BMSat system and the associated air interface specification. It is intended to point out some of the differences between the terrestrial LTE-Advanced system and the mobile satellite BMSat system.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.2 Radio Layer 1

1.2.2.1 TS BMSat 36.201.0

Evolved Universal Satellite Radio Access (E-USRA); BMSat physical layer; General description

This document provides a general description of the physical layer of the E-USRA radio interface. This document also describes the document structure of the E-USRA physical layer specifications, i.e. TS BMSat 36.200 series. The TS BMSat 36.200 series specifies the Uu point for the BMSat systems, and defines the minimum level of specifications required for basic connections in terms of mutual connectivity and compatibility.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.2.2 TS BMSat 36.211.0

Evolved Universal Satellite Radio Access (E-USRA); Physical channels and modulation

This document describes the physical channels and modulation for E-USRA.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.2.3 TS BMSat 36.212.0

Evolved Universal Satellite Radio Access (E-USRA); Multiplexing and channel coding

This document specifies the coding, multiplexing and mapping to physical channels for E-USRA.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.2.4 TS BMSat 36.213.0

Evolved Universal Satellite Radio Access (E-USRA); Physical layer procedures

This document specifies and establishes the characteristics of the physical layer procedures for E-USRA.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.2.5 TS BMSat 36.216.0

Evolved Universal Satellite Radio Access (E-USRA); Physical layer for CGC operation

This document describes the characteristics of the transmissions between SAT-eNB and CGC transmissions.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.3 Radio Layers 2&3

1.2.3.1 TS BMSat 36.300.0

Evolved Universal Satellite Radio Access (E-USRA) and Evolved Universal Satellite Radio Access Network (E-USRAN); Overall description; Stage 2

This document provides an overview and overall description of the E-USRAN radio interface protocol architecture. Details of the radio interface protocols are specified in companion specifications of the 36 series.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.3.2 TS BMSat 36.321.0

Evolved Universal Satellite Radio Access (E-USRA); Medium Access Control (MAC) protocol specification

This document specifies the E-USRA Medium Access Control (MAC) protocol.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.3.3 TS BMSat 36.331.0

Evolved Universal Satellite Radio Access (E-USRA); Radio Resource Control (RRC); Protocol specification

This document specifies the Radio Resource Control protocol for the radio interface between UE and E-USRAN as well as for the radio interface between CGC and E-USRAN.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

1.2.4 Architecture

1.2.4.1 TS BMSat 36.423.0

Evolved Universal Satellite Radio Access Network (E-USRAN); X2 Application Protocol (X2AP)

This document specifies the radio network layer procedures of the control plane between SAT-eNBs in E-USRAN. X2AP supports the functions of X2 interface by procedures defined in this document.

Location: http://www.ccsa.org.cn/english/files.php?docpath=/ITU-R/BMSat.

Annex 2

Specification of the SAT-OFDM radio interface technology

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Page

2.1 Introduction

The SAT-OFDM is a satellite radio interface to provide various advanced mobile telecommunication services defined for the IMT satellite environments. This radio interface could be applied for geostationary-satellite orbit (GSO) satellites for global international communications.

The SAT-OFDM adopts orthogonal frequency division multiple access (OFDMA) in downlink (space-to-Earth) and single carrier frequency division multiple access (SC-FDMA) in uplink (Earth to-space).

The radio interface has a high degree of commonality with the terrestrial radio specifications, 3GPP long term evolution (LTE) technology for IMT-Advanced services, but it also has a number of different features. Those features, which are necessary to reflect the satellite-specific characteristics such as long round trip delay and slow fading satellite channel, are implemented in the form of random access, interleaving, closed loop power control and so on.

In this regard, the radio interface has two operational modes which are normal mode and enhancing mode. The normal mode is fully compatible with 3GPP LTE Release 8, while the enhancing mode provides performance enhancement by incorporating additional satellite specific features. The satellite RAN should support both modes while the UE support either the normal mode only or both modes.

2.2 IMT-Advanced system description using the SAT-OFDM

2.2.1 Architectural description

Figure 2.1 describes an overall system architecture using the SAT-OFDM. The following factors are considered.

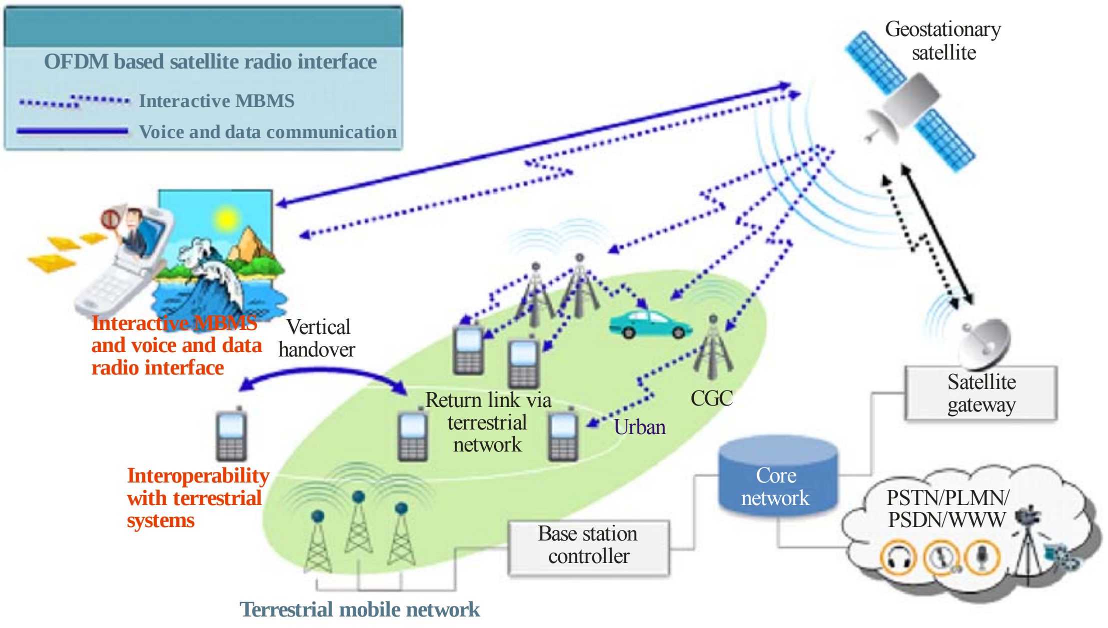
– Satellite: It will provide services and applications similar to those of terrestrial systems outside terrestrial and complementary ground component (CGC) coverage under the inherent constraints imposed by power limitation and long round trip delay.

– CGC: In order to provide mobile satellite broadcasting/multicasting services, they can be deployed in areas where satellite reception is difficult, especially in urban areas. They may be collocated with terrestrial cell sites or standalone.

– IMT-Advanced terrestrial component: Satellite component can provide voice and data communication service in regions outside terrestrial coverage. The areas not adequately covered by terrestrial component include physically isolated regions, gap of terrestrial component and areas where terrestrial component permanently, or temporarily, inoperative due to circumstances.

FIGURE 2.1

An example of IMT-Advanced system architecture using the SAT-OFDM



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The two-way communication scenario is regarded as a coverage extension and service continuity of the terrestrial part. In the scenario, a handover technique with terrestrial part would be most importantly considered. For the cost-effective handover, future satellite radio interfaces should be compatible and have a high degree of common functionality with an envisaged LTE-based terrestrial radio system. It would also be possible to reuse terrestrial part technology to minimize user terminal chipset and network equipment for low cost and fast development.

In addition, the SAT-OFDM can be used to provide efficient interactive multimedia broadcasting services, since the envisaged terrestrial mobile radio interfaces can handle services for broadcast as well as a bidirectional communication in a cellular system. Indeed, the satellite component has an advantage over the terrestrial component for the delivery of the same content to spread over a wide geographic area.

2.2.1.1 Constellation

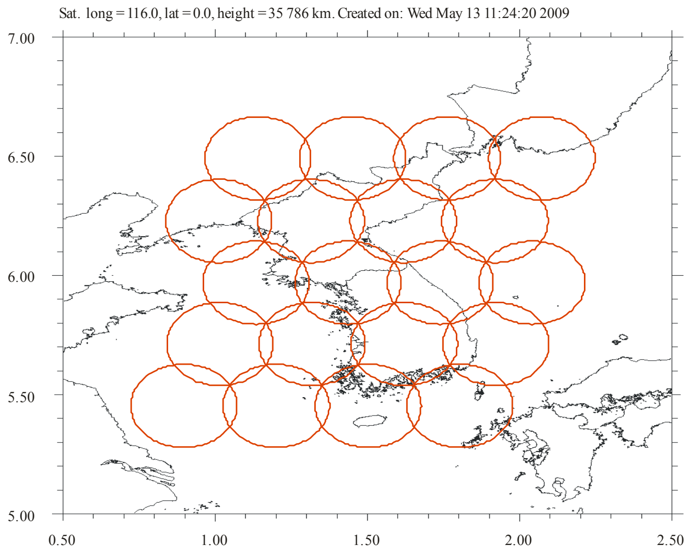
This interface is able to cope with several satellite constellation types, i.e. low Earth orbit (LEO), high Earth orbit (HEO), medium Earth orbit (MEO) or GSO. It is noted however that descriptions in the following sections are mostly based on the GSO constellation type.

2.2.1.2 Satellites

Several architectures are envisaged depending on throughput requirements, e.g. global beam, multi-beam, and multi-satellite configurations. Figure 2.2 shows an example of the multi-beam configuration, and this configuration is used to estimate system characteristics including RF specifications.

FIGURE 2.2

Multi-beam configuration example with a 24 m satellite antenna



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2.2.2 System description

2.2.2.1 Service features

This radio interface could provide a wide range of telecommunication services indicated in Recommendation ITU-R M.1822 to mobile users, as shown in Table 2.1.

TABLE 2.1

Supportable services

User experience class	Service class	Example services
Conversational	Basic conversational	Voice telephony (including VoIP) Emergency calling Push-to-talk
	Rich conversational	Videoconference High-quality video telephony Remote collaboration e-education (e.g. video call to teacher) Consultation (e.g. video interaction with doctor) Mobile commerce
	Conversational low delay	Interactive gaming Consultation Priority service
Interactive	Interactive high delay	e-education (e.g. data search) Consultation (e.g. data search) Internet browsing Mobile commerce Location-based services ITS-enabled services
	Interactive low delay	Emergency calling e-mail (IMAP server access) Remote collaboration (e.g. desktop sharing) Public alerting (e.g. with feedback) Messaging (instant messaging) Mobile broadcasting/multicasting (mobile interactive personalized TV) Interactive gaming
Streaming	Streaming live	Emergency calling Public alerting e-education (e.g. remote lecture) Consultation (e.g. remote monitoring), Machine-to-machine (e.g. observation) Mobile broadcasting/multicasting Multimedia
	Streaming non-live	Mobile broadcasting/multicasting e-education (e.g. education movies) Multimedia Mobile commerce Remote collaboration

TABLE 2.1 (*end*)

User experience class	Service class	Example services
Background	Background	Messaging, Video messaging Public alerting e-mail (transfer RX/TX, e.g. POP) Machine-to-machine File transfer/download e-education (file download/upload) Consultation (file download/upload) Internet browsing Location-based service

Quality of service (QoS) for various telecommunication services supported by this interface would be different from that in the terrestrial component of IMT-Advanced due to inherent satellite features such as long round trip delay. In this interface, maximum transfer delay of one way for the real time services at the bearer transport level could be less than 400 ms in the range of values 1×10^{-3} to 1×10^{-7} of BER.

2.2.2.2 System features

This radio interface is based on the key technical characteristics listed in Table 2.2.

TABLE 2.2

Key technical characteristics of the SAT-OFDM

Multiple-access scheme	OFDMA (downlink), SC-FDMA (uplink)
Duplex scheme	Frequency division duplexing (FDD)
Chip rate	A multiple or submultiple of 3.84 Mcps
subcarrier spacing	15 kHz
Carrier spacing	1.3, 3, 5, 10, 15, 20 MHz
Frame length	10 ms
Inter-spot synchronization	No accurate synchronization needed (Accurate synchronization needed for inter-beam coordination)
Multi-rate/Variable-rate scheme	Variable modulations and coding rates + multi-layer
Channel coding scheme	Convolutional coding 1/3 Turbo coding 1/3

2.2.2.3 Terminal features

The user equipment may be of various types: hand-held, portable, vehicular, transportable or aeronautical. The data rate and mobility restriction for each type of terminal are described in Table 2.3. For the maximum capacity assessment it is necessary to distinguish data rates of the forward link from those of the return link.

TABLE 2.3

Mobility restrictions for each terminal type

Terminal types	Data rates of the applied services (return link) (bps/(Hz·layer))	Data rates of the applied services (forward link) (bps/(Hz·layer))	Nominal mobility restriction (km/h)
Hand-held (class 3)	≤ 0.089	≤ 1.556	500
Portable	≤ 1.156	≤ 1.556	500
Vehicular	≤ 1.556	≤ 1.556	500 (maximum 1 000)
Transportable	≤ 1.556	≤ 1.556	Static

2.2.2.4 Handover

This radio interface will support handover of communications from one satellite radio channel to another. The handover strategy is mobile-assisted network-decided handover.

Only hard handover is supported.

The following handover types are the most common in the system.

Beam handover

The UE periodically measures the level of the reference symbol $C/(N + I)$ coming from adjacent beams and report such information to the satellite RAN. Based on the measurement reports, the serving satellite beam starts handover preparation which may involve exchange of signalling between serving and target beams and admission control of the UE in the target beam. Upon successful handover preparation, the handover decision is made and consequently, the handover command will be sent to the UE. The connection between UE and the serving beam will be released, then the UE attempts to synchronize and access the target beam by using the random access channel.

Inter-satellite handover

The procedure is analogous to that of inter-beam handover. The only difference is that the UE has also to search for different satellite specific reference symbol identities.

Inter-frequency handover

Inter-frequency handover may not generally be needed. This handover is decided by the satellite RAN without any support by the UE (i.e. this handover type is not a mobile-assisted handoff).

On the reverse link, the satellite RAN can instead combine all signals received from the same UE through different beams and/or satellites.

2.3 RF specifications

2.3.1 Satellite (space station)

Satellite characteristics considered in performance evaluation are summarized in Table 2.4.

TABLE 2.4

Satellite multi-beam architecture with 24 m satellite antenna

Number of spot beams	20
Downlink frequency (satellite to UE) (MHz) Polarisation On board e.i.r.p. per carrier (dBW)	2 170-2 200 LHCP or RHCP 73
Uplink frequency (UE to satellite) (MHz) Polarisation Rx Antenna gain (dB)	1 980-2 010 LHCP or RHCP ≤ 50

2.3.2 Mobile earth station (MES)

The mobile earth station is also named User Equipment (UE). The UE may be of several types:

3G standardized handset: the use in satellite environment requires adaptation for frequency agility to the MSS frequency band. The basic assumption is UE power class 1, 2 and 3, equipped with standard omni-directional antenna.

Portable: the portable configuration is built with a notebook PC to which an external antenna is appended.

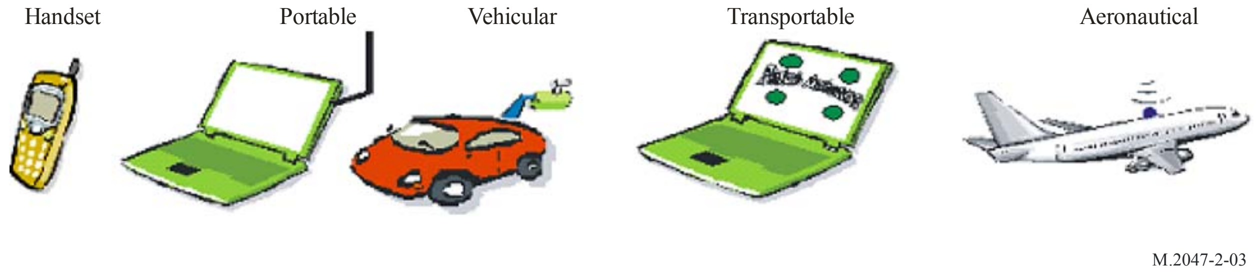
Vehicular: the vehicular configuration is obtained by mounting an RF module on a car roof connected to the UE in the cockpit.

Transportable: the transportable configuration is built with a notebook of which the cover contains flat patch antennas (manually pointed towards the satellite).

Aeronautical: aeronautical configuration is built by mounting an antenna on top of the fuselage.

FIGURE 2.3

UE configuration



The power and gain characteristics for four UE configurations are summarized in Table 2.5.

TABLE 2.5

UE characteristics

UE type	Maximum transmit power	Reference antenna gain	Maximum e.i.r.p.	System temp.	*G/T*
3G Handset					
Class 1	2 W (33 dBm)	0 dBi	3 dBW	290 K	–24.6 dB/K
Class 2	500 mW (27 dBm)		–3 dBW		
Class 3	250 mW (24 dBm)		–6 dBW		
Portable	2 W (33 dBm)	2 dBi	5 dBW	200 K	–21 dB/K
Vehicular	8 W (39 dBm)	4 dBi	13 dBW	250 K	–20 dB/K
Transportable	2 W (33 dBm)	14 dBi	17 dBW	200 K	–9 dB/K

2.4 Baseband specifications

2.4.1 Multiple access

The contents in this section are normatively referenced by clause 4.2.1 of TTAT.3G-36.201[1], provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

To support transmission in paired 2 GHz band spectrum, one duplex mode is supported: Frequency Division Duplex (FDD), supporting full duplex and half duplex operation.

In downlink of enhancing mode, single-carrier frequency division multiplexing (SC-FDM) with a cyclic prefix is also supported. Details on this can be referred to § 2.4.6.6.

In uplink of enhancing mode, resource blocks narrower than 180 kHz are also supported for power-limited handheld terminals in uplink. Details on this can be referred to § 2.4.6.5.

2.4.2 Overall baseband transmission description

Overall downlink and uplink transmissions of the SAT-OFDM are described in Figs 2.4 and 2.5, respectively. The SAT-OFDM has basically the same transmission blocks with 3GPP LTE release eight radio interface for commonality but can also modify some blocks or add new blocks in order to adopt satellite-specific features.

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[1] Standard TTAT 3G-36.201 is the transposed document of 3GPP TS 36.201 http://committee.tta.or.kr/include/Download.jsp?filename=stnfile/TTAT.3G-36.201(R8-8.3.0).zip. TTA is one of the identified Transposing Organizations of 3GPP LTE(-Advanced) specifications.

FIGURE 2.4

Downlink transmissions in the SAT-OFDM

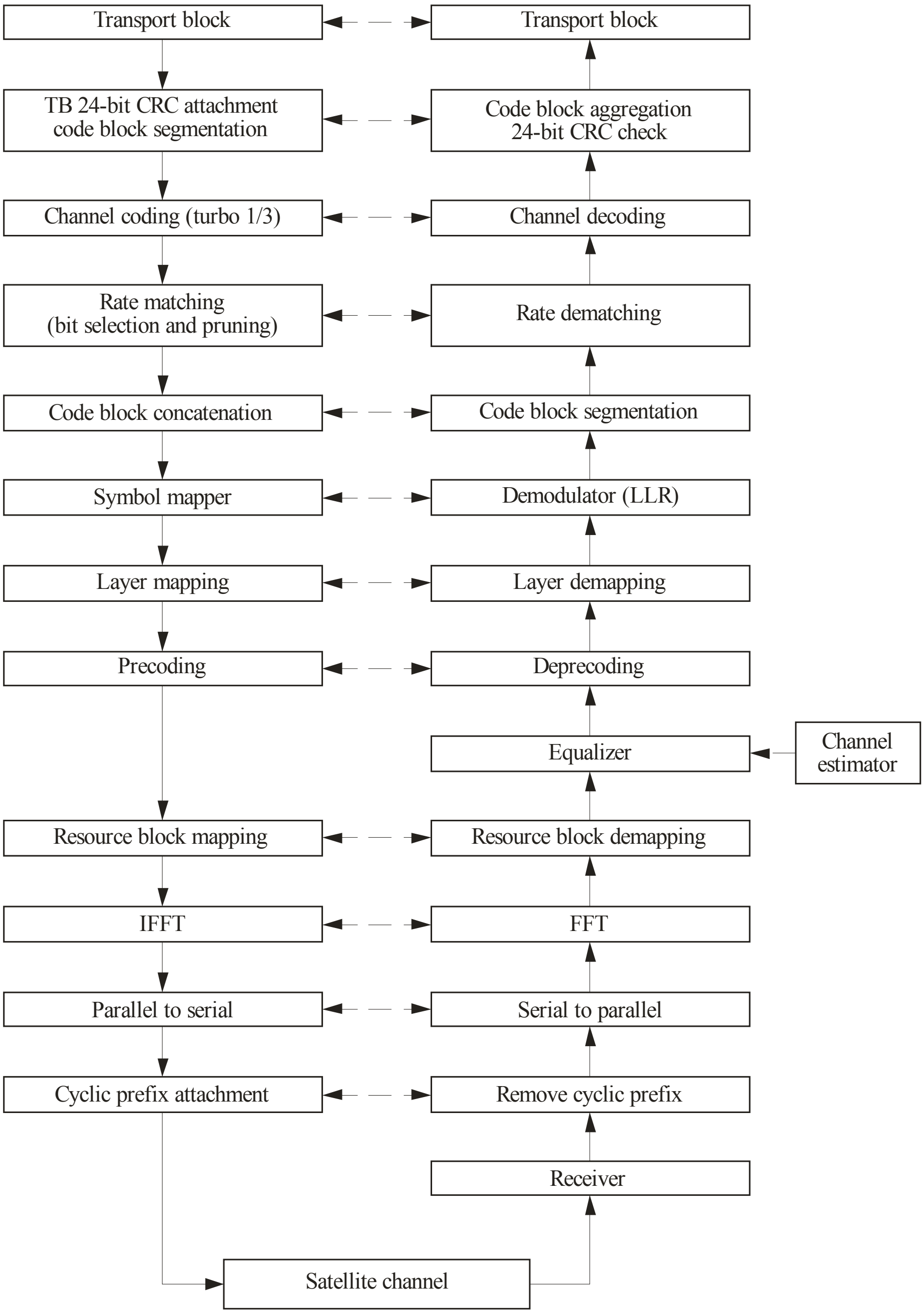

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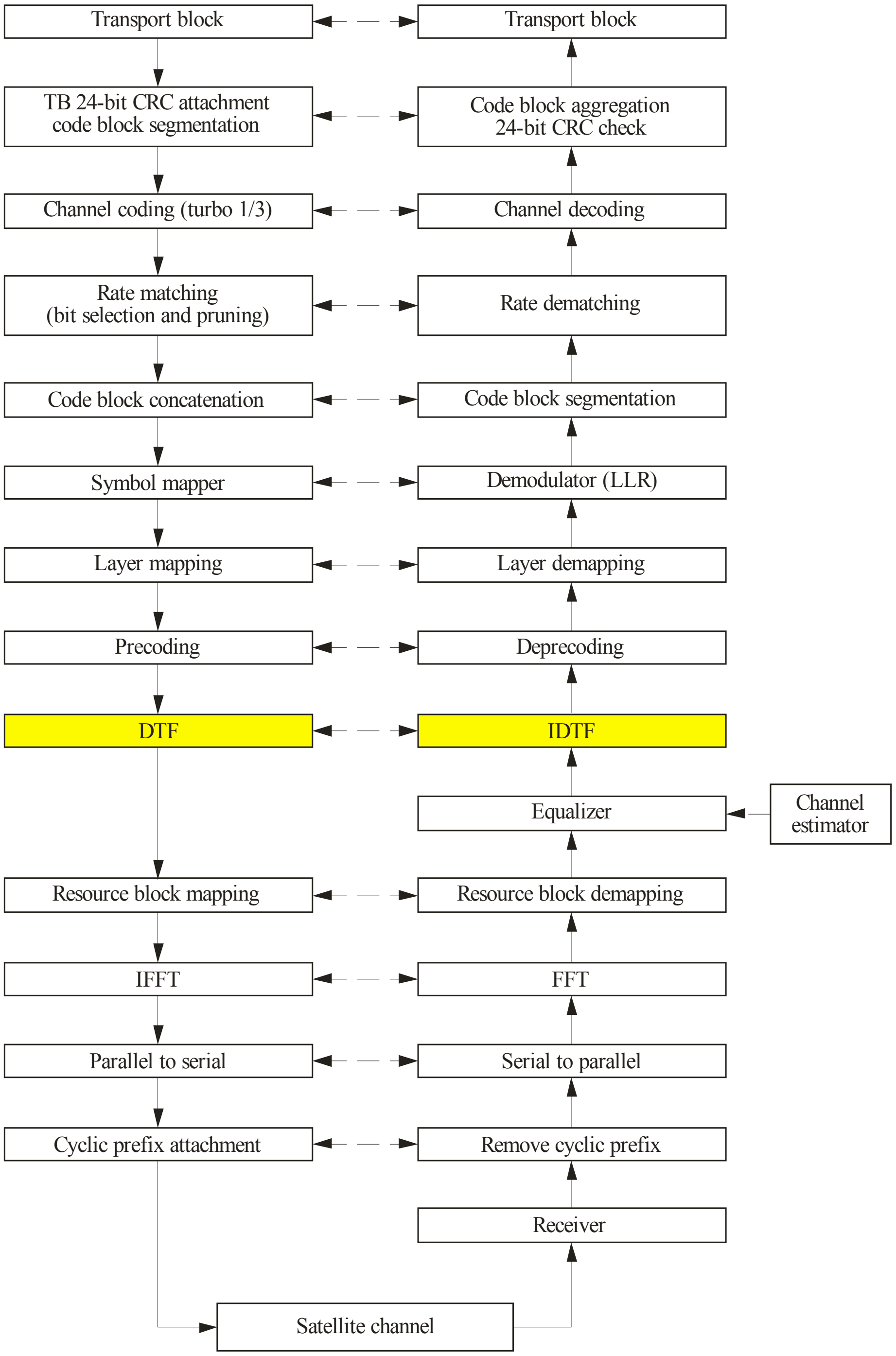
FIGURE 2.5

Uplink transmissions in the SAT-OFDM



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2.4.3 Physical channels and timing relations

The following physical channels are defined in the SAT-OFDM.

– Downlink
  - Physical channels: user data, control, information
    - – PDSCH (Physical Downlink Shared Channel)
    - – PMCH (Physical Multicast Channel)
    - – PDCCH (Physical Downlink Control Channel)

    - PBCH (Physical Broadcast Channel)
    - PCFICH (Physical Control Format Indicator Channel)
    - PHICH (Physical Hybrid ARQ Indicator Channel)
  - Physical signals: cell search, channel estimation
    - RS (Reference Signal)
    - SCH (Synchronization signal)
- Uplink
  - Physical channels: user data, control
    - PUSCH (Physical Uplink Shared Channel)
    - PUCCH (Physical Uplink Control Channel)
    - PSRACH (Physical Satellite Random Access Channel)
  - Physical signals: channel estimation
    - RS (Reference Signal)

2.4.3.1 Frame structure

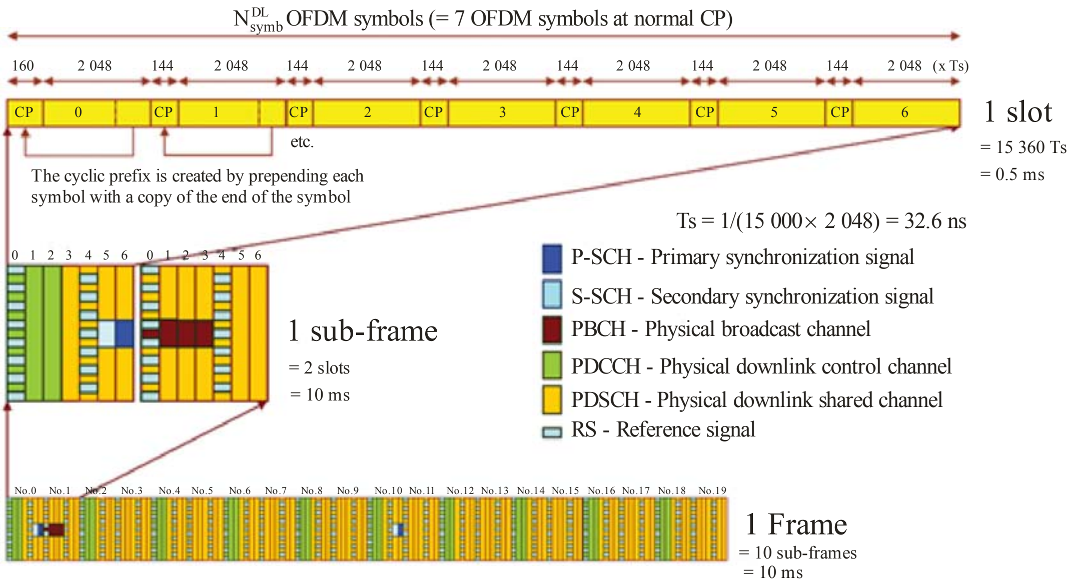
The contents in this section are normatively referenced by clause 4 of TTAT.3G-36.211[2], provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, only frame structure type 1 is supported, applicable to FDD.

Figures 2.6 and 2.7 show downlink and uplink frame structures of the SAT-OFDM with seven OFDM symbols at normal cyclic prefix, respectively.

FIGURE 2.6

Downlink frame structure of the SAT-OFDM



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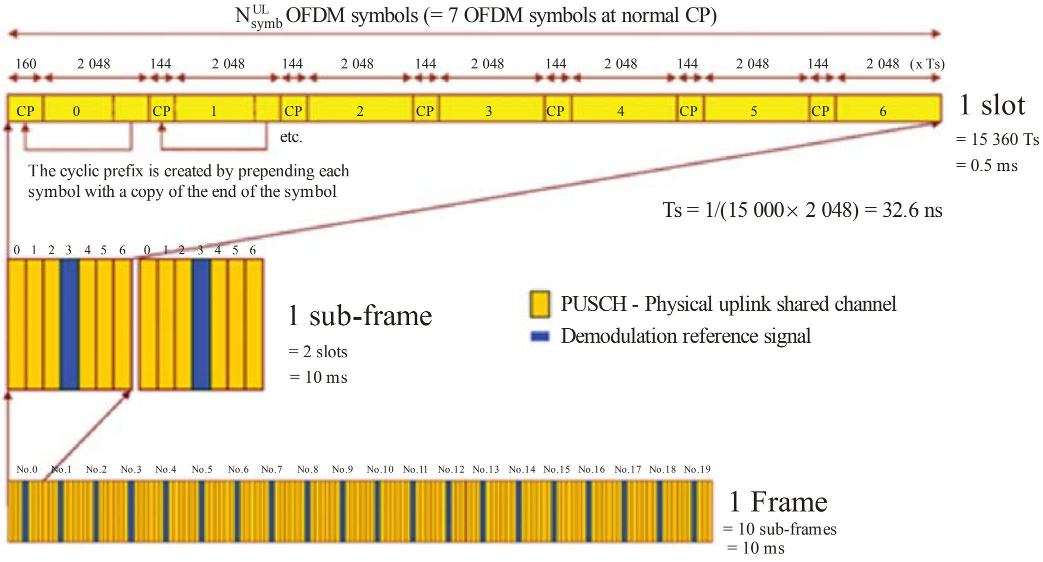
[2] Standard TTAT.3G-36.211 is the transposed document of 3GPP TS 36.211 http://committee.tta.or.kr/include/Download.jsp?filename=stnfile/TTAT.3G-36.211(R8-8.6.0).zip.

FIGURE 2.7

Uplink frame structure of the SAT-OFDM



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2.4.3.2 Uplink physical channels

The contents in this section are normatively referenced by clause 5.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.1 Slot structure and physical resources

2.4.3.2.1.1 Resource grid

The contents in this section are normatively referenced by clause 5.2.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.1.2 Resource elements

The contents in this section are normatively referenced by clause 5.2.2 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.1.3 Resource blocks

The contents in this section are normatively referenced by clause 5.2.3 of TTAT.3G-36.211, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

In enhancing mode, a narrow-band physical resource block in the uplink is also supported, corresponding to 2 slots and 90 kHz, 4 slots and 45 kHz, and 6 slots and 30 kHz in the time and frequency domains, respectively.

2.4.3.2.2 Physical uplink shared channel

The contents in this section are normatively referenced by clause 5.3 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.2.1 Scrambling

The contents in this section are normatively referenced by clause 5.3.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.2.2 Modulation

The contents in this section are normatively referenced by clause 5.3.2 of TTAT.3G-36.211, provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, 64QAM modulation scheme is not supported.

TABLE 2.6

Uplink modulation schemes

Physical channel	Modulation schemes
PUSCH	QPSK, 16QAM

2.4.3.2.2.3 Transform precoding

The contents in this section are normatively referenced by clause 5.3.3 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.2.4 Mapping to physical resources

The contents in this section are normatively referenced by clause 5.3.4 of TTAT.3G-36.211, provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, TDD related operation is not considered.

2.4.3.2.3 Physical uplink control channel

The contents in this section are normatively referenced by clause 5.4 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.4 Reference signals

The contents in this section are normatively referenced by clause 5.5 of TTAT.3G-36.211, provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, TDD operation for sounding reference signal in clause 5.5.3 of TTAT.3G-36.211 is not considered.

2.4.3.2.5 SC-FDMA baseband signal generation

The contents in this section are normatively referenced by clause 5.6 of TTAT.3G-36.211, provided by TTA.

2.4.3.2.6 Physical random access channel

2.4.3.2.6.1 Operation in normal mode

The contents in this section are normatively referenced by clause 5.7.1 of TTAT.3G-36.211, provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, a physical random access channel for TDD is not considered.

2.4.3.2.6.2 Operation in enhancing mode

In enhancing mode, new RA preambles are defined for system capacity improvement in satellite environments. The parameter values are listed in Table 2.7, and the values are determined by the random access configuration. The preamble format is controlled by higher layers.

TABLE 2.7

Random access preamble parameters

Preamble format	T_{CP}	T_{SEQ}
4	$9 \cdot 6240 \cdot T_s$	$3 \cdot 24576 \cdot T_s$
5	$3 \cdot 21024 \cdot T_s$	$6 \cdot 24576 \cdot T_s$

The transmission of a random access preamble, if triggered by the MAC layer, is restricted to certain time and frequency resources. These resources are enumerated in increasing order of the subframe number within the radio frame and the physical resource blocks in the frequency domain such that index 0 corresponds to the lowest numbered physical resource block and subframe within the radio frame. PRACH resources within the radio frame are indicated by a PRACH resource index.

The physical layer random access is configured by two preamble formats listed in Table 2.7 and the subframes in which random access preamble transmission is allowed for a given configuration in frame structure type 1. The configuration index parameter of PRACH is given by higher layers. The start of the random access preamble shall be aligned with the start of the corresponding uplink subframe at the UE. For some PRACH configurations the UE may for handover purposes assume an absolute value of the relative time difference between radio frame *i* in the current beam and the target beam.

The random access opportunities for each PRACH configuration shall be alighted in time first and then in frequency if and only if time multiplexing is not sufficient to hold all opportunities of a PRACH configuration needed for a certain PRACH density value per 10 ms without overlap in time.

For preamble formats 5 and 6, the frequency multiplexing shall be done according to:

$$n_{\mathrm{PRB}}^{\mathrm{RA}} = \begin{cases} n_{\mathrm{PRB\,offset}}^{\mathrm{RA}} + 2\left\lfloor \dfrac{f_{\mathrm{RA}}}{2} \right\rfloor, & \text{if } f_{\mathrm{RA}} \bmod 2 = 0, \\ N_{\mathrm{RB}}^{\mathrm{UL}} - 2 - n_{\mathrm{PRB\,offset}}^{\mathrm{RA}} - 2\left\lfloor \dfrac{f_{\mathrm{RA}}}{2} \right\rfloor, & \text{otherwise,} \end{cases}$$

where:

$N_{\mathrm{RB}}^{\mathrm{UL}}$: number of uplink resource blocks

f_{RA}: PRACH resource frequency index within the considered time-domain location

$n_{\mathrm{PRB}}^{\mathrm{RA}}$: first physical resource block allocated to the PRACH opportunity considered and where the parameter prach-Frequency Offset

$n^{\mathrm{RA}}_{\mathrm{PRBoffset}}$: first physical resource block available for PRACH expressed as a physical resource block number configured by higher layers and fulfilling $0 \le n^{\mathrm{RA}}_{\mathrm{PRBoffset}} \le N^{\mathrm{UL}}_{\mathrm{RB}} - 2$.

The random access preambles are generated from Zadoff-Chu sequences with zero correlation zone, generated from one or several root Zadoff-Chu sequences. The network configures the set of preamble sequences which the UE is allowed to use.

There are 64 preambles available in each beam. The set of 64 preamble sequences in a beam is found by including the first, in order of increasing cyclic shift, all the available cyclic shifts of a root Zadoff-Chu sequence with the logical index RACH_ROOT_SEQUENCE, where RACH_ROOT_SEQUENCE is broadcasted as part of the System Information. Additional preamble sequences, in case 64 preambles cannot be generated from a single root Zadoff-Chu sequence, are obtained from the root sequences with the consecutive logical indexes until all the 64 sequences are found. The logical root sequence order is cyclic.

The time-continuous random access signal $s(t)$ is defined by

$$s(t) = \beta_{\mathrm{PRACH}} \sum_{k=0}^{N_{\mathrm{ZC}}-1} \sum_{n=0}^{N_{\mathrm{ZC}}-1} x_{u,v}(n) \cdot e^{-j\frac{2\pi nk}{N_{\mathrm{ZC}}}} \cdot e^{j2\pi\left(k+\varphi+K\left(k_0+\frac{1}{2}\right)\right)\Delta f_{\mathrm{RA}}\left(t-T_{\mathrm{CP}}\right)},$$

where:

$0 \le t < T_{\mathrm{SEQ}} + T_{\mathrm{CP}}$

β_{PRACH} : amplitude scaling factor in order to conform to the transmit power

$x_{u,v}(n)$: random access preambles

$$k_0 = n^{\mathrm{RA}}_{\mathrm{PRB}} N^{\mathrm{RB}}_{\mathrm{sc}} - N^{\mathrm{UL}}_{\mathrm{RB}} N^{\mathrm{RB}}_{\mathrm{sc}} / 2$$

The location in the frequency domain is controlled by the parameter $n^{\mathrm{RA}}_{\mathrm{PRB}}$ which is the first physical resource block allocated to the PRACH opportunity considered. The factor $K = \Delta f / \Delta f_{\mathrm{RA}}$ accounts for the difference in subcarrier spacing between the random access preamble and uplink data transmission. The variable Δf_{RA}, the subcarrier spacing for the random access preamble, and the variable φ, a fixed offset determining the frequency-domain location of the random access preamble within the physical resource blocks, are both given by Table 2.8.

TABLE 2.8

Random access baseband parameters

Preamble format	Δf_{RA}	φ
4-5	416.67 Hz	–6

2.4.3.2.7 Modulation and up-conversion

The contents in this section are normatively referenced by clause 5.8 of TTAT.3G-36.211, provided by TTA.

2.4.3.3 Downlink physical channels

The contents in this section are normatively referenced by clause 6.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.1 Slot structure and physical resources

The contents in this section are normatively referenced by clause 6.1 of TTAT.3G-36.211, provided by TTA.

In addition, in order to adapt satellite specific conditions or performance enhancement in the satellite system, § 6.2.6 regarding guard period for TDD operation is not considered.

2.4.3.3.2 General structure for downlink physical channels

The contents in this section are normatively referenced by clause 6.3 of TTAT.3G-36.211, provided by TTA.

TABLE 2.9

Modulation scheme

Physical channel	Modulation schemes
PDSCH	QPSK, 16QAM
PMCH	QPSK, 16QAM

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

64QAM modulation scheme is not supported.

In enhancing mode, the following steps are additionally defined for the baseband signal representing a downlink physical channel:

– long-time interleaving of the complex-valued modulation symbols over several subframes (Details are specified in § 2.4.6.1);

– generation of complex-valued time-domain SC-FDM signal for each antenna port (Details are specified in § 2.4.6.6).

In enhancing mode, precoding for cooperative transmit diversity with complementary ground components (CGCs) is also added for performance enhancement in an integrated satellite CGC configuration (Details are specified in § 2.4.6.4).

2.4.3.3.3 Physical downlink shared channel

The contents in this section are normatively referenced by clause 6.4 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.4 Physical multicast channel

The contents in this section are normatively referenced by clause 6.5 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.5 Physical broadcast channel

The contents in this section are normatively referenced by clause 6.6 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.6 Physical control format indicator channel

The contents in this section are normatively referenced by clause 6.7 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.7 Physical downlink control channel

The contents in this section are normatively referenced by clause 6.8 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.8 Physical hybrid ARQ indicator channel

The contents in this section are normatively referenced by clause 6.9 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.9 Reference signal

The contents in this section are normatively referenced by clause 6.10 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.9.1 Cell-specific reference signals

The contents in this section are normatively referenced by clause 6.10.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.9.2 MBSFN reference signals

The contents in this section are normatively referenced by clause 6.10.2 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.9.3 UE-specific reference signals

The contents in this section are normatively referenced by clause 6.10.3 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.10 Synchronization signal

The contents in this section are normatively referenced by clause 6.11 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.10.1 Primary synchronization signal

The contents in this section are normatively referenced by clause 6.11.1 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.10.2 Secondary synchronization signal

The contents in this section are normatively referenced by clause 6.11.2 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.11 OFDM baseband signal generation

The contents in this section are normatively referenced by clause 6.12 of TTAT.3G-36.211, provided by TTA.

2.4.3.3.12 Modulation and up-conversion

The contents in this section are normatively referenced by clause 6.13 of TTAT.3G-36.211, provided by TTA.

2.4.3.4 Timing

2.4.3.4.1 Uplink-downlink frame timing

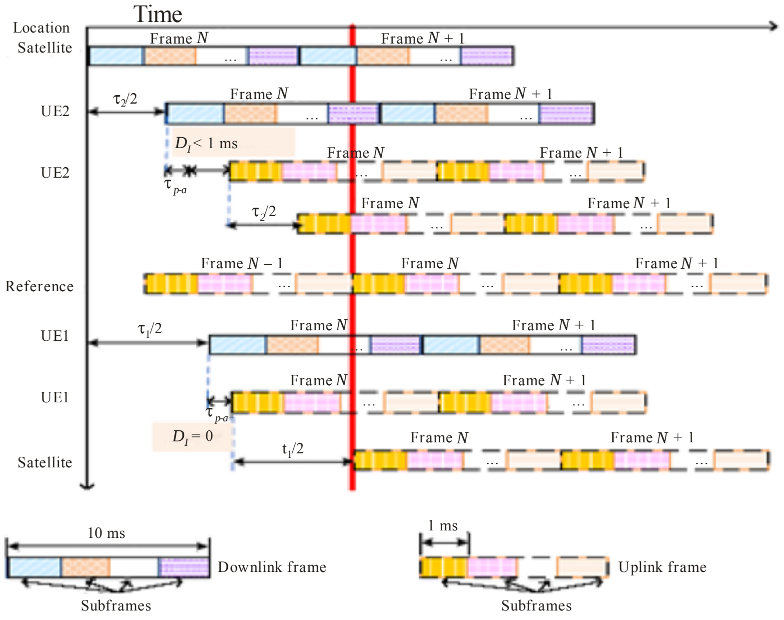
The contents in this section are normatively referenced by clause 8 of TTAT.3G-36.211, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

Resource allocation needs to be made to satisfy the uplink-downlink frame timing defined in clause 8 of TTAT.3G-36.211. Figure 2.8 illustrates a resource allocation method designed for this purpose, by considering satellite specific conditions. UE1 and UE2 represent terminals located at the beam edge and the centre, respectively. Therefore, UE1 and UE2 have the maximum and minimum round trip delays (RTDs), respectively, and thus $\Delta t_{1,2}$ has the maximum value among all available $\Delta t_{i,j}$. The timing reference is set for uplink transmission with respect to the RTD of UE1. With this reference, UE1 can transmit its uplink signal as soon as the resource allocation information is received via the downlink, i.e. D_I=0. On the other hand, for UE_j, $\Delta t_{i,j}$ is compensated by using the modified resource allocation method without any modification of the terrestrial LTE uplink-downlink timing. In fact, the scheduler in a satellite can get location information of each UE via its own random access trial. By using this information, the scheduler allocates available resources to the most appropriate subframes paired with a specific downlink subframe. For instance, as shown in Fig. 2.8, UE1 and UE2 receive downlink signal after $t_1/2$ and $t_2/2$, respectively, where t_i is the RTD of UE$_i$. The scheduler allocates available resources to the most adjacent uplink reference subframe just after the downlink signal reception and switching delay, t_{pro}. Because the scheduler has information on $\Delta t_{i,j}$, the orthogonality problem can be resolved.

FIGURE 2.8

Resource allocation for uplink-downlink frame timing



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2.4.3.4.2 Timing relation between PRACH and PDCCH related AI

The uplink PRACH access frames are time-aligned with the reception of downlink PDCCH related to acquisition indicator (AI) access frame. Uplink access frame number *n* is transmitted from MES

$\tau_{p\text{-}a}$ subframes prior to the reception of downlink access frame number n, n=0, 1, …, 9. The PRACH/PDCCH timing relation is shown in Fig. 2.9. The transmission offset τ_{off} shall be a value between the range of $-\tau_{off,max}$ to $\tau_{off,max}$, where $\tau_{off,max}$ is maximum transmission offset and is signalled by higher layers. The preamble-to-preamble distance $\tau_{p\text{-}p}$ shall be larger than or equal to the minimum preamble-to-preamble distance $\tau_{p\text{-}p,min}$. In addition to $\tau_{p\text{-}p,min}$, the preamble-to-AI distance $\tau_{p\text{-}a}$ is defined as follows:

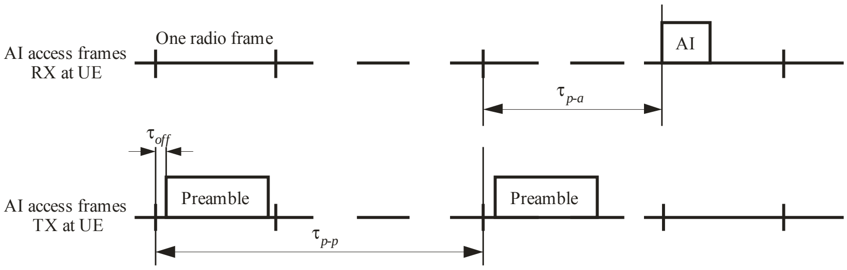
– when AI_Transmission_Timing is set to 0, then $\tau_{p\text{-}p,min}$ = 300 subframes (thirty radio frames) and $\tau_{p\text{-}a}$ = 280 subframes (twenty-eight radio frames);

– when AI_Transmission_Timing is set to 1, then $\tau_{p\text{-}p,min}$ = 560 subframes (fifty-six radio frames) and $\tau_{p\text{-}a}$ = 540 subframes (fifty-four radio frames).

The parameter AICH_Transmission_Timing is signalled by higher layers.

FIGURE 2.9

Timing relation between PRACH and AI as seen at the MES



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2.4.4 Channel multiplexing and coding

2.4.4.1 Mapping to physical channels

2.4.4.1.1 Uplink

The contents in this section are normatively referenced by clause 4.1 of TTAT.3G-36.212[3], provided by TTA.

2.4.4.1.2 Downlink

The contents in this section are normatively referenced by clause 4.2 of TTAT.3G-36.212, provided by TTA.

2.4.4.2 Channel coding, multiplexing and interleaving

The contents in this section are normatively referenced by clause 5 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1 Generic procedure

2.4.4.2.1.1 CRC calculation

The contents in this section are normatively referenced by clause 5.1.1 of TTAT.3G-36.212, provided by TTA.

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[3] Standard TTAT.3G-36.212 is the transposed document of 3GPP TS 36.212 http://committee.tta.or.kr/include/Download.jsp?filename=stnfile/TTAT.3G-36.212(R8-8.6.0).zip.

2.4.4.2.1.2 Code block segmentation and code block CRC attachment

The contents in this section are normatively referenced by clause 5.1.2 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.3 Channel coding

The contents in this section are normatively referenced by clause 5.1.3 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.3.1 Tail biting convolutional coding

The contents in this section are normatively referenced by clause 5.1.3.1 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.3.2 Turbo coding

The contents in this section are normatively referenced by clause 5.1.3.1 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.4 Rate matching

2.4.4.2.1.4.1 Rate matching for turbo coded transport channels

The contents in this section are normatively referenced by clause 5.1.4.1 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.4.2 Rate matching for convolutionally coded transport channels and control information

The contents in this section are normatively referenced by clause 5.1.4.2 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.1.5 Code block concatenation

The contents in this section are normatively referenced by clause 5.1.5 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.2 Uplink transport channels and control information

2.4.4.2.2.1 Random access channel

The contents in this section are normatively referenced by clause 5.2.1 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.2.2 Uplink shared channel

The contents in this section are normatively referenced by clause 5.2.2 of TTAT.3G-36.212, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

TDD related operation is not considered.

In enhancing mode, 5 bits of wideband CQI is also added as shown in Table 2.10. The addition is for channel quality information feedback with wideband CQI reports, and used for transmission modes 4 and 6.

TABLE 2.10

Wideband CQI field for enhancing mode

Field	Bit width			
	Two antenna ports		Four antenna ports	
	Rank = 1	Rank = 2	Rank = 1	Rank > 1
Wideband CQI codeword 0	5	5	5	5
Wideband CQI codeword 1	0	5	0	5

2.4.4.2.2.3 Uplink control information (UCI) on PUCCH

The contents in this section are normatively referenced by clause 5.2.3 of TTAT.3G-36.212, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

TDD related operation is not considered.

In enhancing mode, the receiver memory (RM) field is added to HARQ-ACK (details are specified in § 2.4.6.10).

In enhancing mode, 5 bits of wideband CQI is also added as shown in Tables 2.11 and 2.12. Table 2.11 defines channel quality information feedback for wideband CQI reports, and it is used for transmission modes 1, 2, 3 and 7. Table 2.12 is used for transmission modes 4, 5 and 6.

TABLE 2.11

UCI field for enhancing mode (transmission mode 1, 2, 3 and 7)

Field	Bit width
Wideband CQI	5

TABLE 2.12

UCI field for enhancing mode (transmission modes 4, 5 and 6)

Field	Bit width			
	Two antenna ports		Four antenna ports	
	Rank = 1	Rank = 2	Rank = 1	Rank > 1
Wideband CQI	4	4	4	4

2.4.4.2.2.4 Uplink control information on PUCCH without UL-SCH data

The contents in this section are normatively referenced by clause 5.2.4 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.3 Downlink transport channels and control information

2.4.4.2.3.1 Broadcast channel

The contents in this section are normatively referenced by clause 5.3.1 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.3.2 Downlink shared channel, paging channel and multicast channel

The contents in this section are normatively referenced by clause 5.3.2 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.3.3 Downlink control information (DCI)

The contents in this section are normatively referenced by clause 5.2.3 of TTAT.3G-36.212, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

TDD related operation is not considered.

In enhancing mode, the number of indicator bits in DCI format 0 is changed for satellite carrier aggregation.

– New data indicator – 2 bits (increased to 2 bits from 1 bit in clause 5.3.3 of TTAT.3G-36.212).

In enhancing mode, the number of indicator bits in DCI formats 1, 1A, 1B, 1D, 2, 2A and 2B is changed for satellite HARQ and satellite carrier aggregation.

– HARQ process number – 9 bits (increased to 9 bits from 3 bits in clause 5.3.3 of TTAT.3G-36.212).

– New data indicator – 2 bits (increased to 2 bits from 1 bit in clause 5.3.3 of TTAT.3G-36.212).

2.4.4.2.3.4 Control format indicator (CFI)

The contents in this section are normatively referenced by clause 5.3.4 of TTAT.3G-36.212, provided by TTA.

2.4.4.2.3.5 HARQ indicator (HI)

The contents in this section are normatively referenced by clause 5.3.5 of TTAT.3G-36.212, provided by TTA.

2.4.5 Physical layer procedures

2.4.5.1 Beam search

The contents in this section are normatively referenced by clause 4.1 of TTAT.3G-36.213[4], provided by TTA.

2.4.5.2 Timing synchronization

The contents in this section are normatively referenced by clause 4.1 of TTAT.3G-36.213, provided by TTA.

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[4] Standard TTAT.3G-36.213 is the transposed document of 3GPP TS 36.213 http://committee.tta.or.kr/include/Download.jsp?filename=stnfile/TTAT.3G-36.213(R8-8.6.0).zip.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

The resource allocation method for this transmission timing adjustments in satellite environments is specified in § 2.4.3.4.

2.4.5.3 Power control

2.4.5.3.1 Uplink power control

2.4.5.3.1.1 Operation in normal mode

The contents in this section are normatively referenced by clause 5.1 of TTAT.3G-36.213, provided by TTA.

2.4.5.3.1.2 Operation in enhancing mode

The uplink power control is based on both signal-strength measurements done by the terminal itself (open-loop power control), as well as measurements by the base station.

Even though the uplink uses orthogonal SC-FDMA access, high level of interference from neighbouring beams can still limit the uplink coverage if UEs in the neighbouring beams are not power controlled. The average inter-cell interference level received at the satellite is effectively reduced by the slow power control on each UE to compensate for path-loss and shadowing.

For the uplink, an event-based combined open-loop and closed-loop power control algorithm is applied.

The uplink power control adjusts the UE transmission power in order to keep the transmission power spectral density (PSD) at a given PSD target for each MCS, PSD_{target}. The uplink power control shall be performed while the UE transmission power is below the maximum allowed output power.

Any change in the uplink transmission power shall take place immediately before the start of the frame. The change in power with respect to its previous value is derived by the UE and is denoted by Δ_{UP} (dB).

The satellite-RAN should estimate power spectral density PSD_{est} of the received uplink SRS, generate TPC commands, and transmit the commands once per more than one radio frame according to the following rule:

Define the variable:

$\Delta_\varepsilon(i)$: PSD_{est}–PSD_{target} for a given MCS level

$\Delta_p(i)$: power control step whose value is determined according to the TPC_cmd for the i^{th} frame, where the step sizes are [–1 dB 0 dB +1 dB +3 dB] under the control of the Satellite-RAN

N_{frame}: loop delay expressed in frames

and then, $\Delta_p(i)$ is generated by using $\Delta_\varepsilon(i)$ and the past N_{frame} power control steps $\Delta_p(k)$, $k = i - N_{frame} - 1, ..., i - 1$ as follows:

Compute:

$$\Delta_{\varepsilon,c} = \Delta_\varepsilon(i) + \chi G_1(PSD_{SRS}(i) - PSD_{SRS}(i-1)),$$

where the loop delay compensation indicator, G_1 ($0 \leq G_1 \leq 1$) is the higher layer parameter and is identical for all MESs in the same beam. When SRS can be used for channel estimation, the value χ has 1, otherwise χ is zero.

- if $|\Delta_{\varepsilon,c}| < \varepsilon_T$ and $\Delta_{\varepsilon,c} < 0$, $\Delta_p(i) = 1$ dB
- if $|\Delta_{\varepsilon,c}| < \varepsilon_T$ and $\Delta_{\varepsilon,c} > 0$, $\Delta_p(i) = 0$ dB
- if $|\Delta_{\varepsilon,c}| < \varepsilon_T$ and $\Delta_{\varepsilon,c} < 0$, $\Delta_p(i) = 3$ dB
- if $|\Delta_{\varepsilon,c}| > \varepsilon_T$ and $\Delta_{\varepsilon,c} > 0$, $\Delta_p(i) = -1$ dB.

The MES adjusts the transmit power of the uplink DSCH with a step of Δ_{UP} (dB) using two most recently received power control steps, $\Delta_p(i)$ and $\Delta_p(I-1)$ as follows:

$$\Delta_{UP} = \Delta_p(i) - \alpha\Delta_p(I-1)$$

where α is identical to that used in the serving beam and is signalled by the higher layer.

2.4.5.3.2 Downlink power control

2.4.5.3.2.1 Operation in normal mode

The contents in this section are normatively referenced by clause 5.2 of TTAT.3G-36.213, provided by TTA.

2.4.5.3.2.2 Operation in enhancing mode

Dynamic power control is applied to dedicated control channels addressed to a single UE or a group of UEs. No feedback of TPC commands is provided on the uplink, and power allocation is based on the downlink channel quality feedback from the UEs. Different power levels can be allocated to different resource blocks used for data transmission in a semi-static way to support inter-beam interference coordination (IBIC). Moreover, two different power levels can be defined on OFDM symbols used for data transmission within a subframe to improve satellite RAN power utilization. However, different power levels across antenna ports to resolve the spatial domain power imbalance are not permitted.

In order to decide suitable MCS level from the downlink channel quality feedback, UE may employ a prediction algorithm which estimates the future channel condition after the round trip delay. Prediction for the channel variation can be implemented by observing the trace of the past channel variations of the common channel in the active set. In order to support UEs which employ the prediction algorithm, a nominal round trip delay of the beam to which the UE belongs is signalled by higher layers. The predicted channel variation after round trip delay, Δ_{pred}, is used by the satellite RAN.

$$\Delta_{pred} = G(PSD_{CSI-RS+PBCH+SCH}(i) - PSD_{CSI-RS+PBCH+SCH}(i-1)),$$

where the prediction gain, G is the higher layer parameter and may be different for each MES in the same beam.

Basically, adaptive modulation and coding (AMC) scheme is applied in downlink transmission instead of power control. But power control can be applied in the downlink transmission to keep low PAPR as follows.

- Step 1: Monitor the large scale fading values (L_k) experienced by UEs.
- Step 2: Count the number of UEs (N_u) satisfying $L_k > B_0$.
- Step 3: If $N_u < B_1$, count the number of total subcarriers (N_c) used by N_u UEs.

  Otherwise, AMC mode operation is done.
- Step 4: If $N_c < B_2$, power control mode is done.

  Otherwise, AMC mode operation is done.

where thresholds, B_0, B_1 and B_2 are signalled by high layers.

2.4.5.4 Random access procedure

The contents in this section are normatively referenced by clause 6 of TTAT.3G-36.213, provided by TTA.

In addition, the followings are specified in order to adapt satellite specific conditions or performance enhancement in the satellite system.

A random access procedure for a GPS mounted UE is defined. A GPS mounted UE can predict the amount of round trip delay based on its own location information. After adjusting UE uplink timing to within a fraction of the cyclic prefix of a random access preamble, it performs the random access transmission with the same preamble formats as that of terrestrial LTE. The UE should provide the adapted uplink timing information to the satellite RAN by selecting an appropriate preamble sequence group from Table 2.13. Some of a total of 64 sequences are configured for contention-based random access and their grouping information is signalled by the high layer.

TABLE 2.13

RA preamble sequence group

RTD difference from a beam centre	Used preamble sequence group
RTD difference ≤ 1 ms	Preamble sequence group 1
RTD difference ≤ 2 ms	Preamble sequence group 2
RTD difference ≤ 3 ms	Preamble sequence group 3
RTD difference ≤ 4 ms	Preamble sequence group 4

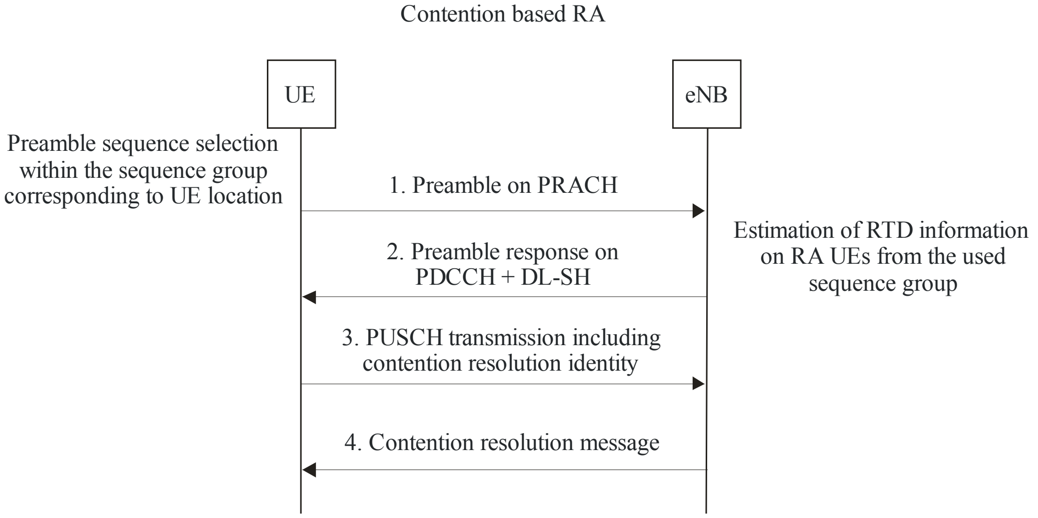
Random access via the sequence grouping allows the satellite RAN to estimate and, if needed, adjust the UE uplink scheduling timing. The steps of the adjusting UE uplink scheduling timing are as follows:

- The satellite RAN estimates the RTD of UE using the received random access preamble and Table 2.13.
- The satellite RAN schedules the access timing of UE using the estimated RTD.

When the satellite RAN successfully received a random access preamble, it sends a random access response indicating the successfully received preamble(s) along with the time advance (TA) and uplink resource allocation information considering RTD to the UE as in Fig. 2.10.

FIGURE 2.10

The contention-based random access procedures with preamble sequence groups



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2.4.6 Satellite-specific features for performance enhancement

The SAT-OFDM has a high degree of commonality with the LTE-based terrestrial radio interface but it also has a number of different features. Those features, which are necessary to reflect the satellite-specific characteristics, such as long round trip delay, are implemented. For this purpose, the following techniques are included for enhancing mode operation.

2.4.6.1 Long-time interleaver for efficient AMC operation

This scheme is used for an efficient AMC operation in satellite environment.

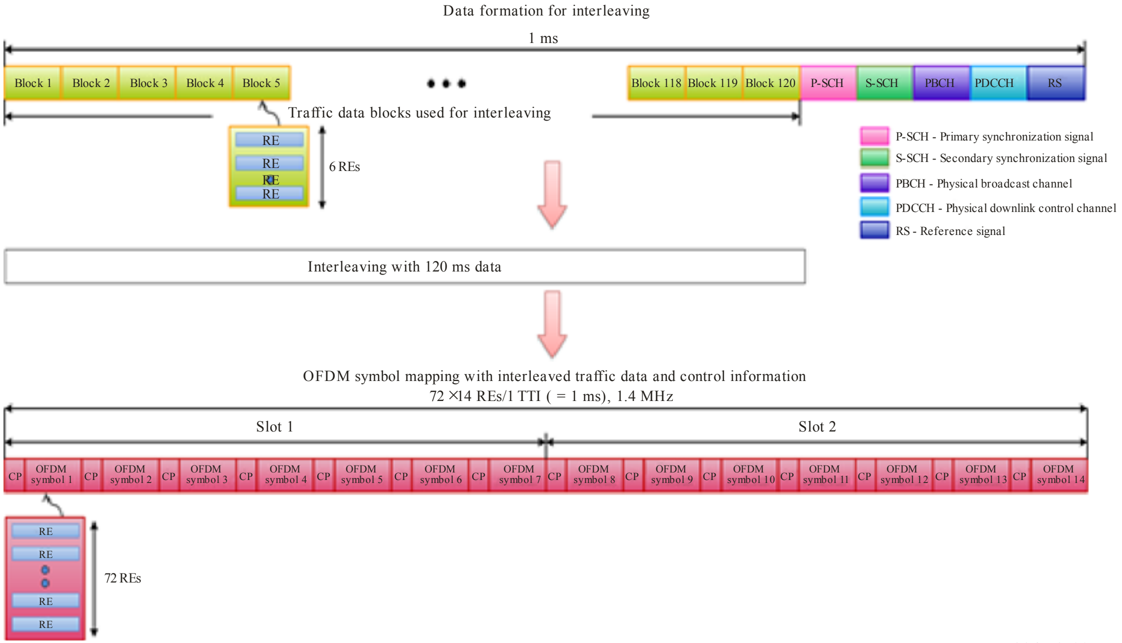
Considering the RTD of a GSO system, the AMC of the satellite systems cannot effectively counteract to short-term fading. A long time-interleaving technique can be used in conjunction with AMC to compensate short-term fading.

After turbo coding with mother code rate of 1/3, rate mating is applied to produce various code rates for adaptive usage. Interleaving is applied to data blocks composed of resource elements (REs) of traffic data after the baseband modulation and before resource block (RB) mapping and IFFT for OFDM modulation.

Figure 2.11 shows an example of data formation for interleaving and OFDM symbol mapping before IFFT, when the interleaver size is 120 ms. The example assumes that a single user is allocated to six RBs, i.e. 720 resource elements (REs) with 1.4 MHz bandwidth. Traffic data contained in a codeword of 1 ms is divided into 120 blocks for interleaving, and each block is called an Interleaving unit (IU). Figure 2.12 shows the configuration of the corresponding square type block interleaver which can be used to implement interleaving in Fig. 2.11. Although Fig. 2.12 shows a block type interleaver, an equivalent convolutional type interleaver can be used to reduce memory size of the interleaver. With the interleaver, a codeword consists of 120 IUs, and an IU contains different number of REs depending on the allocated bandwidth. The notation C_1^2 in a single IU in Fig. 2.12 represents the second segment of the first codeword. When interleaving is operated, the transmission will start from the first element of the first column, and continue to the last element of the same column. Then, it will continue from the first element of the second column with the same manner up to the last element of the last column. Table 2.14 represents interleaver parameter examples according to the allocated bandwidth.

FIGURE 2.11

An example of data formation for interleaving and OFDM symbol mapping



M.2047-2-11

FIGURE 2.12

An example of square type block interleaver

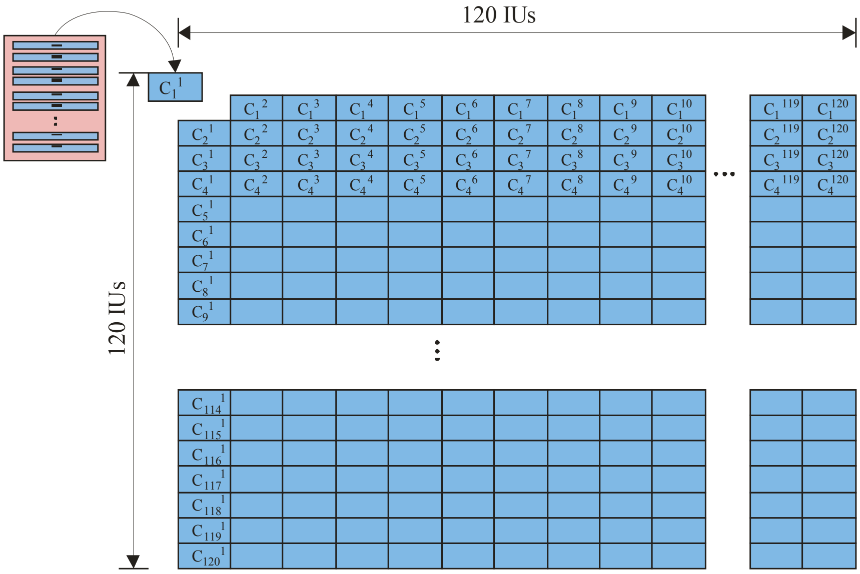


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TABLE 2.14

Long-time interleaver parameter examples

Allocated bandwidth (MHz)	**No. of RBs**	**No. of REs**	**Interleaver size (ms)**	**No. of REs in an IU**	**No. of IUs/ms**
1.4	6	720	120	6	120
			360	2	360
			720	1	720
3	15	1 800	120	15	180
			360	5	360
			1 800	1	1 800
5	25	3 000	120	25	120
10	50	6 000	120	50	120
15	75	9 000	120	75	120
20	100	12 000	120	100	120

The interleaver information based on resource allocation type and memory information is exchanged between S-eNodeBs and UEs for long-time interleaving. The interleaver information indicates an interleaver identifier (ID) representing an interleaver size (*N*) and interleaving unit (IU). Table 2.15 shows the interleaver IDs.

TABLE 2.15

Long-time interleaver ID

Interleaver ID	***N***	**IU**
0001	120	1
0010	120	2
0011	120	3
0100	120	4
0101-1111	Reserved	Reserved

Especially, the symbol-interleaving process comprises interleaving the symbol-level data using an interleaver having a maximum size of 120 IUs with respect to a single RB when the resource allocation type information includes the type 2 defined in clause 7.1.6 of TTAT.3G-36.213.

The application of the (long-time) symbol interleaver is based on service information. The long-time interleaver is only applicable to non-real-time services.

For continuous transmission with the long interleaving process, a padding bits timer is applied. When no data is input to the interleaving buffer until the padding bits timer is expired, the random data may be input to the long-time interleaver. That is, when the interleaving buffer does not include the new data and the timer is yet to expire, the data is not transmitted.

2.4.6.2 Fractional frequency reuse within multi-beams

This scheme is used to support broadband satellite services as well as to increase spectral efficiency in a multi-beam satellite system. It can also be applied without any modification of LTE chipset in normal mode because it is implementation specific.

For fractional frequency reuse (FFR) within multi-beams, the satellite RAN shall obtain UE location information in order to distinguish beam centre UEs from beam edge UEs. The location information is determined during the random access trial of an UE, on the help of GPS mounted in an UE, or with the received SINR values from the target and adjacent beams into an UE.

When the UE timing information from the random access trial is obtained by satellite RAN, it is given as follows:

– if $\theta_1 < T_{RTD\_difference} < \theta_2$, the UE is located at the beam centre region;

– otherwise, the UE is located at the beam edge region,

where $T_{RTD\_difference}$ is round trip delay difference between the target UE and the UE that has minimum round trip delay within the target beam, and the threshold values, θ_1 and θ_2 are high layer parameters.

When the received downlink SINRs from target and adjacent beams are estimated by a UE, the UE timing information can be also given as follows:

– if $\theta_3 < \frac{\text{the received SINR from a target beam}}{\text{the received SINR from an adjacent beam}}$, the UE is located at the beam centre region,

– otherwise, the UE is located at the beam edge region,

where the threshold value, θ_3 is a high layer parameter.

The location information obtained by the UE shall be sent to the satellite RAN as follows:

– if the UE is located at the beam centre region, “0” is sent;

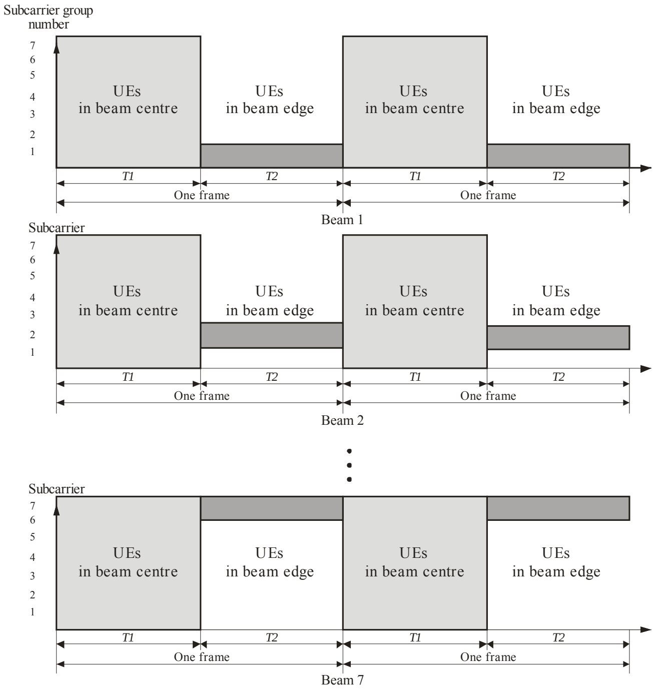
– if the UE is located at the beam edge region, “1” is sent.

In case of application of the fractional frequency reuse in a multi-beam satellite system, each beam is partitioned into two regions and each frame should be divided into two time sections, T_1 and T_2, in each beam, as shown in Fig. 2.13. The first section, T_1 is allocated to UEs in the beam centre, and all subcarriers are used for transmission during this time period. On the other hand, the second time section, T_2 is allocated to UEs in the beam edge. During this time period, only identified fractional subcarriers out of whole subcarriers are used.

The identification of fractional subcarriers is made by MAC layers. The values, T_1 and T_2 are determined by high layer, considering total system throughput and inter-beam interference.

FIGURE 2.13

Frame structure for fractional frequency reuse



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2.4.6.3 Coordinated multi-beam transmission

This scheme is used for performance enhancement in beam-edge region and reduction of inter-beam interference. It can also be applied without any modification of LTE chipset in normal mode because it is implementation specific on the satellite transmitter.

For coordinated multi-point transmission (CoMT) within multi-beams, the satellite RAN shall obtain UE location information in order to distinguish between beam centre UEs and beam edge UEs. The location information can be given on the help of GPS mounted on UEs or with the received SINR values from the target and adjacent two beams into an UE.

When the received downlink SINRs from the target and adjacent two beams are estimated by an UE, it can be given as follows:

– if $\theta_4 < \frac{\text{the received downlink SINR from a target beam}}{\text{sum of the received downlink SINRs from adjacent two beams}}$, the UE is located at the beam centre region;

– if $\theta_5 < \frac{\text{the received downlink SINR from a target beam}}{\text{sum of the received downlink SINRs from adjacent two beams}} < \theta_4$, the UE is located at two beams-overlapped region;

– otherwise, the UE is located at three beams-overlapped region,

where the threshold values, θ_4 and θ_5 are high layer parameters.

The location information obtained by UEs shall be sent to the satellite RAN as follows:

– if the UE is located at the beam centre region, "00" is sent;

– if the UE is located at two beams-overlapped region, "01" is sent;

– if the UE is located at three beams-overlapped region, "11" is sent.

In the CoMT scheme, multiple satellite beams cooperate to transmit signals to an UE. That is, the CoMT scheme means a multi-beam transmission scheme that enables a signal from an adjacent beam to improve a communication service quality. Figure 2.14 shows a system using a CoMT scheme. The satellite transmits signals for UE1 to UE3 through beam 1. UE1 represents terminals located in the beam centre region, UE2 represents terminals located in the area where two beams are overlapped, and UE3 represents terminals located in the area where three beams are overlapped. In the CoMT, UE2 and UE3 may receive multiple signals from all available overlapped beams, resulting in performance enhancement.

FIGURE 2.14

Coordinated multi-point transmission

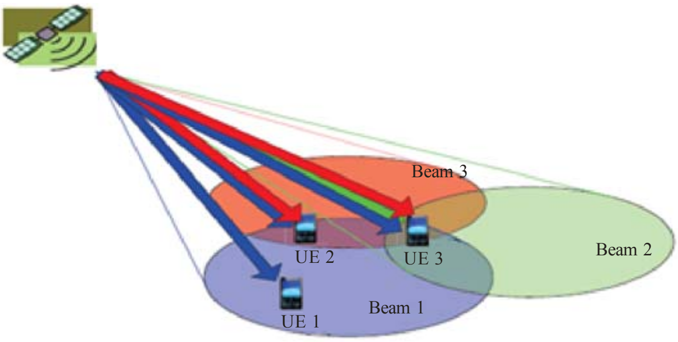

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Figure 2.15 represents an example of beam planning for multi-beam CoMT MSS system consisting of one beam and six adjacent beams. In the multi-beam MSS system, a signal is transmitted on the same frequency band f1 from all beams to realize the frequency reuse factor of one. All beams are divided into beam centre region, two beams-overlapped region and three beams-overlapped region.

Figure 2.16 shows one example of frame structure to realize the beam planning of Fig. 2.14 for the CoMT in SAT-OFDM-based MSS system. In this figure, one frame is divided into three transmission intervals in time domain and three subcarrier groups in frequency domain. The transmission intervals, T1, T2, and T3 are allocated to a beam centre UE, a two beams-overlapped UE, and a three beams-overlapped UE, respectively. The beam centre UE can receive its own signal over whole subcarrier during T1, while the two beams and three beams-overlapped UEs can have frequency resources over only predetermined fractional part of whole subcarriers such as subcarriers groups SC1 to SC3 and SC1' to SC3'. The size of each subcarrier group and time interval can be flexibly decided in satellite RAN depending on the traffic demand over each corresponding region.

FIGURE 2.15

Beam planning for CoMT

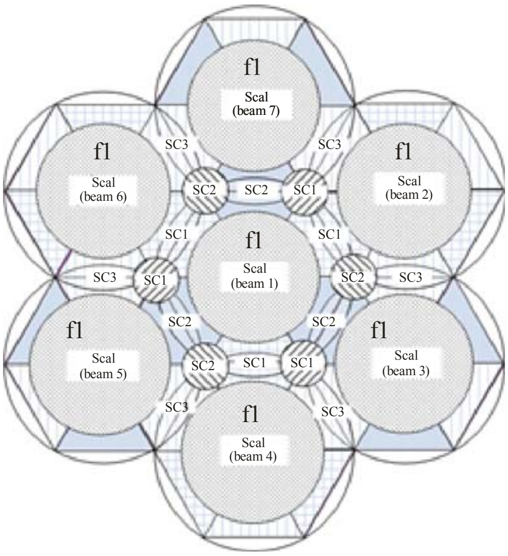

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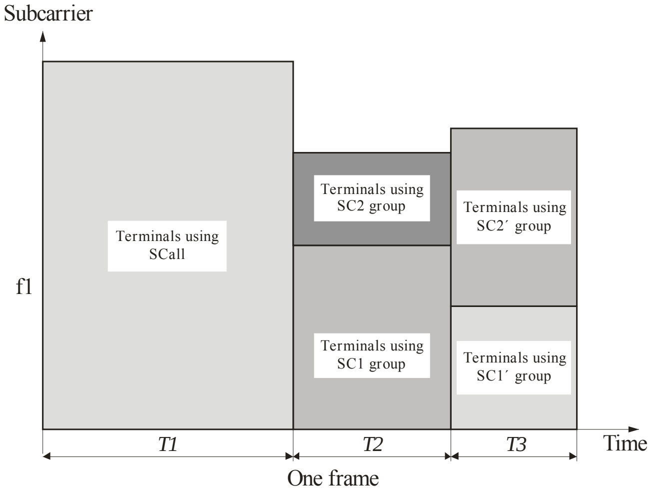
FIGURE 2.16

Frame structure in beam 1 for CoMT



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In two beams-overlapped regions, the following signal is transmitted applying to cyclic delay diversity (CDD) between two beams.

$$\begin{bmatrix} y_k^o \\ y_k^1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\varphi^1 k} \end{bmatrix} x_k,$$

where x_k is a user data on the kth subcarrier, y_k^i (i=0, 1) is the transmitted signal from the ith beam, and $\varphi^1 k$ is the cyclic delay offset to generate the phase shift on the kth subcarrier signalled by high layer due to the delay operation.

In three beams-overlapped regions, the following signal is transmitted applying to CDD between two beams.

$$\begin{bmatrix} y_k^o \\ y_k^1 \\ y_k^2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & e^{j\varphi^2 k} & 0 \\ 0 & 0 & e^{j\varphi^3 k} \end{bmatrix} x_k$$

where x_k is a user data on the k^{th} subcarrier, y_k^i(i=0, 1, 2) is the transmitted signal from the i^{th} beam, and $\varphi^2 k$ and $\varphi^3 k$ are the phase shifts on the k^{th} subcarrier signalled by high layer due to the delay operation. The satellite RAN determines an appropriate cyclic delay offset per each beam and the determined cyclic delay offset is applied to the transmission signal of each beam.

2.4.6.4 Cooperative transmission between a satellite and CGCs

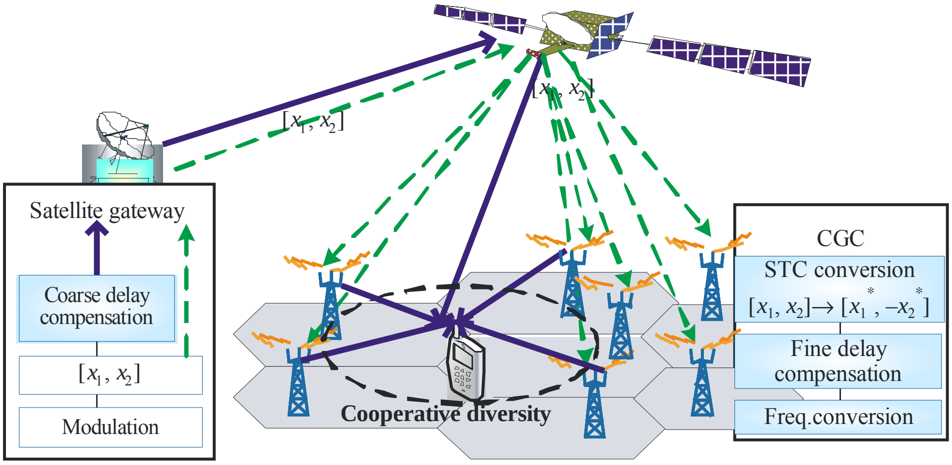
This scheme is used for performance enhancement in an integrated satellite/CGC configuration. It can also be applied without any modification of LTE chipset in normal mode because it is implementation specific on the transmitters of satellite and CGCs.

Figure 2.17(a) shows the concept of a system model where a cooperative diversity technique using a space-time coding (STC) scheme is employed, while Fig. 2.17(b) shows an STC-encoded signal transmission to a user terminal equipped with an STC decoder. The STC scheme employed here is called the Alamouti scheme. The satellite transmits data to the UEs and all ground components. In order to achieve diversity gains via utilization of the STC schemes, each of the alternate CGC must transform the received signals into a given encoded signal format, and retransmit them to the UE. The ground components and satellite can cooperate to transmit space-time coded signals, and the ground components can encode signals rather than serving as simple amplifiers. An UE can receive the STC-encoded signals. If the UE receives multiple signals from both repeaters and the satellite, then it can achieve STC gains using these signals.

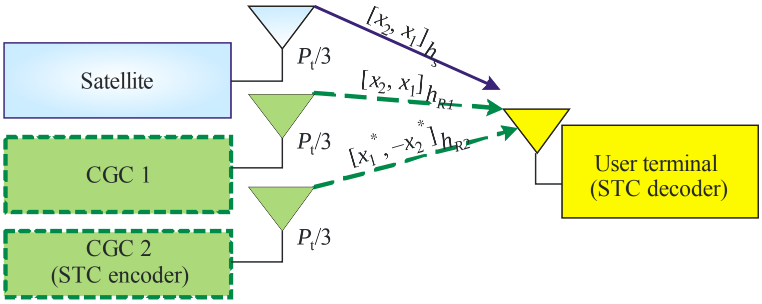
In addition, a delay compensation algorithm is required. Since the processing delay to transform a given STC-encoded format at the ground component as well as the time difference of propagation delay between the links from the satellite and ground components can be estimated, the delay compensation for the signal paths of the ground components can achieve successful synchronization at the UE. For example, as shown in Fig. 2.17, a coarse and fine compensation can be made at the satellite gateway and each ground component, respectively.

FIGURE 2.17

An example of system model using cooperative diversity technique for an integrated system



(a) system concept



b) STC encoded signal transmission to a user terminal equipped with STC decoder

M.2047-2-17

First, the modulated symbol sequence $[x_1, x_2]$ is transmitted during the two symbol period $2T$. Then, the satellite passes this symbol sequence $[x_1, x_2]$ during the period $2T$. By using a suitable delay compensation algorithm for the signal to the terrestrial repeater, the signal re-transmitted from the repeater can arrive at the user terminal at almost the same time as the one transmitted directly from the satellite.

After receiving the error-free symbol sequence $[x_1, x_2]$ from the satellite, each alternative CGC applies Alamouti encoding. The following encoding matrix X_2 is used to generate the symbol sequences transmitted by the two repeaters.

$$X_2 = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix},$$

where * represents a complex conjugate operation.

In the encoding matrix of an STC scheme, each row of the matrix represents time slots, and the columns represent the corresponding transmit antennas. Therefore, the encoding matrix, X_2 indicates that the first CGC transmits the signal set $[x_1, x_2]$, whereas the second one transmits $[-x_2^*, x_1^*]$, during the period $2T$. By this means, a user terminal can achieve diversity gains via a combination of both signal paths from the satellite and repeaters, wherever possible.

A user terminal can receive various combinations of signal sets depending on the signal availability, which mainly depends on the location. If the user terminal receives three signal sets, i.e. $[x_1, x_2]$ from the satellite with channel gain h_s, $[x_1, x_2]$ from one of the repeaters with a channel gain of h_{R1}, and $[-x_2^*, x_1^*]$ from the other repeater with a channel gain of h_{R2}, then it can achieve maximal diversity gain via the ordinary decoding algorithm for the Alamouti scheme. Assuming a flat-fading channel during the period $2T$, the received signal r_1 and r_2 at the user terminal during that period can be represented as follows:

$$\begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = H_2 \cdot \begin{bmatrix} x_1 \\ x_2^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix},$$

where n_i is the complex Gaussian noise added at the i^{th} time period. H_2 is the channel matrix for the scheme in Fig. 2.17(b), which is represented by:

$$H_2 = \begin{bmatrix} h_{R1} + h_s & -h_{R2} \\ h_{R2}^* & h_{R1} + h_s^* \end{bmatrix},$$

where h_s is the channel coefficient of the path from the satellite to the user terminal, and h_{R1} and h_{R2} are the channel coefficients of the path from the first and second CGCs to the user terminal, respectively.

Because the encoding matrix X_2 is orthogonal, as is the channel matrix H_2, the user terminal can determine the estimates of the transmitted symbols, via the following linear equation.

$$\begin{bmatrix} \hat{x}_1 \\ \hat{x}_2^* \end{bmatrix} = H_2^H \cdot \begin{bmatrix} r_1 \\ r_2^* \end{bmatrix}$$

2.4.6.5 Narrowband RB uplink transmission

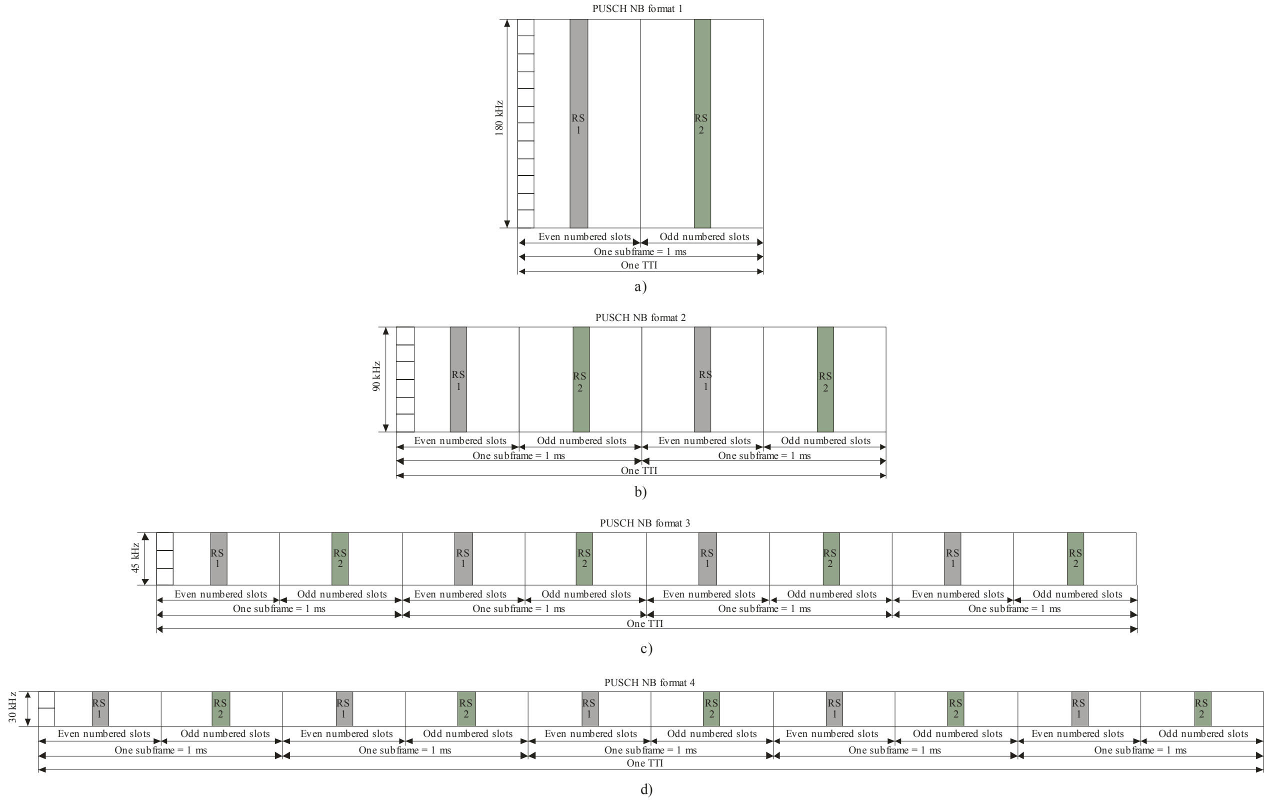
This scheme is used to increase supportable maximum data rate in hand-held type terminals.

In general, a MSS system would be a power-limited system and a hand-held terminal has a limited maximum transmitted power. Considering that the total transmitted power would be distributed over whole subcarriers in one RB, the large RB size of 180 kHz in normal mode may not be allocated with sufficient power in hand-held terminals. In this case, high modulation and coding rate scheme may not be supported. A narrowband RB transmission may be defined in order to solve this problem. For high layer commonality, the size of transport block in the RB is the same as in normal mode.

Figure 2.18 shows the PUSCH structure in order to support narrowband transmission.

FIGURE 2.18

Uplink PUSCH channel structure for narrow-band transmission



M.2047-2-18

Figure 2.18(a) shows the normal mode PUSCH structure with the large RB size of 180 kHz, which has 12 subcarriers and 2 slots. The information bits are first channel-coded with a turbo code of mother code rate with 1/3, which is adapted to a suitable final code rate by a rate-matching process. This is followed by symbol-level channel interleaving, which follows a simple “time-first” mapping – in other words, adjacent data symbols end up being mapped first to adjacent SC-FDMA symbols in the time domain, and then across the subcarriers. The coded and interleaved bits are then scrambled by a length-31 Gold code prior to modulation mapping, DFT-spreading, subcarrier mapping and OFDM modulation. For channel estimation and data demodulation, reference signals (RSs) 1 and 2 are transmitted in each even-numbered and odd-numbered slots of a TTI, respectively.

Figure 2.18(b) shows the narrowband PUSCH structure with the RB size of 90 kHz, which has 6 subcarriers and 4 slots. Its channel bandwidth is decreased to the half and TTI is increased to twice, compared to those of the conventional PUSCH. A simple “time-first” mapping is also made for efficient transmission in power-limited satellite uplink. Within one TTI, adjacent data symbols are mapped first to adjacent SC-FDMA symbols in the time domain, and then across the subcarriers. On the other hand, in order to reuse the conventional RSs 1 and 2 in narrowband PUSCH and get a time diversity gain, the first half of RSs 1 and 2 are transmitted in the first and second slots, respectively, and then the rest half of RSs 1 and 2 are mapped in the third and fourth slots, respectively.

In a similar way to Fig. 2.18(b), Figs 2.18(c) and (d) also show the proposed narrowband PUSCH structure with the RB sizes of 45 and 30 kHz, respectively. The number of subcarriers in the narrowband PUSCHs is limited to products of 2, 3 and 5 for commonality with terrestrial LTE because DFT size in terrestrial LTE is limited to those for low complexity of DFT implementation.

When satellite RAN delivers uplink resource allocation information to an UE, it shall include uplink PUSCH format information via the following format indicators.

– if PUSCH with the RB size of 180 kHz is used, the format indicator “00” is sent by satellite RAN;

– if PUSCH with the RB size of 90 kHz is used, the format indicator “01” is sent by satellite RAN;

– if PUSCH with the RB size of 45 kHz is used, the format indicator “10” is sent by satellite RAN;

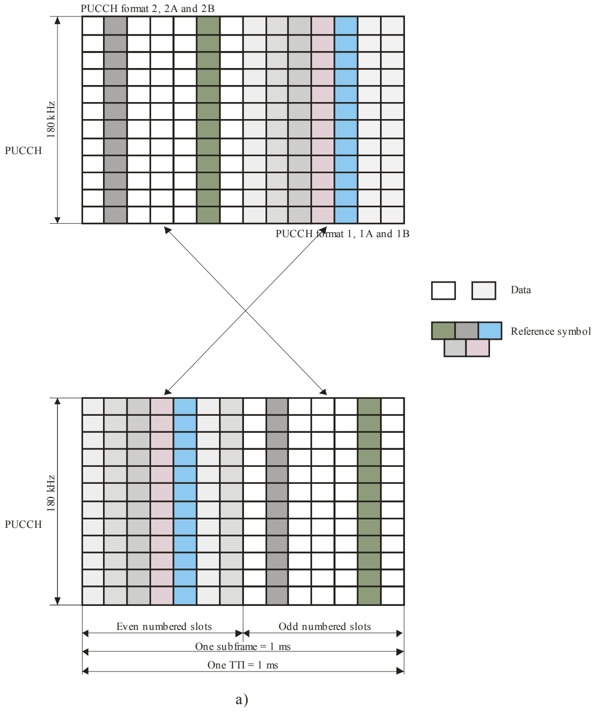
– if PUSCH with the RB size of 30 kHz is used, the format indicator “11” is sent by satellite RAN.

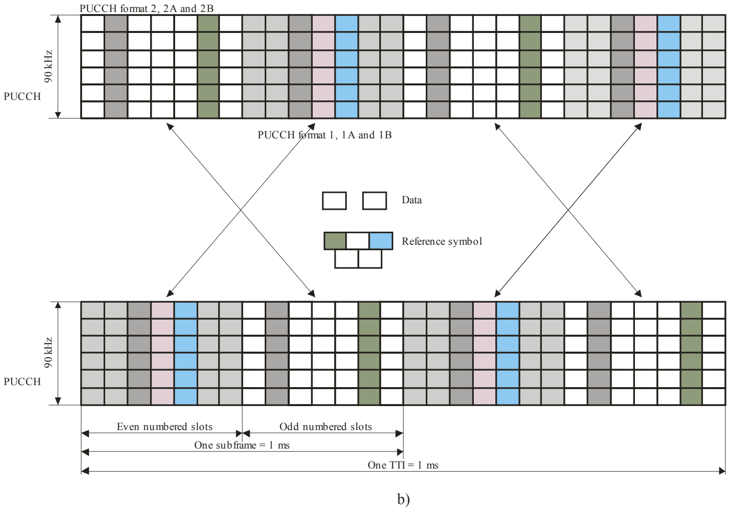
Because the normal mode is operated with 180 kHz size of RB, narrowband PUSCHs shall be grouped with 180 kHz bandwidth size within one TTI in order to be compatible with normal mode as well as terrestrial LTE.

In the same principle, PUCCH structure is shown in Fig. 2.19. PUCCH is used by a UE to transmit any necessary control signalling only in subframes, in which the UE has not been allocated any RBs for PUSCH transmission. The control signalling on the PUCCH is transmitted in a frequency region on the edges of the system bandwidth. In order to minimize the resource needed for transmission of control signalling in one subframe, each PUCCH transmission in one subframe is comprised of a single RB at or near one edge of the system bandwidth, followed by a second RB at or near the opposite edge of the system bandwidth, as shown in Fig. 2.19. Similarly to PUCCH structure, Figs 2.19(a) and 2.19(b) represent the normal mode PUCCH formats 1 and 2 and their narrowband transmissions for adaptation to satellite uplink. Figure 2.19(b) shows the narrowband PUCCH structure with the RB size of 90 kHz, which has 6 subcarriers and 4 slots. Other narrowband PUCCH structures can be applied in a similar way to Figs 2.18(c) and 2.18(d) for narrowband PUSCH structures.

FIGURE 2.19

Uplink PUCCH channel structure for narrowband transmission





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When satellite RAN delivers uplink resource allocation information to an UE, it shall include uplink PUCCH format information via the following format indicators.

– if PUCCH with the RB size of 180 kHz is used, the format indicator “00” is sent by satellite RAN;

– if PUCCH with the RB size of 90 kHz is used, the format indicator “01” is sent by satellite RAN;

– if PUCCH with the RB size of 45 kHz is used, the format indicator “10” is sent by satellite RAN;

– if PUCCH with the RB size of 30 kHz is used, the format indicator “11” is sent by satellite RAN.

Because the normal mode is operated with 180 kHz size of RB, narrowband PUCCHs shall be grouped with 180 kHz bandwidth size within one TTI in order to be compatible with normal mode as well as terrestrial LTE. In addition, multiplexing narrowband PUCCH with normal mode PUCCH can be considered in order to reduce the resources used for PUCCH transmission.

2.4.6.6 Downlink transmission scheme with low PAPR

This scheme is used to reduce peak to average power ratio (PAPR) in downlink transmission of the enhancing mode. Because SAT-OFDM downlink shall support both normal and enhancing mode UEs in downlink frame, only MBSFN subframes indicated to normal mode UE are used as subframes to transmit signals of enhancing mode UEs. For compatible operation with normal mode UEs, multiplexing enhancing mode UEs with normal mode UEs within one radio frame is achieved according to the flow in Fig. 2.20.

FIGURE 2.20

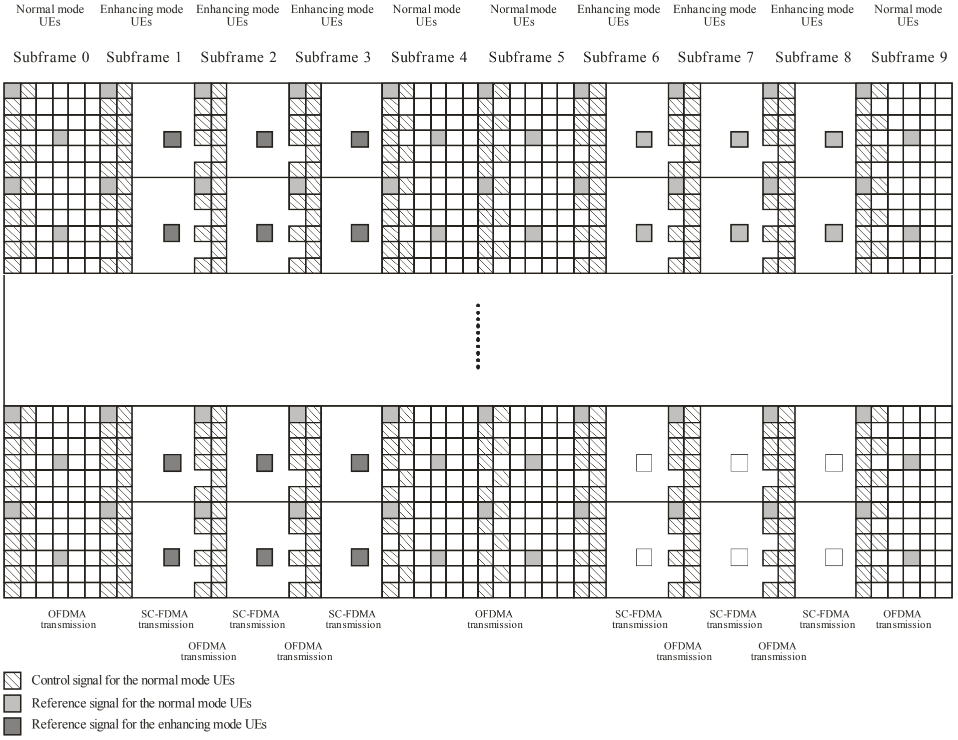
Downlink OFDMA transmission combined with SC-FDM

M.2047-2-20

Figure 2.21 shows an example of frame structure for downlink transmission with low PAPR in enhancing mode UEs. The subframes 0, 4, 5, and 9 shall be used for normal mode UEs and other subframes can be used for enhancing mode UEs. The normal mode UE recognizes the subframes for enhancing mode UEs as MBSFN subframes. System information (SI) on which subframes are used for enhancing mode (or MBSFN) is transmitted to UEs via PBCH. The first one or two symbols of MBSFN subframes shall be used for PDCCH for normal mode UEs but the normal mode UEs do not receive data on the other symbols of MBSFN subframes. Therefore, the other symbols of MBSFN subframes can be used for single carrier transmission with low PAPR for performance enhancement of enhancing mode UEs from non-linearity of power amplifier in satellite. Satellite RAN controls that the subframes 4 and 9 are not used for paging, and then they can also be allocated to enhancing mode UEs.

FIGURE 2.21

Frame structure for downlink transmission with low PAPR



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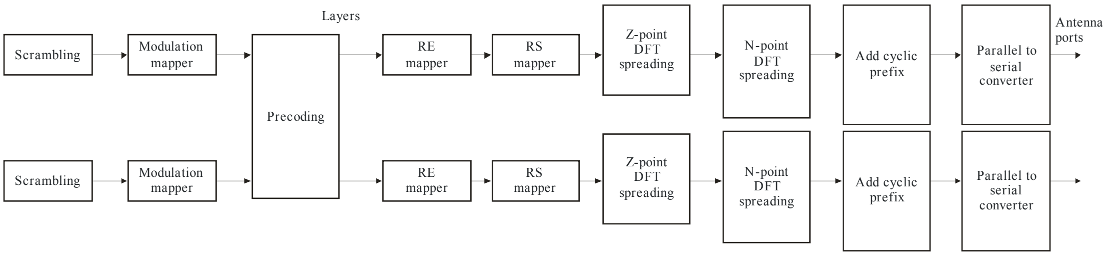
Generation of an SC-FDM signal for enhancing mode UEs in the frequency domain uses a Discrete Fourier Transform-Spread OFDM (DFT-S-OFDM) structure, as shown in Fig. 2.22.

FIGURE 2.22

Downlink transmission block with low PAPR



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RE mapping for data symbol and RS mapping for RS symbol apply to the same rule for normal mode operation. The size of Z-point DFT depends on the number of subcarriers which are used for data and RS symbol. The RBs for UEs shall be continuously mapped in order to keep single carrier property.

2.4.6.7 Efficient AMC scheme combined with power control

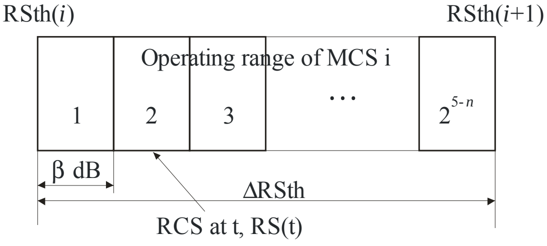
A channel quality indicator (CQI) structure in normal mode is changed for the AMC scheme combined with power control. Five bits are allocated in the normal mode to identify 32 MCS modes. But in enhancing mode, five bits are divided into two parts: the first n bits are allocated to identify MCS modes, and the other (5-n) bits are allocated for power control where the parameter, n is signalled by high layer. When (5-n) bits are used for power control, $2^{(5-n)}$ different power control steps are defined using (5-n) bits. If the reported channel state (RCS) at t corresponds to the k^{th} power level, a UE sends the message to transmit in the $2^{(5-n)\text{th}}$ power level. After satellite RAN receives a CQI showing that the receive power level was at the k^{th} level, the transmitting power level is adjusted as follows:

$$\text{Transmit\_Power}(t) = \text{Transmit\_Power}\ (t-1) + (2^{5-n} - k) \cdot \beta$$

where β is a power difference between i^{th} and $(i+1)^{\text{th}}$ power control steps.

FIGURE 2.23

AMC scheme combined with power control



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In Fig. 2.23, $RS_{th}(i)$ and ΔRS_{th} represent the lower bound of channel state at MCS mode i and the lower bound difference of channel states at MCS modes i and $(i+1)$, respectively.

The procedures of AMC scheme combined with power control are as follows:

- removing a power control level, applied to a previously-received packet, from the calculated received SNR, i.e. substracting the power controlled level in dB from the calculated received SNR in dB;
- using the above subtracted SNR as a final received SNR;
- deciding an MCS mode based on the final received SNR and determining whether power control is required:
  i) when the power control is determined to be required, deciding a required power control magnitude using a channel state positioned in a corresponding MCS mode range (in Fig. 2.23, when the RCS location is 2^{5-n}, the power control is not required);
- transmitting the decided MCS mode and a power control information of the decided power control magnitude through the channel quality indicator (CQI) feedback or the MCS information.

2.4.6.8 HARQ/ARQ interaction

In normal mode, each of the HARQ and ARQ independently performs an assigned task in a corresponding layer. In enhancing mode, the HARQ and ARQ interactively perform for improving transmission efficiency, by interacting between an HARQ operation performed in a MAC layer or a physical layer and an ARQ operation performed in a radio link control (RLC) layer. Feedback information received from the HARQ is reported to the ARQ layer; this enables the ARQ to perform prompt retransmission and to cope with an HARQ feedback error. Accordingly, the transmission efficiency can be improved.

The transmission window is operated according to the HARQ feedback information and the waiting window is operated according to the status PDU. The transmission window is operated based on the VT(A), VT(S), and VT(MS) of the RLC transmission window, and the waiting window is operated based on the VT(CA).

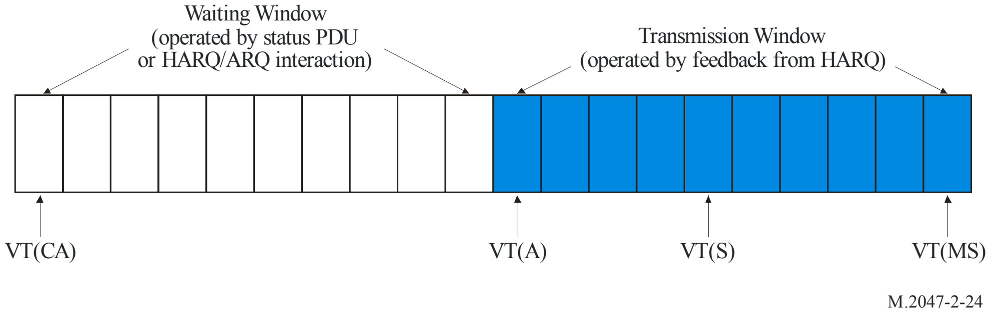
The transmission window is operated in the manner described in normal mode. In enhancing mode, only an operation scheme of the VT(A) is modified according to the HARQ feedback information. In normal mode, the VT(A) is updated based on a received positive acknowledgment signal, namely ACK of the status PDU. On the other hand, in enhancing mode, the VT(A) is updated based on inner feedback information with respect to reception of ACK of HARQ.

In enhancing mode, the VT(CA) of the waiting window is updated based on an ACK in the status PDU. In case of separately managing the transmission window and the waiting window, the transmission window is operated according to inner ACK information from the HARQ, thereby promptly transmitting a subsequent protocol data unit (PDU). When a packet is retransmitted with HARQ and NACK is received from the status PDU, the packet is excluded in the retransmission list of ARQ, thereby preventing unnecessary retransmission.

The VT(CA) has the SN value of a subsequent data packet for which an ACK is to be received via the status PDU according to a sequence, and is provided to the waiting window, as a lower value.

FIGURE 2.24

Window structure for HARQ/ARQ interaction



MAC determines whether a packet transmission of HARQ succeeds or fails, using the feedback information received in response to the packet transmission. RLC transfers a packet from a transmission window to a waiting window, when the MAC determines that the packet transmission of HARQ succeeds. On the other hand, RLC transfers the packet from the transmission window to a transmission buffer to retransmit the packet, when MAC determines that the packet transmission of HARQ fails after the maximum retransmission. RLC receives the feedback information of status PDU, and determines a process of the retransmitted packet based on the feedback information. RLC deletes the packet, when the packet transmission succeeds as a result of analysis of the status PDU. RLC does not perform retransmission of the packet when MAC is performing retransmission of the packet, when the packet transmission fails and when the packet exists in the transmission window as a result of the status PDU. RLC performs retransmission of the packet when MAC is not performing retransmission of the packet, when the packet transmission fails, and when the packet exists in the waiting window as a result of the status PDU.

2.4.6.9 Modified RBG group size for resource allocation

In normal mode, the size of resource block group (RBG) is determined according to system bandwidth as in Table 2.16. On the other hand, in enhancing mode the maximum size of RBG is additionally defined according to a UE type and a satellite specification of S-eNodeB as shown in Table 2.17. In Table 2.17, it is considered that the maximum antenna gain of S-eNodeB is 50 dBi and the antenna beam pattern of Recommendation ITU-R S.672-4 is used. If the satellite antenna gain of S-eNodeB or the antenna beam pattern is changed, RBG size according to the UE type may be adjusted. In order to support smaller size of RBG in handheld type over wide system bandwidth, the size of RBG is determined in enhancing mode as follows:

RBG_Size = min (the size of RBG from system bandwidth, Maximum size of RBG from UE type)

TABLE 2.16

The size of RBG from system bandwidth

System bandwidth (the number of RBs)	**The size of RBG (the number of RBs)**
10 or less	1
11-26	2
27-63	3
64-110	4

TABLE 2.17

The size of RBG from UE type

UE type	**The size of RBG (the number of RBs)**
Handheld class 1, 2, 3	1
Portable	2
Vehicular, Transportable	4

2.4.6.10 Definition of a new receiver memory field for HARQ

A direct implementation of the HARQ scheme into a satellite system will cause a serious memory problem at the receiver, due to the long RTD of a satellite communication system. For compatible operation with 8-channel HARQ, the receiver requires a large amount of memories for continuous transmission, in order to manage erroneous packets. In enhancing mode of the SAT-OFDM, the receiver memory (RM) field is added in order to solve the above problem. The RM field is inserted into HARQ feedback packet for the continuous transmission.

The RM field in Fig. 2.25 indicates the status of the receiver memory. The interpretation of the RM field is provided in Table 2.18.

FIGURE 2.25

Additional RM field inserted in HARQ feedback packet

M.2047-2-25

TABLE 2.18

RM field interpretation

Value	Description
00	Receiver memory is enough to store new erroneous packet.
01	Receiver memory is not enough to store new erroneous packet.
10	The packet indicated by feedback information was not stored in receiver memory.
11	The packet indicated by feedback information should be retransmitted in the first piece of encoding packet.

When a UE receives a MAC PDU, the UE decides a value of RM field according to a state of the receiver memory, and the UE sends a feedback packet with RM field.

2.4.6.11 Buffer status reporting for satellite communication

The buffer status reporting (BSR) scheme may not be supported in the satellite system due to long RTD. In a satellite system, buffer status information from a UE is not valid after a long RTD, because the buffer status can be greatly changed during the RTD. Therefore, uplink scheduling cannot be performed on the basis of buffer status information of a UE.

The BSR of a UE in the enhancing mode of the SAT-OFDM is performed in two modes; a normal reporting operation or a successive reporting operation. In the normal reporting operation, entire buffer status information of the UE is reported as in the terrestrial LTE. On the other hand, in the successive reporting operation, information on the increased amount of data in the buffer since the last reporting is reported. The increased data amount is a value obtained by adding an amount of data, which is waiting for being re-transmitted through feedback of transmission failure among data which has already been transmitted, to an amount of data which is newly added to the buffer of the user terminal. The normal reporting operation and the successive reporting operation are distinguished by logical channel identifier (LCID) values as in Table 2.19.

TABLE 2.19

Values of LCID for UL-SCH

Index	LCID values
00000	Common control channel (CCCH)
00001-01010	Identity of the logical channel
01011-10110	Reserved
10111	Truncated BSR for successive reporting
11000	Short BSR for successive reporting
11001	Long BSR for successive reporting
11010	Power Headroom Report
11011	Control-radio network temporary identifier (C-RNTI)
11100	Truncated BSR

2.4.6.12 HARQ retransmission in satellite carrier aggregation

In case of enhancing mode operation, the component carriers are changed for the HARQ retransmission. This can be used to reduce upper layer delay. When different feedback packets are received from component carriers, and the gain from the change of component carriers is larger than that of a HARQ retransmission without the change of component carriers, the transmitter changes component carriers for a HARQ. The gain from the change of the component carriers can be obtained if the channel condition improves due to the change of the component carriers, and the previous MCS mode is applied, and subsequently the BLER performance improves. When the transmitter changes the component carrier for the retransmission, the initial version of HARQ packet is transmitted in a new component carrier and a new data packet is transmitted in the previous component carrier. For discriminating the component carrier change, NDI field is modified as in Table 2.20.

TABLE 2.20

NDI field interpretation

Value	Description
00	New data packet
01	Retransmitted packet
10	New data packet with changing component carrier
11	Reserved

Basically, the NDI field (value: 00 and 01) is used the same in normal mode operation. When an event of the component carrier change is occurred, the transmitter, which received a negative acknowledgement, sends a new packet with the newly defined NDI field (value: 10).

The steps of the HARQ retransmission in carrier aggregation are as follows:

– receiving different feedback packets from component carriers;

– comparing the gain of the component carrier change with the average gain of HARQ retransmission:

  i) when three or more component carriers are used, the priority according to the sequence number of the upper layer packet and the channel condition is applied to the component carrier change;

– applying the component carrier change, when the gain of the component carrier change is larger than that of HARQ retransmission:

  i) an initial version packet of HARQ is transmitted at the component carrier where a packet error is not occurred;

  ii) a new packet is transmitted at the component carrier where a packet error is occurred;

– not applying the component carrier change, when the average gain of HARQ retransmission is larger than that of the component carrier change:

  i) the continued operation is the same in the normal operation.

2.5 Detailed specifications

Since SAT-OFDM is derived from 3GPP LTE(-Advanced), the organization of the SAT-OFDM specifications closely follows the original 3GPP structure. The SAT-OFDM numbers have been designed to follow the corresponding 3GPP LTE numbering system. All SAT-OFDM specifications have the following numbering system.

– SAT-OFDM xx.yyy

where the numbers xx and yyy correspond to the 3GPP-numbering scheme.

Due to the differences between terrestrial and satellite channel characteristics, some modifications to the LTE standards are necessary. Some specifications are directly applicable, whereas others are applicable with modifications.

A SAT-OFDM system is defined by the combination of a family of SAT-OFDM specifications and 3GPP specifications, as follows:

– If a SAT-OFDM specification exists it takes precedence over the corresponding 3GPP specification (if any). This precedence rule applies to any references in the corresponding 3GPP specifications.

– If a SAT-OFDM specification does not exist, the corresponding 3GPP specification may or may not apply.

The detailed specifications for SAT-OFDM radio interface is based on the following set of documents:

– Physical layer: the most recent version of the SAT-OFDM documents derived from the 36.200 series.

– Protocols: the most recent version of the SAT-OFDM documents derived from the 36.300 series.

This set of detailed specifications in SAT-OFDM Release 1 is presently being elaborated based on 3GPP LTE Release 8 specifications inside the Radio Access Working Group (WG7011) under IMT-Advanced Project Group (PG701) of TTA in Korea (Republic of).