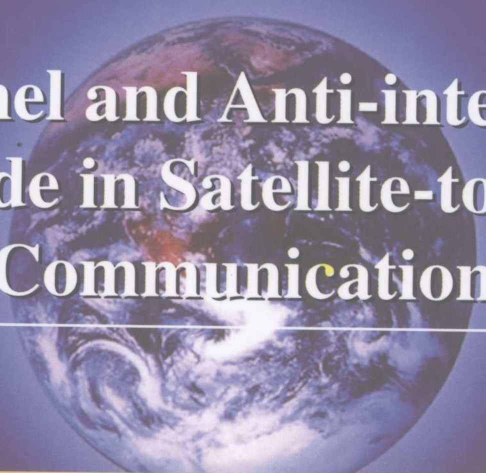
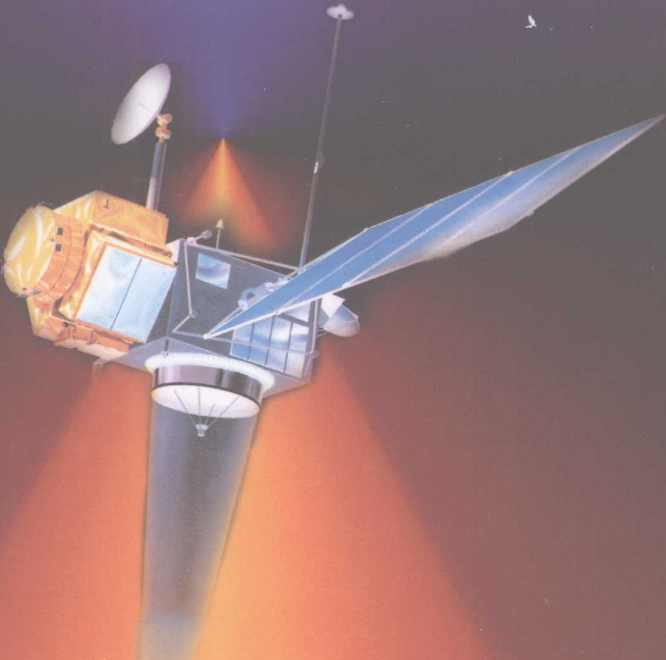
The Channel and Anti-interference Turbo Code in Satellite-to-ground Optical Communication Links



Xiaofeng Li



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Tianbing Li

The Channel and Anti-interference Turbo Code in Satellite-to-ground Optical Communication Links

Xiaofeng Li

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Preface

The book, with a name of "The Channel and anti-interference Turbo code in satellite-to-ground optical communication links", is based on a set of lecture notes prepared for a first-year graduate course on the principle and technology of optical communication links, given in the University of Electronic Science and Technology of China (UESTC) for the past several years.

Lots of contents (especially refer to the theory and theoretic model) in this book are excerpted from the published references which were vended by the experts and scholars in domestic and overseas. This book labels the references cited as much as possible. However, because of restriction of different reasons, it is difficult to ensure that there is no omission and error, and hope learners of insight to criticize and make comment.

The author of this book appreciates all the authors of references. Because of their diligent and highly effective work for many years, which make me have some superficial understanding to many theoretic problems in satellite-to-ground optical communication links.

The characteristics and the equation of satellite-to-ground optical communication links are mainly introduced in Chapter 1.

The basic information of the atmosphere and the characteristic of the satellite-to-ground channel are mainly introduced in Chapter 2.

The effects of attenuation and turbulence effects are introduced in Chapter 3 and Chapter 4, and the aperture averaging effects are introduced in Chapter 5, many contents in above three chapters are extracted or edited from the literatures that published openly in domestic and overseas whose authors include Ruizhong Rao, Yixin Zhang, Kerr J R, Yura H T, Mckinly W G, Andrews L C and Fried D L, etc..

The basic knowledge of digital modulation and code are mainly introduced in Chapter 6 and Chapter 7, To make the contents more abundant, exhaustive and accurate, many contents are extracted and compiled from the published literatures whose authors include Amnon Yariv, Zushun Song, Changxing Fan, Bernard Sklar and Stephen G. Wilson, etc..

The basic principle of Turbo code and its application in satellite-to-ground optical communication links are introduced in Chapter 8, many contents in this chapter are come from the literatures that openly published in recent years whose authors include Sergio Benedetto, Guido Montorsi, Bernard Sklar, R. Garello, P. Pierleoni, C. Berrou, Donghua Liu, Eric K. Hall and P. Thitimajshima, etc..

This book is recommended to those, who have interest in research of satellite-to-ground optical communication links. It can be used for an introductory level course as well as for a senior level course to engineering students. The practicing engineers can also find it's useful to update their knowledge in this field. In addition, this book can also be useful as a working reference in the design of satellite-to-ground optical communication links.

I am pleased to thank my colleagues, friends and students who made many valuable suggestions and skilful services in the preparation of the manuscript. Especially, I would like to thank my students Xiaomei He, Jianqiang Lai, Yang Liu, Hua Zhang, Jixiong Liang, Ruixiang Ren, etc..

I would like to thank my wife and child for their patience during the time I devoted to edit this book.

I hope that this book will be useful for researchers not only in satellite-to-ground optical communication links but also in other fields of optical communication links.

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Dec. 20th, 2007

List of Abbreviations

AlGaAs Aluminum Gallium Arsenide
APD Avalanche Photo Diode
APP A-Posteriori-Probability
APT Acquisition, Pointing and Tracking
ASK Amplitude Shift Keying
AWGN Additive White Gaussian Noise
BCH Bose Chaudhuri Hocquenghem Code
BER Bit-Error Rate
Bps Bits per Second
CCD Charge Coupled Device
CCSDS Consultative Committee for Space Data Systems
CRL Communication Research Laboratory
CWEF Conditional Weight Enumerating Function
DSO Distance Spectrum Optimized
DSP Digital Signal Process
EFD Effective Free Distance
ESA European Space Agency
FEC Forward Error Correction
FER Frame-Error Rate
FIR Finite Impulse Response
FOV Field of View
FPGA Fild Programmable Gate Array
FSK Frequency Shift Keying
FSP Finite State Permuter
GEO Geostationary Earth Orbit
IGA Interleaver Growth Algorithm
IOWEF Input-Output Weight Enumerating Function
IRWEF Input Redundancy Weight Enumerating Function
ISLs Inter-Satellite Communication Links
ISS International Space Station
JPL Jet Propulsion Laboratary
LD Laser Diode
LEO Low Earth Orbit
LLR Log-Likelihood Ratio
MAP Maximum a Posteriori
ML Maximum Likelihood
NASA National Aeronautics and Space Administration
Nd: YAG Neodymium Yttrium Aluminum Garnet
NSC code Nonsystematic Convolutional Code
ODS Optimal Distance Spectrum
OISL Optical Inner Satellite Links
OOK On Off Keying
PCBC Parallel Concatenated Block Code
PCCC Parallel Concatenated Convolutional Codes
PDF Probability Density Functions
PIN P junction-I Intrinsic Layer-N junction Photodiode
PMF Probability Mass Funciton
PPM Pulse Position Modulation
PSK Phase Shift Keying
R-S code Reed-Solomon Code
RSC Recursive Systematic Convolutional
SCBC Serially Concatenated Block Code
SCCC Serially Concatenated Convolutional Code
SILEX Semiconductor Intersatellite Link Experiment
SISO Soft Input Soft Output
SOLACOS Solid State Laser Communication in Space
SOTT Small Optical Telecommunication Terminal
SW-SISO Sliding Window-Soft Input Soft Output Module
UMTS Universal Mobile Telecommunications System
VA Viterbi Algorithm
WEF Weight Enumerating Function

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CHAPTER 1

Introduction

1.1 Introduction

According to the different kinds of the channels, wireless optical communication links can be grouped into the following categories: satellite-to-satellite optical communication links, satellite-to-ground optical communication links, satellite-to-sea optical communication links, ground-to-ground optical communication links, ground-to-sea optical communication links, indoor optical communication links, etc. In this book, we mainly discuss satellite-to-ground optical communication links. Thus, many models given in this book are related to the above channels.

In this book, the "link" is defined as something which include transmit module, channel, receive module, etc., the "system" is defined as the link except channel. When discuss wireless optical communication links, it means the wireless laser communication links whose wavelength is from 0.5μm to 10.6μm. Therefore, the basic principle is same, there are some differences between not only wireless RF/micro/mm communication links but also fiber communication links because the channels are different.

This book is to introduce the characteristics of satellite-to-ground or ground-to-ground wireless optical communication links, and introduce some solutions especially for anti-interference channel code.

It is very necessary and important to do deep research on the principles and technologies of the satellite-to-ground optical communication links.

There are three main factors that make the research of wireless optical communication enter a rapid development period, and expound the necessity and feasibility of developing wireless optical communication links.

Firstly, the rapid growth of the information industry in recent years has resulted in the dawn of the "Teraera". Today's information systems should be able to execute tera-operations per second and to transmit terabits per second. Achieving progress in modern communication systems is stimulated mainly by wide application of optical methods.

Therefore, there are enormous demands and huge market for wireless optical communication links in both civilian and military application field.

With the rapid development of society, more and more communication methods and bandwidths are needed.

The typical bit rates for mobile RF wireless system are in the below Mbps range, and a few hundred Mbps for fixed RF wireless links. Despite of lower data rates, the link error performance and service quality of these RF communication systems are many orders of magnitude below that of the fiber optical transmission systems.

For a single link, the standard communication velocity of microwave communication system is less than 1,000Mbps, compared with it, optical communication's working frequency duration is three to five orders higher than the microwave communication system, in other words, its theoretic standard communication velocity may be three to five orders higher than the microwave communication system.

Nowadays, the fiber communication links can offer high-speed(the data rate up to hundreds of Gigabit per second with low bit error rate), large capacity data transmission to respond to the present and future needs pertaining to information distribution, real-time multimedia applications, high-speed Internet based digital services, and other bandwidth-intensive applications in ground, but the satellite-to-ground communication links only have the standard communication velocity which is less than 1Gbps (single link) by RF/mw/mm, therefore, the high-speed, large capacity data transmission performance have become the bottleneck of satellite-satellite-ground-ground networks.

Secondly, the theories about wireless optical communication links and some key technologies have made great progresses, some achievements can support the theory into application.

Thirdly, the state of making the Optic-electro product such as laser and detector is well for setting up some wireless optical communication links.

1.2

The characteristics of the wireless optical communication links

The characteristics of the wireless optical communication can be simply concluded as follows[1]:

(1) Wide frequency band, large information capability and high potential data transfer rate.

(2) Narrow emitting beam, good direction performance and high energy density.

(3) High secrecy and less mutual interference between equipments.

(4) Small size in antennas and small bulk in terminals.

(5) Low power consumption, small size and light in weight.
(6) Anti-electromagnetic interference.

1.3

The kinds of the laser beam

Generally, there are three kinds of the laser beam which propagate in the satellite-to-ground optical communication links such as plane wave, spherical wave, gaussian wave.

The different laser beam propagate through atmospheric turbulence channel will suffer different degrees of the effect.

1.4

The main problems in satellite–to–ground optical communication links

In contrast to the optic fiber communication links, wireless optical communication links launch light signals into a medium without any attempt to control the propagation of the light after it leaves the transmitter. Wireless optical communication links offer numerous advantages over RF systems such as higher data rates and less sidelobe interference. What's more, the narrow beam allows it for higher antenna gain and smaller antennas. The improvement in system performance over RF designs can be used to decrease power, size, and weight requirements, an important consideration for satellite payloads which are constrained by these parameters.

The disadvantages of wireless optical communication links include the required accurate beam pointing and the degradations inflicted by the medium of propagation.

For being using a narrow beam, it is difficult for ordinary long-distance satellite-to-ground optical communication systems to acquire and point each other, it means that it is difficult for setting reliable links.

In order to solve this problem, the satellite-to-ground optical communication links often adopt APT (Acquisition, Pointing and Tracking) technology, for the main purpose of this book is to discuss the topics about atmospheric channel and anti-interference channel coding, therefore, invite the interested reader to review the principles and technologies of the APT for many details.

The main problems related to degradations inflicted by the medium of propagation in satellite-to-ground optical communication links can be grouped into two categories roughly.

The first is the degradations induced by the attenuation of the transmitting power which is not rigorous denoted as the attenuation effect, and the second is the degradation induced by the turbulent atmosphere random medium which is not rigorously denoted as the turbulence effect[2].

All the degradations are related to the characteristics of propagating laser beam.

There are many molecules and aerosol in the atmosphere, when the laser beam propagate through the atmospheric channel, it will occur the absorption and scattering effects which caused the severe degradations of the satellite-to-ground optical communication links.

When the laser beam propagates through the atmosphere, the electric vector of light wave makes the charged particles in substance structure forced vibration. Part of the light energy is used to support the energy that the forced vibration needs. If the matter particles collide with other atom and molecule, the vibration energy can change into translational kinetic energy, which can increase the energy of the thermodynamic movement, so that the body can heat. Under this condition, this part of light energy change into thermal energy, and the light energy disappears, which represents that the laser beam is absorbed[3].

When laser beam propagate through the satellite-to-ground atmospheric channel, the dispersion particles such as atmospheric molecule and aerosol particle in the channel is acted by laser oscillation electromagnetic wave. Then, the dispersion particle is polarized and induced oscillatory electromagnetic multipole. Electromagnetic oscillation procreant from dispersion particles electromagnetic multipole radiate electromagnetic wave in all directions, and it comes into the phenomenon of light dispersion.

Pure scattering effects will not cause the energy attenuation totally, but it will cause the received energy attenuation in the on-axes direction.

Propagation of laser beam in a turbulent atmosphere random medium gives rise to a variety of fluctuation effects caused by the random inhomogeneities in the medium. As a rule, these effects degrade the radiation by corrupting its coherence. The propagating laser beam which has corrupting coherence not only means its optical quality is not superior, but also cause beam wander randomly, the facular energy has new distribution which phenomena are the beam broaden, malformation and break up, etc..

Atmospheric effects including refractive turbulence and aerosol obscuration can seriously degrade the performance of both optical imaging and laser projection systems for civilian and military applications. These atmospheric degradation effects are the most serious near the ground where the strength of turbulence and the aerosol concentration is the highest.

The problem of wave propagation in the atmosphere has become increasingly important for reliable system design in recent years, particularly in the areas of wireless optical communication links. A complete understanding of these degradation effects is essential for performance analysis, reliable system design, and development of efficient mitigation techniques.

These media are, in general, randomly varying in time and space so that the amplitude and phase of the waves may also fluctuate randomly in time and space. These random fluctuations and scattering of the waves are important in a variety of practical problems.

Communication researchers are concerned with the phase and amplitude fluctuations of waves as they propagate through atmospheric channel and with the coherent time and coherent bandwidth of waves in such medium.

All of these problems are characterized by the statistical description of waves and media. Because of this fundamental similarity, it should be possible to develop basic formulations that are common to all these problems.

In this book, the fundamental formulations of wave propagation and scattering in random media will be presented.

There are three kinds of effects in the course of laser beam propagating through the turbulent atmospheric random medium. Generally, they are called the effect of attenuation, the effect of turbulence and the effect of deflection respectively.

The effect of attenuation will cause the received energy attenuation in the on-axes direction; therefore, the long distance satellite-to-ground optical communication link is usually a power restricted link. It is very important for us to finish anti-interference channel coding, understanding the basic information about the channel is the foundation of the anti-interference channel design.

The effect of deflection make the propagating laser beam deflect in the atmospheric channel. As there are mature principles and technologies in this research area, we will not discuss this topic deeply in this book.

In the latter chapters related to satellite-to-ground channel of this book, the emphasis is laid on the degradations induced by the atmosphere for the received optical signal.

There are four major degradation phenomena of the received optical intensity introduced by the atmosphere[4], they may be characterized as amplitude scintillations, wavefront angle-of-arrival variations (wavefront tilt or image dancing), beam spreading, and beam wander etc..

1.5

The kinds of the satellite-to-ground optical communication links

According to the location of the transmitters or the receivers, the satellite-to-ground optical communication links can be classified as uplinks and downlinks (see Fig.1-1).

The uplinks can be defined as the links that the transmitters are located in ground while the receivers are located in the spacial platform such as satellites and space stations.

When laser beam propagates through atmospheric layer, it will be affected by atmospheric refraction and attenuation immediately. At the same time, as arrival-angle fluctuation and scintillation brought by turbulence effect can also lead to the decline of actual receiving power of the receivers, after propagating through atmospheric layer, the beam quality has been affected greatly and occurred different degree of ecdysis going with great deflection in the beam's propagation direction. When the affected beam arrives at the receivers through free space propagation, the link signal optical system's quality will be seriously influenced, and more important, it's very difficult to ensure and realize micro-radian order Acquiring, Pointing, and Tracking (APT) of the beam (how to deal with degenerate spot affected by atmospheric turbulence and acquire high-precision positioning information technique is the studying hotspot in the field of domestic and overseas laser guidance, satellite remote sensing etc.). According to present application requirements, the uplinks are mainly applied to command propagation and emission of control signal whose transmission rate require not too high.

On the contrary, the downlinks can be defined as the links that the receivers are located in ground station while the transmitters are located in the satellites operating in the free space or the upper atmospheric layer.

As the deflection of the beam is small in free space, the quality (such as coherence and divergence angle) of the beam can still keep better after long-distance propagation in free space, and it can't be affected by attenuation effect, turbulence effect and deflection effect until the beam goes through atmospheric layer again. Compared with uplinks, atmospheric effect on downlinks is fairly weak, therefore, it is easier to receive in ground station than uplinks receiving. The downlinks are mainly applied to spacial information's propagation or forwarding with large amount data whose transmission rate require relatively high.

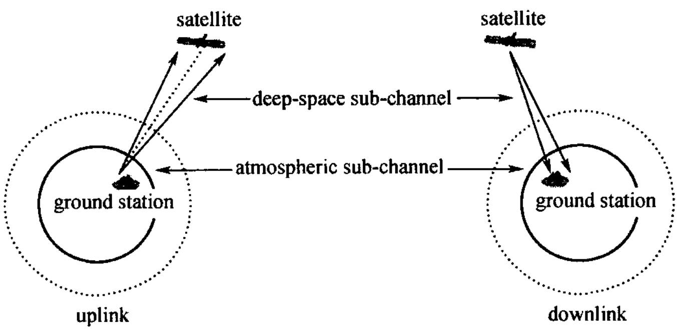

Fig. 1-1

the schematic diagram of satellite-to-ground communication links[1]

According to the principle of satellite-to-ground communication links, space-to-ground laser communication links are composed of the following parts which are based on their role and function respectively.

The main function of Acquisition, Pointing and Tracking (APT) sub-system is to accomplish beam's accurate pointing between satellites and ground stations. The APT sub-system which uses compound-axis control structure can be divided into coarse tracking system, accurate tracking system and signal processing and controlling system. Coarse tracking can accomplish the task of acquisition, pointing and tracking in large field of view. Accurate tracking system can accomplish the task of accurate tracking in small field of view accordingly.

The laser communication link sub-system is to accomplish signal transmitting, acquisition and processing of satellite-to-ground laser communication system. It is composed of laser transmitter, receiver and optical antenna part etc..

The channel of satellite-to-ground is more complex than satellite-to-satellite channel. In the process of propagating, the laser beam will pass through tens of kilometers random atmospheric channel. This will have some bad effects to laser beam transmitting which is different from satellite-to-satellite channel, and this is also the most significant factor that limit the communication links.

Fig.1-2 shows the principle diagram of satellite-to-ground optical communication links[1].

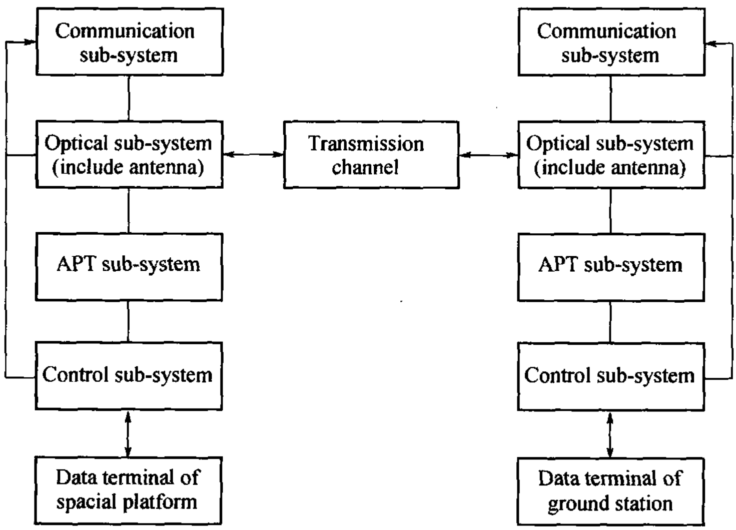

Fig. 1-2

the principle diagram of satellite-to-ground optical communication links

The principle and model study of laser atmospheric random channel transmission is the most significant and basic key technique of satellite-to-ground optical commun-