Review of DIGITAL COMMUNICATION

'State of the Art' in Digital Signalling, Digital Switching and Data Networks

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Preface

"We have now reached a stage when virtually anything we want to do in the field of communications is possible: the constraints are no longer technical, but economic, legal or political. Thus if you want to transmit the Encyclopaedia Britannica around the word in one second, you can do so."

—Arthur C. Clarke

Looking around us and observing the technological developments in electronics and telecommunications all over the world, one is inclined to agree with the futurologists that we have almost reached the Information age and the Information revolution—a revolution much more significant than the Industrial revolution of the last century. The changing social needs and the development of new technologies are bringing the evolution of new communication capabilities in the form of videotex, electronic mail, high-speed FAX, teleconferencing and interactive CATV. These are also leading to automated offices and wired homes, where most of the future information will be generated, processed and utilized for running the industries, business and the government, and for education and recreation. At the same time, the spectacular developments in solid state electronics, computers, digital switching and transmission, have brought in the Digital revolution —leading to universal digital connectivity. It is also evident that communication is getting more and more integrated with computers and data networks, and eventually we shall have a fully integrated general purpose computer-communication (C & C) networks. These C & C networks with their flexibility and multiservice facilities will then lead to the Integrated Services Digital Network (ISDN), which is the desired goal of the current developments in telecommunications.

The futuristic ISDN will not only provide the global digital connectivity through digital switches and digital transmission, but also the required signal processing, data compression, data protection and storage. Technological advances in devices may eventually result in the complete 'system-on-a-chip', requiring completely new approaches to the system design. As a consequence of the above wide ranging developments, the academicians will have to develop new unified theories for end-to-end information systems, including models of humans as information processors. We shall thus need in future more information and communication theorists than we need now; and these theorists will have to be trained in a wide variety of disciplines and technologies.

Most of the technological developments in digital communication has been very rapid and has taken place only during the last two decades. As a result, the senior professionals and academics have not been able to keep pace with these developments and therefore, have an urgent need to update their knowledge in these areas. Moreover, it is very necessary that our electrical engineering students, specialising in communication, must have a strong base in digital communication systems as well. Unfortunately, a comprehensive book giving the 'state-of-the-art' information on Digital Communication is not available so far. To fulfil the need of such a book, the present volume has been written, presenting a review of the recent developments in important areas of digital communication.

The book consists of ten chapters, and discusses such topics as: principles of digital modulation, source encoding, data transmission through cables and optical fibres, digital radio including satellite communication, data networks and digital switching, information theory and coding, survival of communication including spread-spectrum techniques, and future trends including ISDN. Conceptually, a system point of view has been taken in discussing the various topics, and the total range of digital signal processing necessary in a digital network, has been brought out in subsequent chapters, thus presenting a continuity of thought from end-to-end. The main emphasis has been on the 'state-of-the-art' and to discuss important results in the context of present-day developments in digital communication networks. Most of the information contained in the book are now available only in published journals. The book also contains an exhaustive bibliography.

The book is an outgrowth of the author's teaching and research activities in the area of digital communication over the last three decades. Further, the author has been called upon, over the years, to give many series of lectures in various international and national workshops. The book is actually compiled out of these lecture notes, presently edited and updated. It is hoped that the book will fulfil the need of a reference volume for the faculty and the professionals; and the exhaustive bibliography would help the reader to continue further reading in the area of his interest. The book may also be used in teaching courses in digital communication systems by selectively choosing the topics of interest. The contents of the book is mainly complementary (but in a few cases overlapping) to the topics in 'Principles of Digital Communication' by Das, Mullick and Chatterjee. By choosing selectively from the two books, two/three semester courses at the senior level may easily be organised. Although the book is primarily addressed to the professionals, it is no doubt that the senior students and academics will also find it useful and informative.

In writing the book, the author has drawn largely from the published materials in recent journals and some of the recent books in communication. As such, the author is indebted to a large extent to his predecessors and the researchers; and the acknowledgements have been made in proper places in the text. The author has spent a lifetime at the Indian Institute of Technology, Kharagpur and recently at the Indian Institute of Technology, Kanpur, and as such, he is largely indebted to his innumerable students, some of them colleagues later on, for the intellectual enrichment he derived through their interaction in class rooms, laboratories and research projects over all these years.

The author is grateful to the authorities of IIT, Kanpur, for providing financial support to the project through Quality Improvement Program. The author also wishes to thank Mr. J.C. Verma for excellent artwork, Mr. Joseph John for correcting the manuscript with care and patience, and Mr. C.M. Abraham for excellent typing of the manuscript and for general secretarial help.

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Contents

CHAPTER 1

Introduction

In ancient civilizations, the development of signs, symbols, codes and languages led to better communication between member units of a society, and the art of printing, with the availability of books, widened the area of communication between man and man at great distances. Although Joseph Henry invented the telegraph in 1831 and Samuel Morse followed with his code in 1832, the major breakthrough in long-distance telecommunication was due to: (i) the invention of the telephone by Graham Bell in 1875; (ii) the successful production and detection of electromagnetic waves by Heinrich Rudolf Hertz in 1888; and (iii) G.M. Marconi's success in the transatlantic radio experiment in 1901. It is indeed an interesting exercise to correlate the growth of the modern civilization with the landmarks of discoveries/inventions in electronics and telecommunication, as given in Table 1.1. The range of human communication has expanded through many orders because of the successful developments in telegraph, telephone, radio, TV and, now, satellite and fibre-optic systems. The present status of telecommunication is easily visualized by going through the progress made in last two decades.

The status of telecommunication varies widely in different countries [1]. From the statistics of 1974, it is observed that the world total number of telephones was 336×10^6, and, with an average growth of 20% per year, the expected total in 1984 was 10^9 (approximately). However, the telephone density in the developed First World is about 40; in the socialistic Second World, the density is 1.76; and in the developing Third World, the density is 1.15 only, for every 100 people. It has been also analysed that countries with high GNP have a high telephone density and, at the same time, the growth rate is also high in developed countries. The traffic growth and the related network development depend on various factors, such as: economic activity, service improvements, telecommunication maturity and service reliability. Thus, it becomes more difficult for developing countries to expand their telecommunication facilities because of their dependence on capital, technical knowhow, and a much higher demand for more telephones. The growth of the international telecommunication network depends on the traffic behaviour, and that on economic activity and social needs. The traffic growth during the last decade for different countries varies from 10% to

Table 1.1 Some landmarks in electronics and communication

Mediterranean civilization—(Egyptian)—pictograph, ideograph and hieroglyphs
Phonetic writing—tachygraphy by Greeks—400 B.C
True shorthand—Tyro, 60 B.C. (for recording the speech of Cisero)
Cipher—Roger Bacon's scripts (A.D. 1214-1294)
Bush telegraph—talking drum of Congo tribes (2-state code)
Ogam script—by ancient Celts, A.D. 400
Universal language (artificial)—by Descartes 1629
John Wilkins—1668, invention of new language with special grammar—supported by the Royal Society
Lingua Franca—1921 (League of Nations)
Electrical signalling—Roger Bacon 1267, Watson 1746
Morse code—1832; Joseph Henry—telegraph—1831
Submarine telegraph cable—1850
Maxwell's theory of EM field—1864
Quadruplex telegraphy—Heaviside and Edison—1875
Graham Bell—magneto telephone—1875; Microphone—1878
Gramophone/phonograph—Edison—1877
Voice modulation of a light beam by microphone—Bell—1878
First manual exchange—1878
Piezoelectric crystals (Pierce *et al.*)—1880
Edison effect—1883
Hertz's experimental production and detection of EM waves at $\lambda = 5$ m and 50 cm; reflectors, 1888
Strowger automatic switch—1889
Generation and detection of EM wave ($\lambda = 6$ mm)—1895 by J.C. Bose
Marconi-transmitted coded message at 1.75 miles—1895
Marconi's transatlantic radio experiment—1901
Heaviside and Kennedy—discovery of ionosphere—1902
I.T.U.—1865 in Paris, International Radiotelegraph Union—1906
First telegraphic transmission of picture from Munich to Numbering—Korn—1904
Electron (Thomson)—1897
Vacuum diode (Fleming)—1904
Cathode ray tube—1905
Triode valve—De Forest—1906
Auto exchange—1907
Radio transmitter—Marconi—1916
Wave filters—Campbell (birth of FDM)—1914-18
Ultrasonics (submarine detection)—1914-18 (World War I
Superhet radio receiver (Armstrong)—1918
Crossbar switch—1919
Printing telegraphy—1920
Experimental radar—1922
FM theory—John Carson—1922
Electronic TV picture tube (Zworykin)—1923
Telegraph theory—Nyquist—1924
Carrier and VFT on lines—1925
Information theory (Hartley)—1928
Television (Jenkins)—1925, Fransworth—1929
Commercial transatlantic radio telephone—1926
Negative feedback amplifier (Black)—1927

Photoelectric devices—1929
MW transmission experiment—1931 (Clavier)
Vocoder (Dudley)—1936
Coaxial multichannel circuits—1933
Radio telemetering (radiosonde)—1937
Bell Lab. Crossbar Exchange No. 1—1938
Magnetron, Klystron, Radar—1939 (World War II)
Control and telemetry—WW II
First Computer at Harvard University—1944
Pulsed Radar—14 MW; 10 cm—1949
Information theory—Gabor—1946; Shannon—1948; Wiener—1948
Transistor—Bardeen—1947; Shockley—1949
Audio submarine cable—1950
Transatlantic coaxial cable—1955
ESS—1955-60
Maser (Gordon *et al.*)—1955-56
Laser (Schawlow and Townes)—1958-60
Tunnel diode—Esaki—1957
Integrated circuits—1960
Man-on-Moon—Apollo Program—1961-66
ESS No. 1—1964
Microprocessor—1970
ESS No. 5—1980
Fibre-optic communication—1966-76

Satellite—1957-80

Sputnik—1957
Score—1958
Courier—1960
Telstar—1962
Relay—1963
Syncom—1963
Early Bird—1964
Mariner IV—1965
Mariner V—1966
Intelsat—(I-IV)—1968-74
ATS-F—1974
Intelsat V—1979-80
INSAT IA—1982

Digital communication

PCM (Reeves)—1938
Oliver, Pierce, Shannon—1948
T_1-carrier—1962
DM—(CC Cutler)—1952
F. De Jeager—1952
Greefkes—1968

Coding

R.W. Hamming—1950
P. Elias—1955
BCH—1959-60
Woozencraft—1957 (sequential decoding)
Viterbi—1967 (M-L decoding)

45%; the highest growth rate being that of Brazil, and the world average is 16%. Major investments for international telecommunication have been made in submarine cables and satellite system networks, and the total was approximately $ 4000 million till 1978. Since the media diversity for international network is provided by cable and satellite paths in a complementary way, equal importance is now given for the development of both the systems. It is estimated that approximately $ 1000 million for satellites and $ 1000 million for cables have been invested after 1978 [2]. Thus, telecommunication, both national and international, supports a very large industry, indeed!

1.1 PROGRESS IN NETWORKS AND SYSTEMS

Over the decades, the telecommunication network in many countries has grown from a small regional system to a worldwide one. At present, a long-distance telephone call is processed through a central office (CO) and a toll exchange; and for international calls, an additional gateway exchange is involved. The transmission media available are subscribers' cables, coaxial cables and MW LOS links, and, recently, satellite and fibre-optic links are being used extensively. A large telecommunication network using many exchanges and various media is shown in Fig. 1.1. Till 1960, the communication networks including exchanges were basically analog and the services handled were mostly voice and telex circuits. With the success of Pulse code modulation (PCM) and Time division multiplexing (TDM) through Bell System T_1-carrier in 1962, all transmission circuits, first short-haul trunks and then long-haul circuits, are fast becoming all-digital. Concurrently, digital exchanges using PCM-TDM techniques are also being introduced in communication networks. In the early days, transoceanic circuits were either through narrow-band submarine cables or HF radio; but with growing demands for more circuits, wideband transmission systems using MW links, coaxial cables, and now, satellite and fibre-optic systems are being used. The demand for more radio spectrum for expanding communication is further growing, and this will soon lead to the utilization of millimetric waves and optical communication. At the same time, the national and regional networks are maturing into all-digital global networks through the use of MW

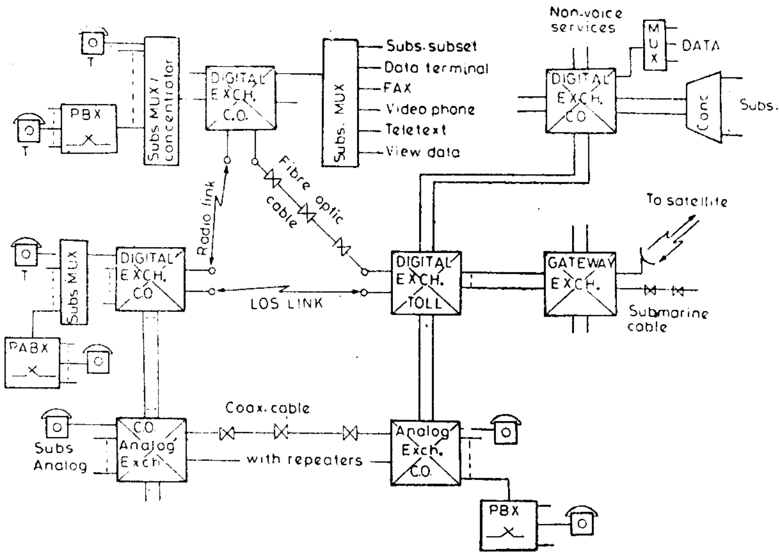

Fig. 1.1 Scheme of a large telecommunication network including analog/digital exchanges serving both voice and non-voice subscribers. Transmission media are: MW LOS links, satellite links, coaxial/fibre-optic cables and submarine cables (C.O.: central office, SUBS.: subscribers).

links, satellites, submarine cables and optical fibres, incorporating digital techniques.

1.1.1 Switching and Data Networks [3, 4, 5]

Historically, the switching networks have developed through manual to automatic and then digital exchanges. The automatic exchanges first developed were Strowger and Panel systems, and in the late 1930's, the Crossbar exchanges were introduced. This system was improved further till early 1960, when the concept of PCM-digital exchanges matured. An operational electronic switching system (ESS) was first installed in France (known as RITA) in 1968. Then, of course, the progress in ESS was very rapid, and, today, all major telecommunication administrations are committed to the futuristic all-digital switching networks.

In the context of the development of all-digital switching and transmission systems, the major contributions have been by the Bell Labs, ITT, CNET of France, and NEC/HITACHI of Japan. ITT has proposed the Network 2000 as the concept of their telecommunication network for A.D. 2000. The ITT system-12 is the first generation of digital exchanges developed with the concept of Network 2000, using distributed processing and fibre optics for transmission. In Japan, similarly, digital switching systems, such as, HDX-10 of Hitachi, NEAX-61 of NEC, are being installed using latest LSI technologies to achieve a compact, economical and fully electronic switching system. In UK, the system-X, an integrated digital switching and transmission system, has been developed for both data and telephone switching.

Bell Labs have developed the No. 4 ESS for toll switching and a newer version No. 5 ESS for local offices. Both the systems use stored-program-controlled (SPC) digital time-division switching and provide operational savings and ease in system growth. The digital switch consists of four major subsystems: (a) the central processor; (b) a message switch; (c) a time-multiplex switch; and (d) interface modules. The ESS uses fibre-optic links as trunks, microprocessor-controlled interface modules, and a time-space-time switching network. The SPC is distributed among the central processor and interface module units. The No. 5 ESS has a subscriber capacity of 12,000 lines and the No. 4 ESS has a capacity of 10^5 trunks. Both use the PCM format for incoming lines and the information rate of 32.768 Mb/s through fibre-optic links. Modular hardware, custom LSI chips and high-level programming languages are the key factors in these ESS.

Concurrently, the computer architecture has gone through an evolution, and today's distributed processing system has developed through point-oriented computers in the 1950's, the family series in the 1960's, large computers in the early 1970's and then, area-oriented horizontally distributed types in the late 1970's and supercomputers in the 1980's. The distributed system is intended to carry out all possible processing at the site, where information is generated and used. Instead of a single ultra-large computer,