EVALUATION OF ANALOG/DIGITAL BROADCAST VALUE CHAIN IMPLEMENTATION IN GHANA: CASE STUDY OF CONTENT AND MULTIPLEXING COMPONENTS

BY

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Declaration or certificate of approval page

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

Digital television broadcasting has content production, multiplexing (content aggregation), transmission and reception in its value chain. The study evaluates the content production and multiplexing components/services of some digital television systems in Ghana.

The study first establishes that Ghana is currently in what experts call the dual illumination stage of the digital migration. Dual illumination is generally expensive for networks such as Ghana Television (GTV) which has a large number of analog transmission system networks. It is recommended that to minimize the cost of dual illumination, right policies should be put in place to migrate all viewers on their services to digital in the shortest possible time and in the most cost effective manner.

To ensure that enough space is available for current incumbent analog stations on a digital multiplex, Standard Definition Television (SDTV) should be the video format choice before analog switch-off. Immediate implementation of High Definition Television (HDTV) could compromise the number of programs per channel. However, SDTV and HDTV could be operated on thematic manner/basis, by the collapsing of a number of SDTV programs for a HDTV program in such situations as sports.

The study establishes that the current digital multiplex operators use both the MPEG-2 and MPEG-4 compression standards. The latest version of MPEG-4, MPEG-4 AVC/H.264 is recommended since it is more bandwidth efficient.

Drop and Add services should be taken into consideration when planning the digital network to ensure efficiency and effectiveness.

The provision of Conditional Access (CA) and Middleware on multiplex and Set-Top-Box (STB) is necessary to regulate digital signal reception and also use it for valued added services such as e-government. Further findings and recommendations are found in the body of the report.

Acknowledgements

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CHAPTER 1
INTRODUCTION

1.1 Review of Broadcasting

Television and television transmission has gone through a number of transitions since the invention of a mechanical device that could scan a picture in 1884 by the German Scientist Paul Nipkow. Television is now one of the most important communications tools available in the world today. This is because it is one of the main ways of providing education, entertainment and information [1].

1.1.1 Analog and Digital Broadcasting

There are two main types of broadcasting employed to carry signals to the homes of consumers: Analog or Digital broadcasting while the modes by which these signals are transmitted are: over the air (terrestrial), underground cables and through satellites [2].

1.1.1.1 Analog Broadcasting

Analog broadcasting involves the encoding of television pictures and sound information and transmitting it as an analog signal where the information transmitted by the broadcast signal is a function of variations in the amplitude and/or frequency of the signal [2].

1.1.1.2 Digital Broadcasting

Digital broadcasting refers to the use of digital techniques in the final mode of transmission of broadcasting signals to viewers/listeners. Digital TV broadcasting has a number of advantages compared to Analog TV broadcasting; a more robust signal, higher and consistent technical quality, increased flexibility, seamless integration into other applications and services, improved user control over what and when one views or listens, and thus creating greater choice in content among others[3].

These advantages produce efficient spectrum usage, lower transmission cost and better service offerings for users. Digital broadcasting also has the potential to revolutionize TV viewing, giving consumers more choice and better quality. Broadcasters can serve multiple interests over the same infrastructure whiles the state can monetize the 'Digital Dividend' for socio economic development [3].

1.2 Broadcast Value Chain

The two ways of television transmission (Analog TV broadcasting and Digital TV broadcasting) give two different Broadcast Value Chains: Analog TV Broadcast Value Chain and Digital TV broadcast Value Chain. The Analog TV Broadcast Value Chain has in its chain: Content Production, Transmission and Reception while the Digital TV Broadcast Value Chain has: Content Production, Multiplexing (Content Aggregation), Transmission and Reception as shown in Figures 1.1 and 1.2 below. The bandwidth allocated for television transmission is 7/8MHz in the VHF (Very High Frequency) and UHF (Ultra High Frequency) bands respectively.

Analog TV transmission is known to be quite wasteful of bandwidth as the entire bandwidth is used to transmit only one program (station/channel). Digital TV transmission on the other hand makes good use of the bandwidth by transmitting six or more programs depending on the compression technique and the television format used.

1.3 Analog to Digital Migration

As a result of the benefits of digital broadcasting the whole world is migrating to Digital Television Broadcasting. The International Telecommunications Union (ITU) is leading the way in order to make the transition from Analog Television Broadcasting to Digital Television Broadcasting as smooth as possible. Countries such as Luxembourg, the Netherlands, Finland, Andorra, Sweden, Switzerland, Germany and the U.S.A have already made the full transition [4].

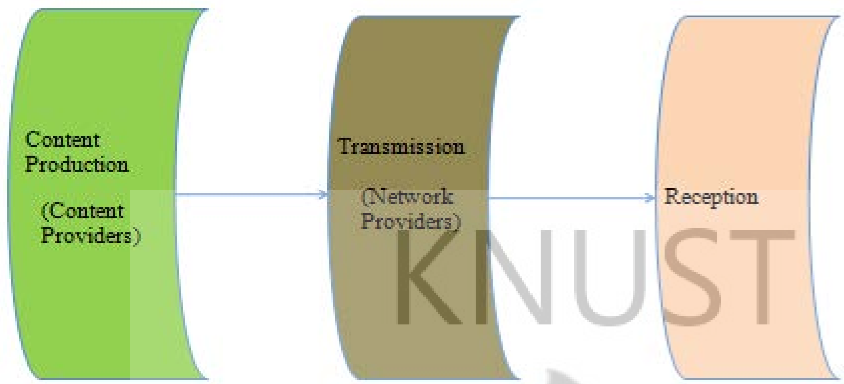

Figure 1.1 Analog TV Broadcast Value Chain

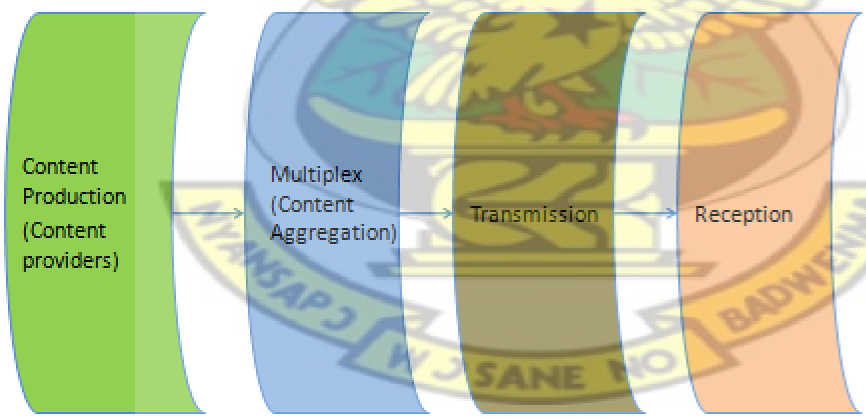

Figure 1.2 Digital TV Broadcast Value Chain

1.3.1 Migration Deadline

Terrestrial television transmission in Ghana has purely been analog up until November 2008. The National Communications Authority (NCA) undertook re-planning of frequencies in the bands 174-230MHz and 470-862 MHz from 2004 to 2006. This was finalized at the ITU´s Regional Radio-communication Conference (RRC-06) in Geneva where a treaty agreement, GE06, was signed [5]. The Conference agreed that the transition period from analog to digital broadcasting, which began at 0001 UTC 17 June 2006, should end on 17 June 2015, but some countries including Ghana preferred an additional five-year extension for the VHF Band III (174-230 MHz). The directive to migrate to digital broadcasting by 2015 is to all countries in Europe, Africa and the Middle East [5].

1.4 Digital Terrestrial TV Transmission in Ghana

At the beginning of the year 2009 the National Communications Authority based on the treaty it signed established a Regulatory & Industry Task Force for Digital Broadcasting Migration. The Task force had members from the following organizations: National Communications Authority (NCA), Ghana Broadcasting Corporation (GBC) and the Ghana Independent Broadcasters Association (GIBA) [5]. Following the Task force the Ministry of Communications inaugurated a National Digital Broadcasting Migration Technical Committee (NDBMC) on 13th January 2010 to among others make policy recommendations to the Government to enable Ghana achieve a cost effective and timely migration from analogue to digital broadcasting. The committee presented its report in August 2010[6].

Digital Migration in Ghana is therefore a reality. Deadline for switch-off of Analog TV is given as December 2014 [6]. Digital switch-on started late 2008. Currently transmissions on all broadcasting platforms have commenced. Digital terrestrial transmissions are currently available in Accra, Koforidua, Kumasi and Takoradi [7].

Ghana Broadcasting Corporation (GBC) in partnership with Next Generation Broadcasting (NGB), a Swedish-based broadcasting network, and five broadcasting companies in Ghana- Ghana Television, TV3, TV Africa, Net 2 Television and Viasat1 undertook a digital television pilot project in Accra. This pilot project also contained two international channels CNBC Africa and KidsCo. The pilot is over and two new multiplexes are currently being operated [7-8].

Skyy Media Group is also currently running a commercial terrestrial digital TV service Skyy Digital now Skyy Plus, in Koforidua, Kumasi, Takoradi and Accra. Crystal TV and Metro TV have at least one redundant DVB-T transmitter [7]. MultiChoice Ghana's DSTV and Multimedia Broadcasting's Multi-TV offer digital satellite TV with nationwide coverage. CATV offers its Cable Gold service on a digital platform in Accra and Tema [7].

Digital television broadcasting presents a lot of opportunities to the Ghanaian broadcasting industry. In Analog television broadcasting there are basically two services content generation and transmission provided by one broadcasting company. Digital television broadcasting provides a number of options. There are three different services as can be seen in Figure 1.2: content production (content providers), multiplexing (content aggregators) and Transmission (Network Operators). Three options are therefore available from the services which provide a lot of opportunities.

In the first option each of the three services can be provided by a different company. In the second option, the content production service is combined to the multiplexing service (content + multiplexing) and operated by a single company. The last service, transmission is then provided by a different company. The third option combines all the three services (content production + multiplexing + transmission) as one as in the analog value chain and provided by a single company [9-10].

This thesis takes a critical look at the Content Production and Multiplexing (Content aggregation) services of the Analog/Digital Television Broadcast value chain considering the technical issues and standards involved. Much of the thesis however, will be dedicated to the digital value chain since digital broadcasting is a new technology in Ghana and its implementation will pose a number of challenges.

The technical standards that will be imposed on content in the digital era in Ghana will mean content providers (broadcasters) will have to invest in new and modern equipments in order to produce content for digital TV broadcasting. A number of TV formats exist [11-12]:

Low Definition Television (LDTV),

Standard Definition Television (SDTV),

Enhanced Definition Television (EDTV) and

High Definition Television (HDTV).

These standards affect the number of programs that can be accommodated on a multiplex. Thus the number of programs depends on the aspect ratios and resolution of the individual TV standards. The number of programs on a multiplex also depends on the picture quality and type of service (e.g. sports requiring HDTV) [13-17]

The signals from six or more programs to be transmitted have to be combined into a single signal through a process called multiplexing. Broadcasters here, also have to invest in encoders, multiplexers and other equipments in order to combine the signals.

1.5 Objectives of Study

The objectives of the thesis among other things will be to:

- Review LDTV, SDTV, EDTV, HDTV and Aspect Ratios of Images
- Review JPEG, MPEG-2 and MPEG-4
- Review ways of assigning multiplexes in some countries around the world
- Evaluate Digital Signal Processing, Conditional Access and Valued Added Sercvices
- Review Digital Migration in Ghana
- Study of Implementation of Digital Television Broadcasting in Ghana
- Evaluation of the Implementations and making appropriate recommendations

1.6 Implementation Outline

This thesis will start with an introduction of Analog and digital television transmissions, showing the standards of each and the benefits of digital television transmission.

Subsequently, digital video compression systems and standards will be reviewed. A quick introduction of the various digital television standards around the world will be given. Digital TV systems used in some selected countries around the world will be reviewed in terms of the content production and multiplexing services of the digital TV value chain.

After this, digital television Implementation in Ghana will be studied in terms of content production and multiplexing. Standards used in Ghana will then be compared with the standards used around the world. Recommendations based on the comparisons will then be made for current digital TV implementation in Ghana and future implementations.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

The discovery of the existence of electromagnetic waves in the nineteenth century marked the beginning of the transmission of audio and video signal to consumers. Electrical signals were used to control the appearance of radio waves by inventers and as such the radio wave became a carrier for messages. This resulted in Radio broadcasting while ways to record music and other sound also developed rapidly [1].

Television is a field of electronic technology that has more direct effect on the world today than any other. The invention of the television and the advances in technology in the last 120 or more years have brought about a number of systems, solutions and methods of broadcasting sound and images to consumers [1].

2.1 Interlaced and Progressive scanning

There are two ways in which pictures are displayed on a television screen: interlaced and progressive scanning. In interlaced scanning, a single electron beam is used to scan a phosphor screen. The beam scans twice per photographed frame, thus there are two sets of lines which are called the first and second fields; together they constitute one complete picture or "frame". The frame rate is fast enough to create the illusion of continuous motion, while the field rate (twice the frame rate) makes the flickering imperceptible to the human eye. Hence, interlaced scanning allows the lowest possible picture repetition rate without visible flicker [1].

In progressive scanning a complete picture is drawn in one single scan line by line. Progressive scan is used for scanning and storing film-based material on DVDs. Progressive scan is used for most cathode ray tube (CRT) computer monitors, all LCD computer monitors, and most HDTVs. It has the following advantages: higher vertical resolution than interlaced video with the same frame rate, absence of visual artifacts associated with interlaced video of the same line rate, offers much better results for scaling to higher resolutions than equivalent interlaced video, and frames have no interlace artifacts and can be used as still photos. A disadvantage of progressive scan is that it requires higher bandwidth than interlaced video that has the same frame size and vertical refresh rate [1, 18].

2.2 Digital Television

Shannon's information theorem is a natural law which puts limitations on how information is transferred. The theorem puts limitation on two factors: the received amount of signal power and the bandwidth of the channel used for the transmission. The amount of received power is determined by the strength of the transmitter and the efficiency of the antenna used for reception. The bandwidth is the amount of frequency space that is occupied by the transmitted signal [1].

Actual radio signals are always limited in bandwidth as well as signal power. This applies to radio signals distributed by satellites, terrestrial transmitters and cable TV networks. If the amount of information in the signal is to be increased, then there has to be either an increase in the power of transmission, the amount of bandwidth or both [1].

When using satellite for distribution, there are several transmitters (called transponders) in each satellite. A transponder is limited in bandwidth and output power. A traditional satellite transponder has a bandwidth of about 30 MHz and may be used to transmit one TV channel (program). To transmit more than one TV program through such a transponder, a way to decrease the amount of information that is required for each TV program has to be found [1].

The principles for reduction of unnecessary information have been known for long. The unnecessary parts containing repeated information has to be removed and a reduced compressed version of the signal has to be created. In the receiver the original signal has to be re-created from the compressed signal [1].

In order to be able to let a computer handle a TV signal we first have to get it digitized. When we have a digital signal it is quite simple to manipulate it as we wish. Getting the signal digitized means that the audio and video signals are represented by a series of digits, rather than any physical media. The digits are then sent to a receiver which has the ability to recreate the physical analog audio and video signals from this information. This digitization is done by analog-to-digital and digital-to-analog converters [1].

2.2.1 Aspect Ratio of an image

The aspect ratio of an image is its width divided by its height. Aspect ratios are mathematically expressed as x: y. The most common aspect ratios used today in the presentation of films in movie theaters are 1.85:1(i.e., the picture is 1.85 times wider than the height of the picture) and 2.39:1. Two common videographic aspect ratios are 4:3 (1.33:1), universal for standard-definition video formats, and 16:9 (1.78:1), universal to high-definition television and European digital television [1, 20]. Figure 2.1 compares two television aspects ratios.

Figure 2.1 Two aspect ratios (4:3 and 16:9 respectively) compared with images using the same diagonal size [20]

2.2.2 Digital TV Formats

Digital television supports many different picture formats defined by the combination of size, aspect ratio (height to width ratio) and scanning technique [19].

2.2.2.1 Standard Definition Television (SDTV)

Standard definition television (or SDTV) refers to television systems that have a resolution that meets standards but not considered either enhanced definition or high definition. The term is usually used in reference to digital television, in particular when broadcasting at the same (or similar) resolution as analog systems [15].

Digital SDTV in 4:3 aspect ratio has the same appearance as the regular analog TV (NTSC, PAL, PAL2, SECAM) minus the ghosting, snowy images and static noises. However, if the reception is poor, one may encounter various other artifacts such as blockiness and stuttering [15]. Some TV standards and related aspect ratios can be seen in Table 2.1.

Table 2.1 Aspect Ratios and associated TV Standards [15]

Video Format (W×H)	**Name**	**Pixel aspect ratio (W:H) (Standard 4:3)**	**Pixel aspect ratio (W:H) (Anamorphic 16: 9)**	**Description**
720×576	576i	16: 15	64: 45	Used on D1/DV PAL
704×576	576p	12: 11	16: 11	Used on EDTV PAL
720×480	480i	8: 9	32: 27	Used on DV NTSC
720×486	486i	8: 9	32: 27	Used on D1 NTSC (ITU-R 601)
704×480	480p	10: 11	40: 33	Used on EDTV NTSC

2.2.2.2 Low Definition Television (LDTV)

Low-definition television (LDTV) refers to television systems that have a lower screen resolution than standard-definition television systems [13-14]. Mobile digital television systems usually transmit in low definition, as do all slow-scan TV systems [13-14].
The most common source of LDTV programming is the Internet, where mass distribution of higher-resolution video files could overwhelm computer servers and take too long to download [14]. Most mobile phones and portable devices such as Apple's video iPod, or Sony's PlayStation Portable use LDTV video, as higher-resolution files would be excessive to the needs of their small screens (320×240 and 480×272 pixels respectively). The current generation iPods have LDTV screens, as does the iPhone (480×320).The Video CD format uses a progressive LDTV signal (352×240 or 352×288), which is half the vertical resolution of SDTV [13].

2.2.2.3 Enhanced Definition Television (EDTV)

Enhanced Definition Television is a Consumer Electronics Association (CEA) marketing shorthand term for certain digital television (DTV) formats and devices, used by the CEA of the United States. Specifically, this term defines formats that deliver a picture that is superior to that of standard definition television (SDTV), but not as detailed as high definition television (HDTV) [16].

The term refers to devices capable of displaying 480 or 576-line signals in progressive scan (commonly referred to as "480p (NTSC)" and "576p (PAL)" respectively) as opposed to interlaced scanning, commonly referred to as "480i (NTSC)" or "576i (PAL)" [16].

EDTV broadcasts use less digital bandwidth than HDTV, so TV stations can broadcast several EDTV stations at once. Most EDTV displays use square pixels, yielding a resolution of 852×480 [16].

2.2.2.4 High Definition Television (HDTV)

High Definition Television (HDTV) is a digital television broadcasting system with higher resolution than traditional television systems (standard definition TV, or SDTV) and enhanced definition TV. HDTV is digitally broadcast; the earliest implementations used analog broadcasting, but today digital television (DTV) signals are used, requiring less bandwidth due to digital video compression [17].

A HDTV compatible television set will not improve the quality of SDTV channels. To display a superior picture, high definition televisions require a High Definition (HD) signal. HDTV broadcast systems are identified with three major parameters:

- *Frame size in pixels* is defined as number of horizontal pixels × number of vertical pixels, for example 1280 × 720 or 1920 × 1080.
- *Scanning system* is identified with the letter *p* for progressive scanning or *i* for interlaced scanning.
- *Frame rate* is identified as number of video frames per second.

For example, *1920×1080p25* identifies progressive scanning format with 25 frames per second, each frame being 1920 pixels wide and 1080 pixels high [17].

2.3 Digital Video Compression Systems and Standards

The television signal conveys a lot of information originating from the analog camera and microphone. The signals in its raw form occupy a lot of bandwidth. Digital video compression technology provides the means to greatly reduce this occupied bandwidth. It is done without degrading the enjoyment of the recovered signal. Digital compression plays a very important role in modern video transmission [19].

2.3.1 Compression Technology

The analog waveform of the NTSC or PAL standard is very effective in its ability to provide entertainment and business communications. These systems are relatively simple in terms of generation and display. The transmission of the video signal is relatively straightforward, provided that the link has adequate bandwidth and good linearity [19].

The fact that video sequences scanned at the rate of either 30 or 25 frames per second with 525 or 625 lines, respectively, contain a significant amount of redundancy both within and between frames provides the opportunity to compress the signal if the redundancies can be removed on the sending end and then restored on the receiving end. This is achieved by the encoder at the source end examining the statistical and subjective properties of the frames and then encoding a minimum set of information that is eventually placed on the link. The effectiveness of this compression depends on the amount of redundancy contained in the original image as well as on the compression technique (called the compression algorithm) [19].

The ultimate performance of the compression system depends on the sophistication of the compression hardware and software and the complexity of the image or video scene. For example, simple textures in images and low video activity are easy to encode and no visible defects (called artifacts) may result with simple encoding schemes. The real test is for scenes with a great deal of detail, including varying textures, and fast-moving live action. Conventional movies that were filmed at 25 frames per second do not represent a challenge; however, TV coverage of live sporting events will severely test any compression system [19].

There are various compression techniques: Spatial Compression (Transform Coding), Temporal Compression (Frame-to-Frame Compression), Motion Compensation, and Hybrid Coding Techniques. Before a signal is compressed it undergoes digital signal processing [19].

2.3.2 Joint Photographic Experts Group (JPEG)

The name JPEG stands for Joint Photographic Experts Group, the name of the committee that created the standard. The group was organized in 1986, issuing a standard in 1992, which was approved in 1994 as ISO 10918-1 [21-22].

The JPEG standard specifies both the codec, which defines how an image is compressed into a stream of bytes and decompressed back into an image, and the file format used to contain that stream [21-22].

In computing, JPEG is a commonly used method of compression for photographic images. The degree of compression can be adjusted, allowing a selectable tradeoff between storage size and image quality. JPEG typically achieves 10:1 compression with little perceptible loss in image quality [21].

JPEG compression is used in a number of image file formats. JPEG/Exif is the most common image format used by digital cameras and other photographic image capture devices; along with JPEG/JFIF, which is the most common format for storing and transmitting photographic images on the World Wide Web. These format variations are often not distinguished, and are simply called JPEG [21].

2.3.3 Motion Picture Expert Group (MPEG)

The Motion Picture Expert Group, affiliated with ITU-T and ISO, provides a solid and stable standard for full motion pictures, making use of frame-to-frame compression with associated sound and ancillary data. A key point is that the compression is done in real time, although there is a delay due to the need to analyze several frames of information before a sequence can be transmitted [22]. Detailed description of MPEG 1, 2 and 4 can be seen in Appendix A1.1 - A1.4.

2.4 Digital Television Transmission Standards

There are a number of digital TV transmission standards adopted around the regions of the world; Digital Video Broadcasting (DVB), which is the standard adopted in Europe, the Advanced Television System Committee (ATSC), the American standard, the Integrated Services Digital Broadcasting (ISDB), the standard used in Japan, and the Digital Multimedia Broadcasting (DMB), the Korean standard [23-24].

2.4.1 Digital Video Broadcasting Standard (DVB)

DVB is a family of standards for DBS (direct broadcast satellite), cable TV, and over-the-air (terrestrial) broadcasting that dominate the global landscape in digital video as GSM does in mobile telephone. The DVB system is a complete package for digital television and data broadcasting. It is built on the foundation of the MPEG-2 standard, providing full support for encoded and compressed video and audio, along with data channels for a variety of associated information services. The MPEG standard provides for data stream syntax to multiplex required functions. On top of this, the DVB standard considers the modulation and RF (radio frequency) transmission format needed to support a variety of satellite and terrestrial networking systems. It includes the following features [19]:

- Information containers to carry flexible combinations of MPEG-2 video, audio and data;
- A multiplexing system to implement a common MPEG-2 transport stream (TS);
- A common service information (SI) system giving details of the programs being broadcast (this is the information for the on-screen program guide)
- A common outer block coding scheme using the Reed-Solomon (RS) forward error correction system that improves the reception by providing a low error rate;
- Inclusion of energy dispersal to maintain spectral spread and interleaving to improve performance in the presence of burst errors;
- A flexible inner convolutional coding scheme using primarily the Viterbi algorithm with the ability to adjust the code rate between R = 1/2 and R = 7/9;

- Modulation and additional channel coding systems, as required, to meet the requirements of different transmission media (including FSS and BSS satellite delivery systems, terrestrial microwave distribution, conventional broadcasting, and cable TV);
- A common scrambling system;
- A common conditional access (CA) interface (to control the operation of the receiver and assure satisfactory operation of the delivery system as a business).

The relationship between DVB and MPEG can be seen in Appendix A1.5.

2.5 Video Encoding

Compression standards are used in equipments called the encoders. Encoders digitize and compress video in digital television broadcasting. There are two types of video encoding; variable bit rate (VBR) and fixed/constant bit rate [25]. Details of the specifications of Head-end equipments can be seen in Appendix C.

2.5.1 Variable bit rate (VBR) video encoding

In any given video section, certain parts contain more movement than others or more fine detail. For example a clear blue sky is simpler to encode than a picture of a tree. As a result the number of bits needed to faithfully encode without artifacts varies with the video material. In order to encode in the best possible way, it is advantageous to save bits from the simple sections and use them to encode complex ones. This is what variable bit rate encoding does, however the process by which the bit rates are calculated is complex [25].

2.5.2 Fixed/Constant bit rate (CBR) encoding

For some applications, it is necessary to transmit the encoded video information with a fixed bit rate. For example, in broadcast mediums (satellite, cable, terrestrial etc.), practical limitations mean that current transmission is restricted to using a fixed bit rate. This is why fixed bit rate MPEG-2 encoders are available. A fixed bit rate encoder is not as efficient as the variable bit rate system; however the MPEG-2 system still provides very high quality video for both encoding methods. Very importantly, fixed bit rate encoding can also be carried out in real time. For live broadcasts, and satellite linkups etc. the real time encoding capability is essential [25].

2.5.3 Advantages of using a variable bit rate

The advantage of using a variable bit rate is mainly the gain it gives in encoding efficiency. For fixed storage mediums (e.g. DVD) the variable bit rate is ideal. By reducing the amount of space needed to store the video (whilst retaining very high quality), it leaves more space on the medium for inclusion of other features e.g. multiple language soundtracks, extra subtitle channels, interactivity, etc [25].

The other important feature of the variable bit rate system is that it gives constant video quality for all complexities of program material. A constant bit rate encoder provides variable quality [25].

2.6 Multiplexing

In telecommunications and computer networks, multiplexing is a process where multiple analog message signals or digital data streams are combined into one signal over a shared medium. The aim is to share an expensive resource [26].

The multiplexed signal is transmitted over a communication channel, which may be a physical transmission medium. Multiplexing divides the capacity of the low-level communication channel into several higher-level logical channels, one for each message signal or data stream to be transferred. A reverse process, known as demultiplexing, can extract the original channels on the receiver side [26].

2.6.1 Digital Multiplexers

In digital circuit design, the selector wires are of digital value. In the case of a 2-to-1 multiplexer, a logic value of 0 would connect I_0 to the output while a logic value of 1 would I_1 connect to the output as can be seen in Figure 2.2. In larger multiplexers, the number of selector pins is equal to $[\log_2 (n)]$ where n is the number of inputs [26].

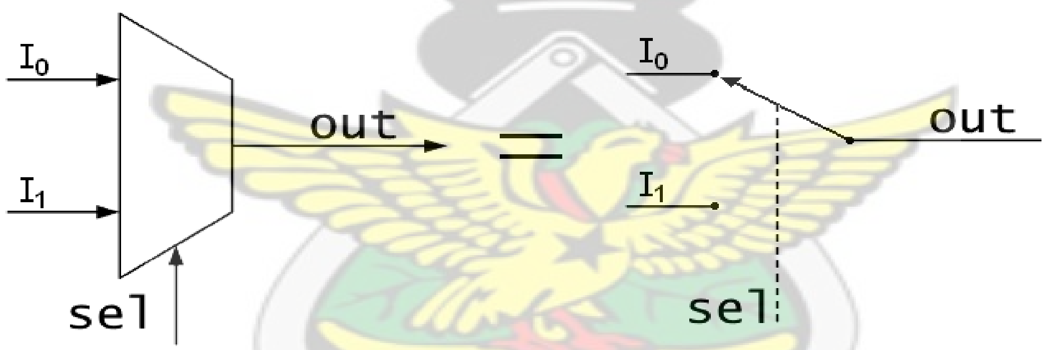

Figure 2.2 Schematic of 2-to-1 multiplexer which can be equated to a controlled switch [26]

A 2-to-1 multiplexer has a boolean equation where A and B are the two inputs, S is the selector input, and Z is the output as can be seen in Figure 2.3 [26]:

$$Z = (A\,.\bar{S}) + (B\,.S)$$

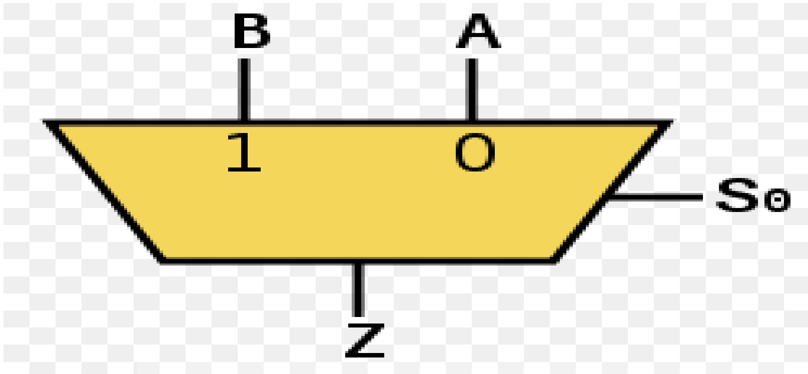

Figure 2.3 2-to-1 Multiplexer [26]

Larger multiplexers are also common and require [$\log_2$ (n)] selector pins for n inputs. Other common sizes are 4-to-1, 8-to-1, and 16-to-1 as can be seen in Figures 2.4 to 2.6. Since digital logic uses binary values, powers of 2 are used (4, 8, 16) to maximally control a number of inputs for the given number of selector inputs [26].

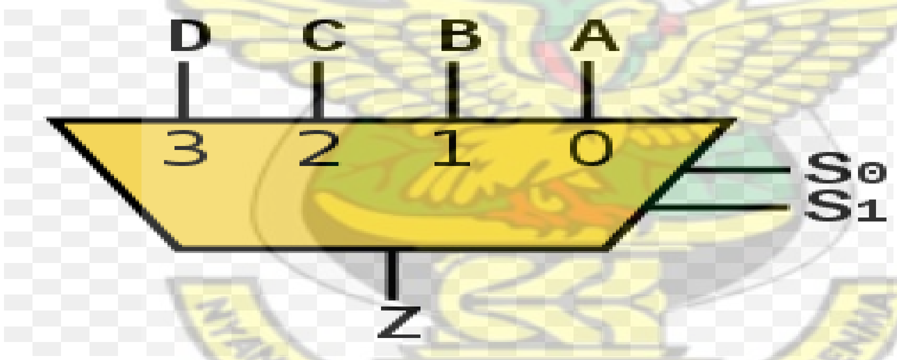

Figure 2.4 4-to-1 multiplexer [26]

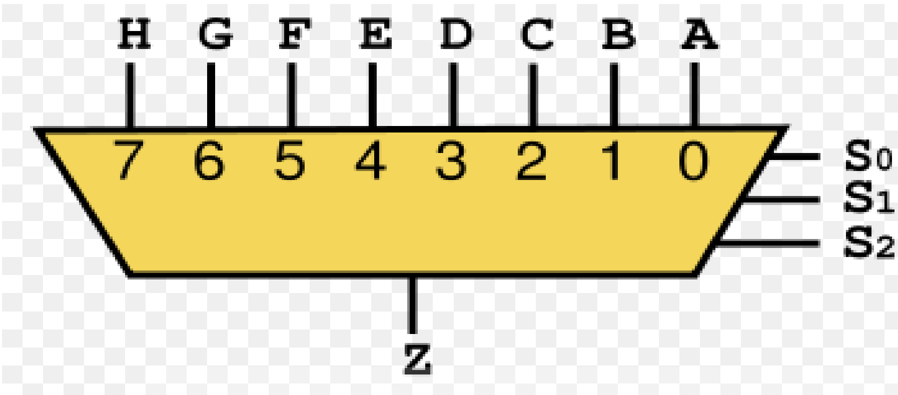

Figure 2.5 8-to-1 multiplexer [26]

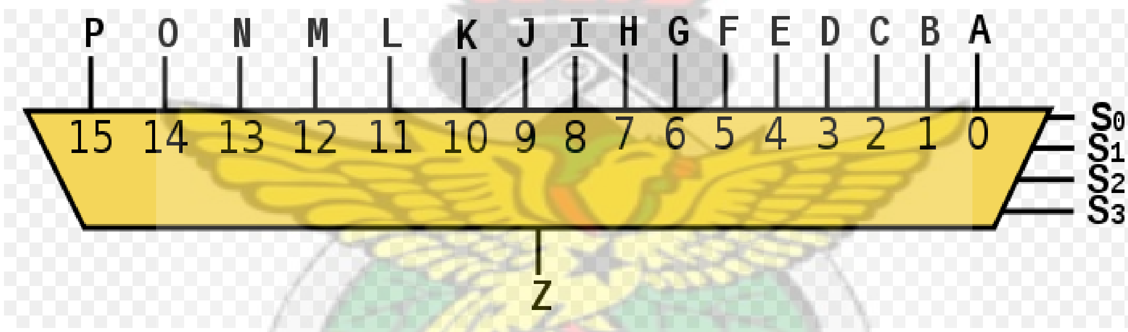

Figure 2.6 16-to-1 multiplexer [26]

The boolean equation for a 4-to-1 multiplexer is [26]:

$$F = (A\,.\overline{S_o}.\overline{S_1}) + (B\,.S_0\,.\overline{S_1}) + (C\,.\overline{S_0}.S_1\,) + (D\,.S_0.S_1)$$

2.6.2 Transport Stream Packets

The compression done by MPEG system produces video signals with reasonable bit rates for transmission. The audio is also compressed using the MUSICAM (Masking pattern adapted Universal Sub-band Integrated Coding And Multiplexing). However, a digital TV signal consists of two or three signals- one video signal, one audio signal and data signal (e.g. teletext). These signals have to be combined into a single signal through multiplexing. However, in order to multiplex the signals, each signal first has to be divided into packages. By transmitting the packages at different intensities, it is possible to mix fast signals (video) with a high bit rate with those having a low bit rate (audio and teletext) [1]. An example of this is shown in Figure 2.7.

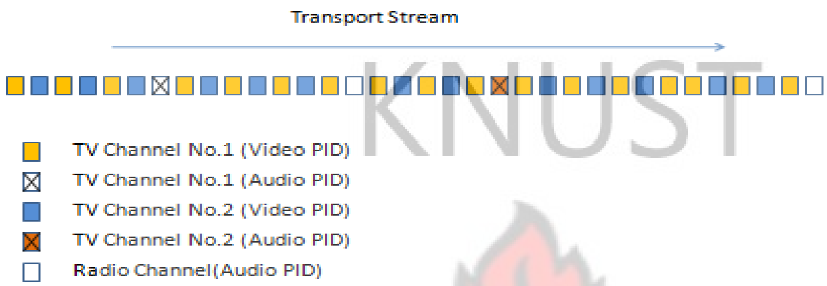

Figure 2.7 An Example of a transport stream [1]

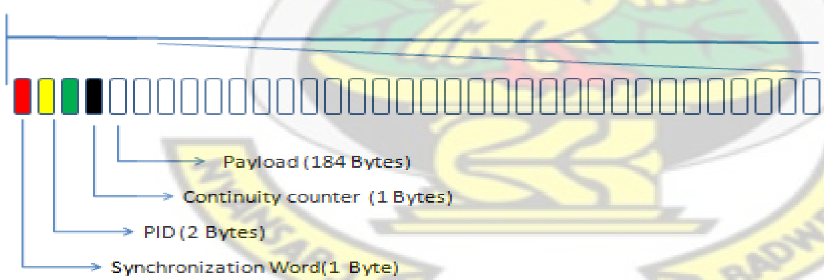

Figure 2.8 A bit stream divided into packets [1]

The packages into which the signals are divided are called transport stream packets. An example is shown in Figure 2.8.The length of each packet is 188 byte. The first four bytes in each packet is called the header. The first byte in the header contains a synchronization word that is unique and that indicate the start of a new packet. This byte is followed by the Package Identification Data (PID), two bytes with the identity of the signal to which the packet belongs. This is the label that makes it possible to separate the signals again (called demultiplexing) at the receiving end. The fourth byte contains a counter that indicates the order between the packets that belong to a specific signal. This counter is also a way to determine if any packet has been lost on the way to the receiver. The remaining 184 bytes contain useful information, the payload. Together, these packets form the transport stream [1].

Splitting the information into packets achieves several advantages, in addition providing the ability to combine signals with different bitrates. The signal also becomes less sensitive to noise and other disturbances. Radio disturbances are actually short spikes of power and often have a very short duration. If one packet is disturbed, the receiver can reject that specific packet and then continue to unpack the rest of the packets [1].

IP traffic across the Internet is two-way communication. If a packet is lost, the sender is notified and retransmission of that specific package is done. Broadcasting signals are fed through a one-way distribution chain and no retransmission of lost packages can be done. To compensate for this error protection is used. Error protection means adding extra bits according to clever algorithms. These extra bits make it possible for the receiver to repair the content of broken packages. Therefore to secure the signal even further, an additional 16 bytes are added to each individual packet. The information in these bytes is calculated based on the information in the 184 bytes of payload. The calculation is conducted using the Reed-Solomon encoding algorithm that, in this case, is configured to be able to correct up to eight errors in the 184 bytes of payload. If there are more than eight errors the complete packet will be rejected [1].

2.6.3 Statistical Multiplexing

In a multiplex of six to eight programs not all of the programs will need maximum capacity all the time. Sharing the capacity of a multiplex among the programs—giving the most bandwidth at any given moment to the most demanding program at that moment—optimizes the use of the available capacity [1].

This is called statistical multiplexing and increases the usable capability by approximately 20 percent [1]. In this way, a satellite transponder (having a capacity of 44 Mbps) that normally houses eight programs will instead be capable of handling 10 programs. A terrestrial DVB multiplex with a capacity of 22 Mbps will be able to handle five instead of four TV programs [1].

An optimum way of using statistical multiplexing is to combine programs containing lots of motion (such as sports programs and music video programs) with less demanding programs (such as news programs and programs which contain a lot of studio content) [1].

2.7 Modulation

Modulation is the process of varying one waveform in relation to another waveform. In telecommunications, modulation is used to convey a message. Often a high-frequency sinusoid waveform is used as carrier signal to convey a lower frequency signal. The three key parameters of a sine wave are its amplitude, its phase and its frequency, all of which can be modified in accordance with a low frequency information signal to obtain the modulated signal. A device that performs modulation is known as a modulator and a device that performs the inverse operation of modulation is known as a demodulator. A device that can do both operations is a modem [27].

There are two forms of modulation: analog and digital modulations. In digital television transmission signals are modulated using either Single Carrier Digital Modulations or Multicarrier Modulations techniques such as coded orthogonal frequency division multiplexing (COFDM) [22, 27].

2.7.1 Single Carrier Digital Modulations

Single carrier systems use only one carrier signal onto which the information signal is modulated. These modulation methods dramatically decrease the bandwidth required to transmit a digital signal in a radio frequency (RF) channel. Single carrier modulations are used in satellite, cable, MMDS (microwave multipoint distribution systems), and some terrestrial transmission systems. The commonly used modulations for digital transmission include quaternary phase shift keying, referred to as QPSK (or 4-QAM), 16 level quadrature amplitude modulation (16-QAM), 32-level quadrature amplitude modulation (32-QAM), 64-level quadrature amplitude modulation (64-QAM), and vestigial sideband modulation (VSB) [22].

2.7.2 Multicarrier Modulation techniques

Coded orthogonal frequency division multiplexing (COFDM) is a multicarrier modulation method that is very robust against multipath reception and is useful for channels that present linear distortions. It is the modulation that was chosen by the Digital Video Broadcasting (DVB) project for development as a European standard for digital terrestrial television. COFDM uses many thousands of separate carriers to convey the data signal, dividing the data between each carrier. The data signal is modulated onto these closely spaced carriers using standard QPSK and QAM modulations [22].

Depending on the type of inner modulation chosen from the DVB-T modes of operation it is possible to achieve payload or useful bit rates between approximately 4 Mbps and 31 Mbps. This is a very attractive and flexible network design feature for broadcasters [22].

2.7.3 Relationship between Modulation and Data Capacity (Bit Rate)

DVB-T has the following characteristics:

1. Uses COFDM
2. Number of carriers: 2k or 8k modes

3. Usually three modulation schemes used: QPSK, 16-QAM and 64-QAM
4. Five valid coding rates 1/2, 2/3, 3/4, 5/6 and 7/8

Tables showing the bit rate attained with different parameters can be seen in Appendix A1.6.

2.7.4 Orthogonality and the use of DFT/FFT

The use of many carriers in COFDM requires the specification of the even spacing between them. The carriers are evenly spaced by precisely [28]:

$$f_u = 1/T_u$$

Where T_u is the period (the "useful" or "active" symbol period) over which the receiver integrates the demodulated signal [28].

When this is done the carriers form an orthogonal set.

The Kth carrier (baseband) is written as [28]:

$$\Psi_k(t) = e^{jkx\omega_u t}$$

where ω_u is $2\pi/T_u$, and the orthogonality condition that the carriers satisfy is [28]:

$$\int_{\tau}^{\tau+T_u} \Psi_k(t)\Psi_l * (t)dt = 0, \qquad k \neq 1$$

$$= T_u, \qquad k = 1$$

Hence, without any explicit filtering, all the carriers can be separately demodulated without any mutual cross-talk, just by a particular choice for the carrier spacing [28].

2.7.5 Modes of Operation

To avoid disturbances by interference from echoes or from the signals from adjacent transmitters in Single Frequency Networks (SFN), a guard interval is inserted between consecutive OFDM symbols [29].

Considering an SFN, the distance between two adjacent transmitter stations determines the necessary length of the guard interval. Simulations have shown that a guard interval of at least 200µs is necessary for large area SFN [29].

A longer guard interval could compensate longer echoes, but the redundancy would increase accordingly reducing the deliverable bit-rate, since the guard interval does not contribute to the useful part of the OFDM signal [29].

Table 2.2 summarizes the possible lengths of the guard interval specified in the DVB-T specification depending on the chosen FFT length.

Table 2.2 Length of guard intervals and its duration [29]

Proportion to the length of the useful interval	Length of the guard interval	
	8k –mode	2k- mode
¼	224µs	56µs
1/8	112µs	28µs
1/16	56µs	14µs
1/32	28µs	7µs

In order to ensure robust transmission of the OFDM signal, an error protection code is applied. In addition to the fixed algorithm of energy dispersal, block coding, outer and inner interleaving, a rate compatible punctured convolutional (RCPC) code has been defined [29].

The mother code has a constraint length of 7 bits and works with a code rate of 1/2. The two generator polynomials of the convolutional encoder are 171 and 133 in octal notation [29].

Every subcarrier is modulated by a modulation symbol. QPSK, 16-QAM and 64-QAM are used as modulation methods, e.g. 2, 4 or 6 bits per modulation symbol. The bits are assigned to the particular points in the phase space according to the so called Gray-code mapping. The advantage of this mapping is the fact that closest constellation points differ only in one bit [29]. The constellation diagrams for each modulation method are illustrated in Figure 2.9.

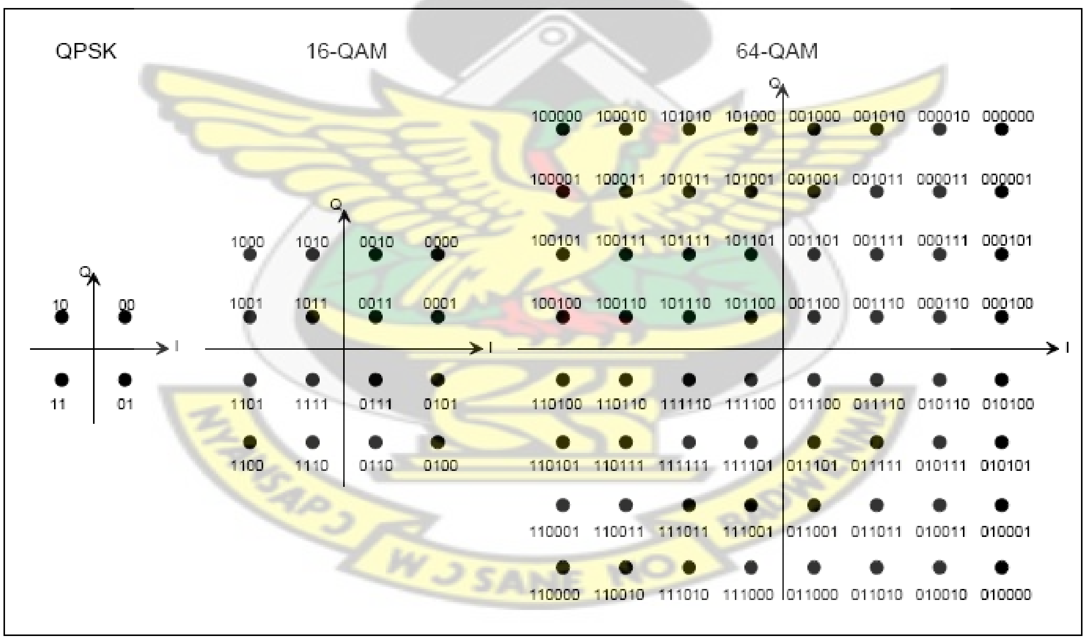

Figure 2.9a Constellation diagram for the modulation methods specified for DVB-T [29]

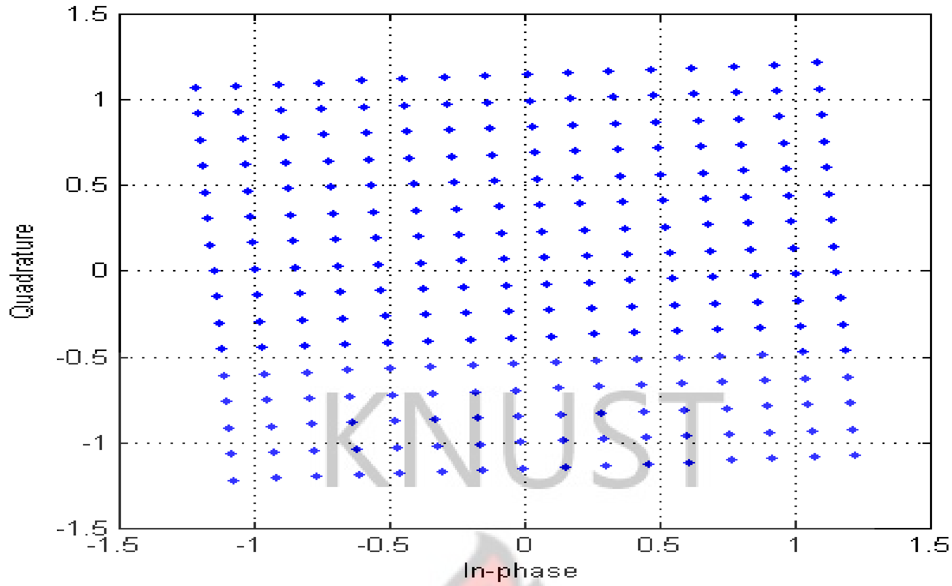

Figure 2.9b Constellation map of the rotated 256-QAM modulation (tilt angle is 3.57 degrees) for DVB-T2 [30]

In summary, the net bit rate depends on the code rate of the inner error correction, the method of the subcarrier modulation and the chosen guard interval length as is summarized in Figure 2.10. The net date rates are calculated from the following formula [29]:

$$R_u = R_s \times b \times CR_i \times CR_{RS} \times (\frac{T_u}{T_s})$$

Where

$R_u = the\ useful\ net\ date\ rate\ (Mbps)$

$R_s = the\ symbol\ rate, 6.75\ Msymbols/s$

$b = bits\ per\ subcarrier$

$CR_i = inner\ code\ rate$

$CR_{RS} = Reed\ Solomon\ code\ rate, 188/204$

$T_u = duration\ of\ (useful) symbol\ part$

$T_s = symbol\ duration, including\ guard\ interval$

$\frac{T_u}{T_s} = 4/5, 8/9, 16/17, or\ 32/33\ depending\ on\ guard\ interval$

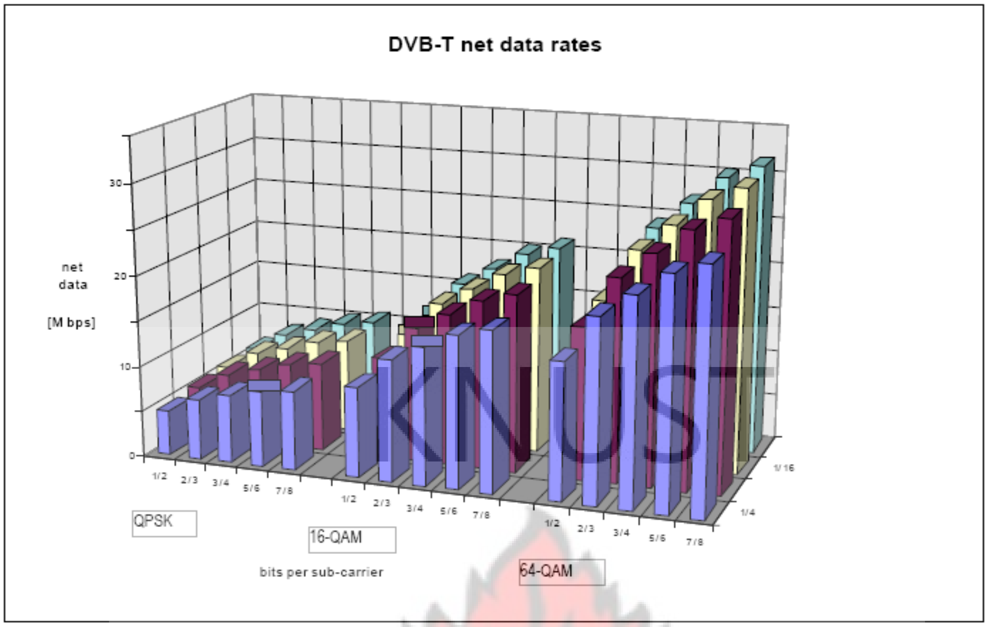

Figure 2.10 Net data rates in the DVB-T system [29]

2.7.6 Digital Video Broadcasting – Second Generation Terrestrial (DVB-T2)

DVB-T2 is an abbreviation for Digital Video Broadcasting – Second Generation Terrestrial; it is the extension of the television standard DVB-T, issued by the consortium DVB, devised for the broadcast transmission of digital terrestrial television [30]. Figure 2.11 gives the system architecture of DVB-T2 while a comparison of DVB-T and DVB-T2 can be seen in Table 2.3.

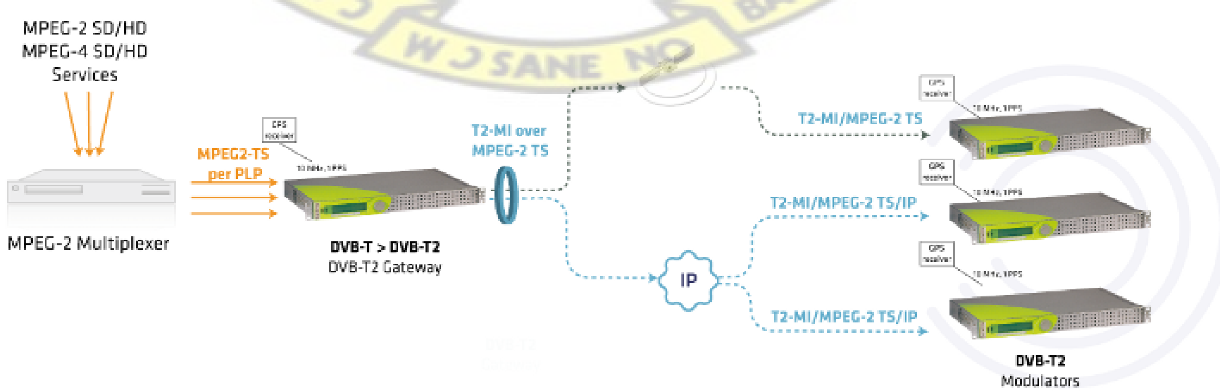

Figure 2.11 DVB-T2 System Architecture [30]

Table 2.3 Comparison of DVB-T and DVB-T2 [30, 31]

Systems	DVB-T	DVB-T2 (new / improved options in red)
Modes	2k and 8k	1k, 2k, 4k, 8k, 16k, 32k
FEC	Convolutional Coding+Reed Solomon 1/2, 2/3, 3/4, 5/6, 7/8	LDPC + BCH 1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM, 256QAM
Guard Interval	1/4, 1/8, 1/16, 1/32	1/4, 19/128, 1/8, 19/256, 1/16, 1/32, 1/128
Typical data rate (U.K)	24 Mbit/s	40 Mbit/s
Max. data rate (@20 dB C/N)	29 Mbit/s	47.8 Mbit/s

Table showing the bit rate attained with different parameters for DVB-T2 can be seen in Appendix A1.7.

2.8 Assigning Multiplexes in some selected countries around the world

A digital multiplex is simply a 6/7/8 MHz bandwidth of radio frequency that many TV programs (number depends on the TV format and compression standard used), radio programs and data can be transmitted on, instead of only one TV program if analog broadcasting is used [1].

2.8.1 United Kingdom

The United Kingdom just like Ghana uses the DVB and MPEG standards. Digital terrestrial television in the United Kingdom is made up of over forty primarily free-to-air television programs (including all the national analog stations) and over twenty radio channels. It includes the Freeview (free-to-air) service. In addition, Pay-TV services are available from Top Up TV and Setanta Sports [32].

Digital terrestrial television was launched in the UK on 15 November 1998. The technology required that the UK government license the broadcast of channels in six groups, or multiplexes labelled 1, 2, A, B, C, and D can be seen in Tables 2.4 and 2.5 [32].

Individual broadcasters or consortium of broadcasters were allowed to bid from the frequency regulator Independent Television Commission (ITC) [32].

Table 2.4 Multiplex allocations for the U.K. [32]

Old Multiplex Name	New multiplex Name	Owing Company
A	BBC A	BBC
B	D3&4	Digital 3&4
1	SDN	“S4C Digital Network” (ITV plc)
2	BBC B	BBC
3	Arqiva A	Arqiva
4	Arqiva B	Arqiva

Table 2.5 Multiplex allocations, coverage, modulation modes and useful bitrates in the U.K [32]

Multiplex	**Coverage**	**Modulation technique**	**Useful bit rate (Mbps)**	**Electronic Program Guide (EPG)**
1	Nationwide	16-QAM	18	Available
2	Nationwide	64-QAM	24	Available
A	Nationwide	64-QAM	24	Available
B	Nationwide	16-QAM	18	Available
C	Nationwide	16-QAM	18	Available
D	Nationwide	16-QAM	18	Available

A table showing bit rate per program allocations on the BBC multiplex can be seen in Appendix A1.7

The Office of Communications (Ofcom) provides certain reference parameters for digital terrestrial television transmissions in the United Kingdom. In order to maintain the ability to receive all the multiplex services, it was necessary for Ofcom to specify certain technical requirements covering common methods of delivering video, audio, text and data applications. The requirement cover modulation and channel coding, source coding of video signals, source coding of audio signals, and multiplexing of signals [33]. These reference parameters can be seen in Tables 2.6.

Table 2.6 OFDM Parameters [33]

Parameter	Option 1 Value	Option 2 Value	Option 3 Value
Number of carriers	1705	1705	6817
Modulation technique	64-QAM	16-QAM	64-QAM
Outer Coding R_c	2/3	¾	2/3
Guard Interval (Δ/T_U)	1/32	1/32	1/32
Carrier spacing	4.464 KHz	4.464 KHz	1.116 KHz
Spacing between carriers K_{max} and K_{min}	7.61 MHz	7.61 MHz	7.61 MHz

Key: K_{max}: Value of maximum carrier number (2K or 8K)

K_{min}: Value of minimum carrier number (2K or 8K)

2.8.2 Germany

Germany launched free-to-air digital platforms region-by-region, starting in Berlin in November 2002. Analog broadcasts were planned to cease soon after digital transmissions started. Berlin became completely digital on 4th August 2003 with other regions completing between then and 2008. Digital switchover has been completed throughout Germany as of 2nd December 2008 and services are now available to 100% of the population [34]. Germany uses the MPEG-2 and MPEG-4 AVC/H.264 compression standards. Table 2.7 shows parameters of some digital channels in Berlin-Brandenburg while Table 2.8 shows the channel designations.

Table 2.7 DVB-T modes used on Berlin-Brandenburg project [35]

Channel	Modulation	Coding rate	Guard interval	Data rate (Mbps)	Content	EPG
43	16-QAM	1/2	1/8	11.06	Programs + data	Available
46, 53	16-QAM	2/3	1/8	14.75	Programs + data	Available
51	16-QAM	2/3	1/8	14.75	Programs	Available
59	64-QAM	2/3	1/8	22.12	Programs	Available

Table 2.8 Definition of Channels used in Table 2.7 for Germany

Channel	Designation/Frequency (MHz)
43	646 – 654
46	670 – 678
51	710 -718
53	726 – 734
59	774 – 782

3.5 to 4.7 Mbps is made available for each program. Therefore taking all program components (picture, sound, program-accompanying data and service information) into account, only 3.2 and 4.4 Mbps respectively remain for the compressed video signal.

Table showing bit rate allocated per program for the above multiplexes can be seen in Appendix A1.7.

2.8.3 France

France's TNT (Télévision Numérique Terrestre) offers 18 free and 11 pay programs (channels) plus up to 4 local free programs. An 89% DTT (digital terrestrial television) penetration rate was expected by December 2008. Free-to-view satellite services offering the same DTT offer were made available in June 2007 [34].

Since October 30 2008, France has had four free HD (high definition) programs (TF1 HD, France2 HD, Arte HD, and M6 HD) and one pay TNT HD program (Canal+ HD) on TNT using the MPEG-4 AVC/H.264 compression format as seen in Table 2.9 [34].

Table 2.9 Parameters of TV programs of TNT of France [34]

Programs	**TV format**	**Resolution**	**System Compression**	**Bit rate per program (Mbps)**	**EPG**
Free TNT SD channels	SDTV	720 × 576	MPEG-2	VBR 3.9 (2.1-6.8)	Available
Pay TNT SD channels	SDTV	720 × 576	MPEG-4 AVC/H.264	VBR 3.0 (1.1-6.0)	Available
Free TNT HD channels	HDTV	1440 × 1080 (1080i50)	MPEG-4 AVC/H.264	7.6 Mbps	Available
Pay TNT HD channels	HDTV	1440 × 1080 (1080i50)	MPEG-4 AVC/H.264	7.6 Mbps	Available

2.9 Conditional Access (CA)/Encryption

A conditional access (CA) system comprises a combination of scrambling and encryption to prevent unauthorized reception. Scrambling is the process of rendering the sound, pictures and data unintelligible. Encryption is the process of protecting the secret keys that have to be transmitted with the scrambled signal in order for the descrambler to work [36].

The purpose of a CA system is to provide service providers with a tool for billing their digital television service customers. This is done by protecting DVB services, e.g. movie programs or single events, from being decoded by people that have not purchased the access rights [36]. A CA system comprises of both hardware and software components and consists of five subsystems namely as shown in Figure 2.12 [36]:

- Subscriber Management System
- Subscriber Authorization System
- Scrambler
- Descrambler
- Smartcard

2.9.1 DVB CA standards

The scrambling algorithm to be used in DVB compliant CA systems is the *Common scrambling algorithm* (CSA). To make it possible for a receiver (with a CA system) to access networks using different CA systems two different techniques have been defined by DVB [36].

(a) Simulcrypt - a technique where different broadcasting networks have made an agreement to send specific control data for all supported CA systems. This allows CA systems to filter out their specific control data and descramble the same service [36].

(b) Multicrypt - a technique for attaching an external module containing a CA system and a smartcard reader to the receiver. The attached module and the receiver communicate via the DVB Common Interface (CI) and allow the module direct access to the transport stream (TS) [36].

A key difference between the two techniques is that in Multicrypt the entire video stream goes through a removable smartcard, whereas in Simultcrypt the video stream is decoded within the installed circuitry of the set-top box [36].

The Multicrypt solution is widely adopted, and many receivers are equipped with both one and two slots for attaching Common Interface modules. A receiver with CI permits the user to access several networks by manually switching the Common CI module to the networks' used CA system [36].

The programming language used on conditional access systems around the world are Java, C and C++ languages [37]. Table 2.10 shows some Conditional Access Systems used around the world.

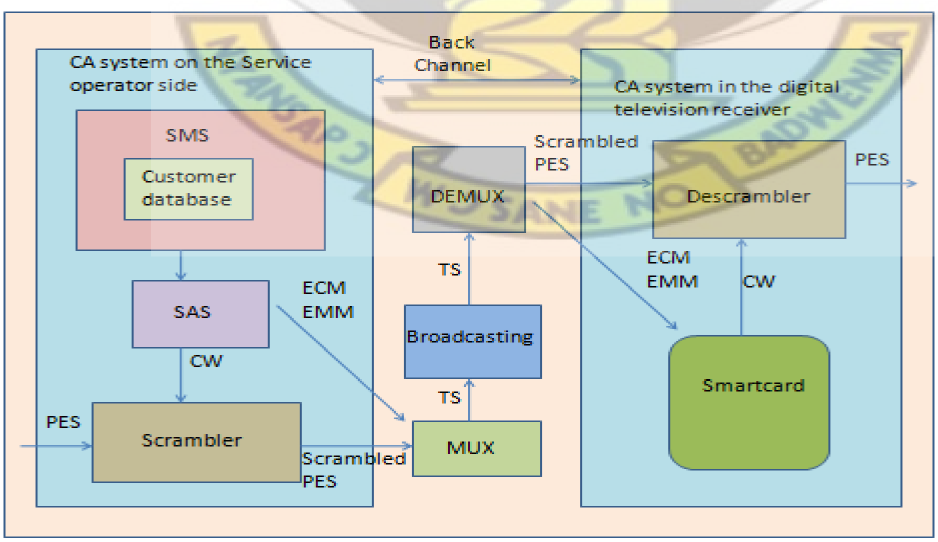

Figure 2.12 CA subsystems locations and interactions in a DVB system [36]

2.10 Valued Added Services (VAS)

Multiplex capacity is generally used for video and related sound services. Sometimes a package of radio programs is also included. In addition, the multiplex may contain data for a variety of services including [38]:

- Electronic Program Guide
- Service Information
- Interactive Services (e.g. e-government services)
- Teletext
- System Software Update

Table 2.10 Conditional Access Systems around the world [37]

System	Origin	Operators	Country
Betacrypt	Betaresearch/IrDETO	Premiere World, German cable	Germany, Netherlands
CryptoWords	Philips	Viacom, MTV Networks	United Kingdom
IrDETO	IrDETO Access	Telepiu, Stream, Multichoice	Netherlands, China, South Africa
Mediaguard	SECA (Canal+)	Canal+, Canal Satellite, ITV Digital	France
Nagravision	Kudelski SA	Via Digital, Quiero, Dish Network	France, Turkey, Spain and Germany
Viaccess	France Telecom	TPS, AB-Sat, Arabesque, SSR, SRG	France
Videogurard	News Datacom (NDS)	BSkyB, Stream	United Kingdom, U.S.A,

2.10.1 Electronic Program Guide

An Electronic Program Guide (EPG) is a digital guide to scheduled broadcast television or radio programs, typically displayed on-screen with functions allowing a viewer to navigate, select, and discover content by time, title, channel and genre by use of their remote control, a keyboard, or other input devices such as a phone keypad [39].

The technology is based upon broadcasting data to an application usually residing within middleware in a set-top box which connects to the television set and enables the application to be displayed [39].

By navigating through an EPG on a receiving device, users can see more information about the current program and about future programs. When EPGs are connected to PVRs (personal video recorders) they enable a viewer to plan his or her viewing and record broadcast programs to a hard disk for later viewing [39].

Typical elements of an EPG comprise a graphical user interface which enable the display of program titles, descriptive information such as a synopsis, actors, directors, year of production, and so on, the channel name and the programs on offer from sub-channels such as pay-per-view and VOD or video-on-demand services, program start times, genres and other descriptive metadata [39].

2.10.2 Interactive Service Types

There are three different types of interactive service that can be delivered through DTV [39-40]:

- Stand alone information services: where the information is stored in the receiver (e.g. teletext)
- Transactional services: where information is sent to the program provider via a return channel, this information can include a reaction to a program (e.g. voting) or a demand for certain programs (video on demand or pay per view).

- Enhanced programming services: With enhanced TV different pictures and text can be transmitted simultaneously through a single channel. There is no return path/channel, but viewers can select different combinations of pictures and text to be displayed on their screen using the remote control. The ability of enhanced TV to tie together content, context and convenience provides significant potential for the provision of interactive services.

2.11 Summary

Digital Television broadcasting has primarily four TV formats: LDTV, SDTV, EDTV and HDTV [13-17, 19]. There are two different ways of multiplexing digital signals based on the two ways of digital video encoding: Constant Bit rates (CBR) encoding and Variable Bit rates (VBR) encoding. There are various ways of assigning multiplexes around the world and also various bit rate allocations per program.

Modulation techniques used determine the useful bit rate (multiplex capacity) of a digital multiplex. For COFDM the multiplex capacity depends on the coding rate, the guard interval and the inner modulation scheme used.

Conditional Access systems are used by service operators to restrict unauthorized reception and there are various systems used around the world.

Digital television broadcasting apart from television transmission allows for other valued added services like the Electronic Program Guide, Service Information, Teletext, Interactive Services and System Software Update

CHAPTER 3
IMPLEMENTATION
Content and Multiplexing in Ghana

3.0 Introduction

Digital television broadcasting (DTB) has changed the face of television broadcasting in Ghana which has been predominantly analog in nature. One 7/8 MHz bandwidth channel can now accommodate six or more programs instead of the just one program under analog television broadcasting [5].

Broadcasters have to invest in the creation of content in order to fill a digital multiplex. These programs to be transmitted have to combined by multiplexing and this requires investments in equipments to transmit TV signals this way.

3.1 Review of Digital Migration

Digital Television broadcasting is not entirely a new technology in Ghana. The first digital TV transmission in Ghana was implemented with the DVB-S standard in the Ku-band by MultiChoice Ghana in 1993. The company operates a pay TV service, DSTV (digital satellite television) which is nationwide. It is a DTH (direct-to-home) satellite service. Subscribers receive the service with a Ku-band satellite receiver (dish) [5].

Terrestrial television however has been purely analog in nature up until late 2008. The national frequency regulator NCA being a signatory to the ITU treaty GE06 is currently preparing for full digital television transmission in Ghana. The National Digital Broadcasting Migration Technical Committee (NDBMTC) set up by the Ministry of Communications has finished its work and has submitted its report. Ghana is currently in the simulcast or dual illumination stage of the digital broadcasting migration with concurrent transmission of analog and digital television with the switch-off of analog transmission scheduled at December 2014 [6].

3.1.1 Digital Television Broadcasting Standards for Ghana

In the report of the National Digital Broadcasting Migration Technical Committee (NDBTC) presented to the Ministry of Communications and the from the Bidding Document for the Procurement of Digital Terrestrial Television (DTT) Network Solution the Digital Video Broadcasting (DVB) is adopted for digital television transmission in Ghana [6, 36]. The platforms of DVB adopted are can be seen in Table 3.1.

Table 3.1 Digital Broadcasting Standards adopted for Ghana [6, 31]

Parameters	Standard Adopted
Digital Transmission Standard	DVB
Terrestrial	DVB-T/DVB-T2
Cable	DVB-C
Satellite	DVB-S/DVB-S2
Compression Technique	H.264/AVC/MPEG-4 (part 10) and Advanced Audio Coding (AAC)
TV format	SDTV(576i), EDTV(576p), HDTV(after analog switch-off)
Mobile TV broadcasting	T-DMB and DVB-H
Digital Sound Broadcasting	T-DAB (Terrestrial Digital Audio Broadcasting)

3.1.2 Digital Television Frequency Allocation in Ghana

Licenses have been issued out to some broadcasters to operate digital multiplexes. This can be seen Table 3.2

Table 3.2 Operational Digital TV allocations so far [6-7]

Channel Name	**Channel**	**Frequency**	**Transmission Standard**	**Compression Standard**	**Coverage**
GBC (pilot)	22	478-486 MHz	DVB-T	MPEG-2	Accra
GBC Smart TV	22	478-486 MHz	DVB-T	MPEG-4	Accra, Kumasi
	23	486-494 MHz			
Skyy Digital (Now Skyy plus)	40	622-630 MHz	DVB-T	MPEG-2	Accra, Tema, Kumasi, Koforidua, Takoradi
DSTV	Ku-band	12169 MHz and 12207 MHz	DVB-S	MPEG-4	Nationwide
Multi TV	Ku-band	12552 MHz	DVB-S	MPEG-4	Nationwide
Cable Gold TV	37	598-606 MHz	DVB-C	MPEG-4	Accra, Tema
Black Star TV	10	VHF Band III (Block D =10D)	T-DMB	MPEG-4	Accra
	7	VHF Band III (Block A =7A)			Kumasi

Key: VHF Band III (Block D = 10D) = 215.072 [41]

VHF Band III (Block A = 7A) = 188.928 [41]

Ku-band = 12-18GHz [42]

3.2 Implementation of Digital Television Broadcasting (DTB) in Ghana

The digital TV broadcast value chain consists of; Content Production, Multiplexing (Content Aggregation), Transmission and Reception as shown in Figure 1.1. Implementation of this value will require observation of a number of standards while certain technical considerations are also made.

This section will take a critical look at all the issues that may arise in the implementation of a typical digital TV system in Ghana. The first two services of the value chain; Content Production and Multiplexing (Content Aggregation) will be considered.

Three digital television broadcasting systems are considered. The systems are the:

- Skyy Digital DVB-T system (Now Skyy Plus) [59]
- GBC DVB-T system (Pilot) [8]
- GBC DVB-T system (New multiplexes, Mux1 and Mux2) – National Roll-Out [8, 31]

3.2.1 Skyy Digital DVB-T System (Now Skyy Plus)

Skyy Digital (Skyy Plus) is a subsidiary of Skyy Media Group a private local broadcaster. Skyy Plus acquired the frequency 622-630 MHz (8 MHz bandwidth) from the national spectrum regulator, National Communications Authority (NCA) to broadcast Digital Terrestrial Television (DTT) in 2008. Skyy Plus currently covers Accra, Koforidua, Kumasi and Takoradi [59].

The Skyy Plus multiplex currently has twelve (12) TV programs (station) as can be seen in Table 3.3.

Table 3.3 TV programs on the Skyy Plus multiplex [59]

Programs	Program Number/ Service_ID	PMT_PID	Video PID	Audio PID
Skyy One	201	0 × 65	0 × 12d	0 × 191
Skyy World	202	0 × 66	0 × 12e	0 × 192
Channel D	203	0 × 67	0 × 12f	0 × 193
KidsCo	204	0 × 68	0 × 130	0 × 194
Cinimax	205	0 × 69	0 × 131	0 × 195
Showtime	206	0 × 6a	0 × 132	0 × 196
Fox Entertainment	207	0 × 6b	0 × 133	0 × 197
Fiesta	208	0 × 6c	0 × 134	0 × 198
Hi Holly	211	0 × 6d	0 × 135	0 × 199
Emmanuel TV	212	0 × 6f	0 × 136	0 × 200
ASN	213	0 × 6g	0 × 137	0 × 201
BBC	214	0 × 6h	0 × 138	0 × 202

Key: PMT_PID: Program Map Table - Package Identification Data

The Skyy Digital set-top box could also receive the TV programs on the GBC DVB-T (pilot) multiplex as can be seen in Figures 3.1 and 3.2. These figures were generated with the Skyy Digital set-top box connected with a computer (laptop). Content production and Multiplexing (content aggregation) of signals takes place at the Skyy House at Abelemkpe in the Greater Accra Region.

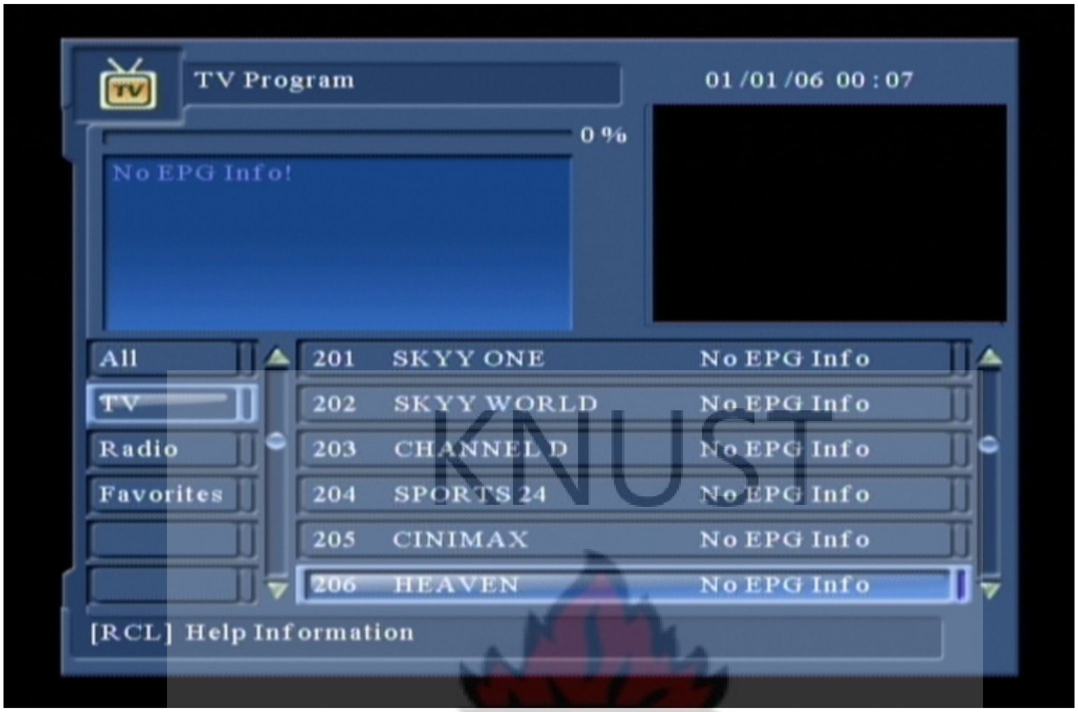

Figure 3.1 Set-up showing some of the TV programs on the Skyy Digital multiplex

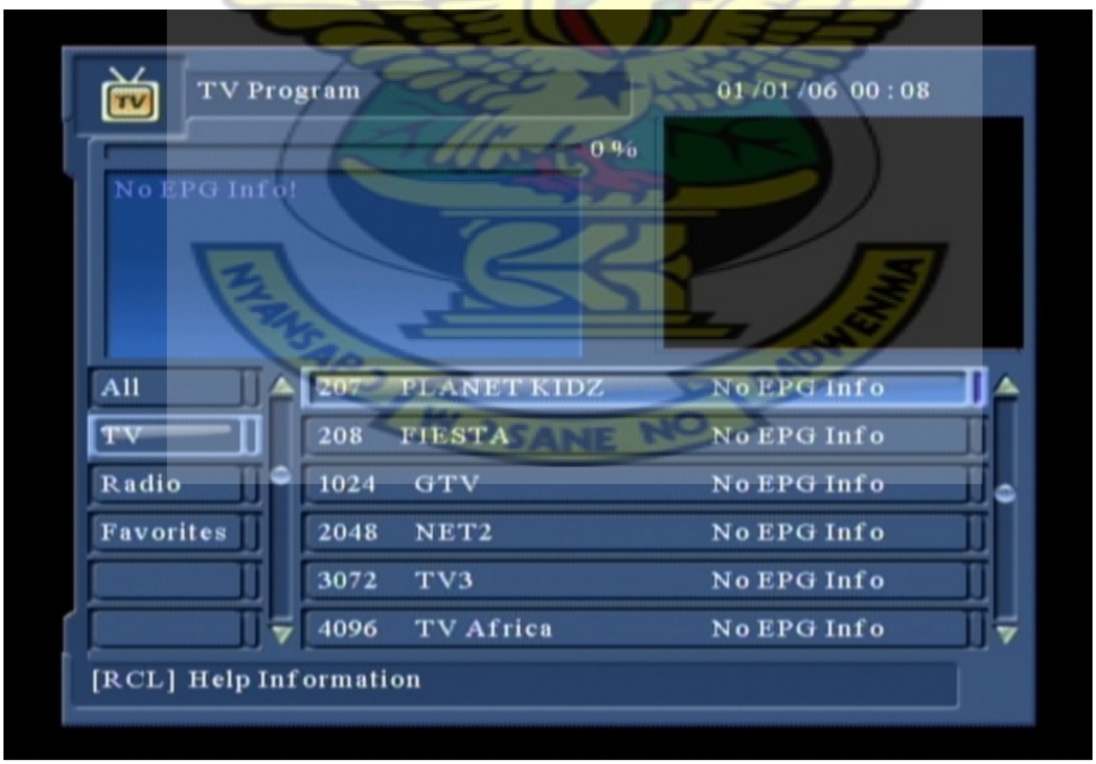

Figure 3.2 Set-up showing some TV programs on Skyy Digital and the GBC multiplexes

3.2.1.1 Set-up of the Skyy Digital System

- Each of the twelve programs has a location (department) from where content is edited and packaged and sent to the Headend as shown in Figure 3.3.
- There are four (4) studios where Live and Recorded content is generated.
- There is a Headend where the signals from the individual departments are sent to be digitized, compressed and multiplexed for transmission.
- There is a microwave link linking the Headend to the main transmitter site.

Figure 3.3 Skyy Digital System Set-up

3.2.1.2 Content Generation

There are various ways of generating content and this depends on the program (station).The main ways include:

(a) Live programs from Studios

(b) Recorded programs from Studios

(c) Satellite Rebroadcast –TBN (Trinity Broadcasting Network), CNN, VOA, France 24, BBC, Aljazera, capital TV, eTV, AUB (African Union of Broadcasters)
(d) Unedited Parliamentary proceedings
(e) News Gathering
(f) Playback of recorded satellite programs
(g) Internet Downloads
(h) Movies on DVDs and VCDs
(i) Recorded Local Music Videos and Interviews
(j) Recorded Local Outdoor Events
(k) Adverts

3.2.1.3 Standards Used in Content Generation

There are certain standards that are followed in the acquisition of data. The television format used is the SDTV 625 with video resolution of 720×576. The PAL video standard is used with an aspect ratio of 4:3 as seen in Table 3.4 [43].

Table 3.4 Standard for content generation for Skyy Digital [43]

Parameters	**Standard**
Video Compression Algorithm	MPEG-2
Video Standard	PAL
Video format	4:3
Video Resolution	720×576
Video Bit Error	5.343
Audio Coding Layer	MPEG-1
Audio Sampling Rate	44.1KHz

3.2.1.4 Multiplexing (Content Aggregation)

Multiplexing of the programs takes place in the Headend of the Skyy Digital DVB-T system

3.2.1.4.1 Headend

The Headend is the main processing room of the Skyy Digital System. This is where all the signals from the various program departments are sent. The signals from the various departments are each sent to the Headend through video and audio cables.

The Headend has the following main equipments which are all on one network as shown in Figures 3.4 and 3.5:

1. Twelve (12) digital Encoders
2. One 8-way Multiplexer
3. Scrambler (Enigma System) which is also a multiplexer with a server
4. Converter (CircLoop)
5. Indoor Unit (IDU) and Outdoor Unit (ODU) of a Microwave link
6. A server for the Encoders and Multiplexers
7. Twelve Receivers (set-top boxes) to receive the twelve programs transmitted
8. 16-way TV channel Combiner MM-16 to combine all the received programs on one TV set.
9. A Television set to monitor the programs

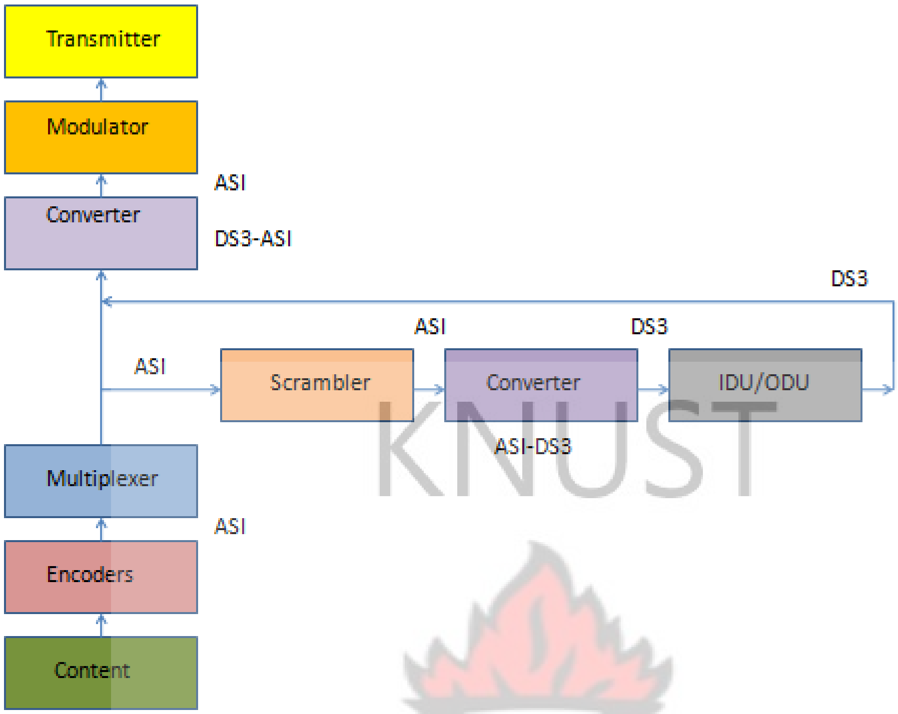

Figure 3.4 Path of Signal in Skyy Digital's Headend

3.2.1.4.1.1 Encoders

There are twelve (12) encoders, one for each program. The video cable and audio cable from each department is connected to the back panel of its encoder.

Each encoder is responsible for digitizing and compressing the signal from the respective departments. The encoder type is: PBI DCH-3000EC MPEG2 Encoder. It has the following features [44]:

- S-Video, SDI and Composite PAL/NTSC/SECAM video input
- MPEG-2 MP@ML video encoding 1.5Mbps-20Mbps
- MPEG-1 Layer1 and Layer2 audio encoding
- Internal two-way Re-Multiplexer
- PAT, PMT generation

3.2.1.4.1.2 Multiplexer

There is one 8-way multiplexer. Out of the twelve (12) programs on the Skyy Digital DVB-T multiplex, seven (7) programs are scrambled (that is they can only be received with a Skyy Digital DVB-T set-top box) while the remaining five (5) are free-on-air as seen in Table 3.5. The free-on-air programs can be received with a DVB-T set-top box or a TV set with an integrated digital tuner.

Table 3.5 Status of the twelve programs on the Skyy Digital (Skyy Plus) multiplex [43]

Programs	Status
Skyy One	Free-on-air
Skyy World	Free-on-air
Channel D	Scrambled
KidsCo	Scrambled
Cinimax	Scrambled
Showtime	Scrambled
Fox Entertainment	Scrambled
Fiesta	Free-on-air
Hi Holly	Scrambled
Emmanuel TV	Free-on-air
ASN	Scrambled
BBC	Free-on-air

The signals from each of seven encoders which are to be scrambled are passed through the 8-way Multiplexer. The main function of the multiplexer is to combine all the signals from the encoders into a single signal.

The multiplexer type is: PBI DCH-3000MX DVB Multiplexer. It has the following features [45]:

- Fully compliant with DVB ETSI 300421 standard
- Processing of up to 8 SPTS or MPTS
- 8 ASI inputs, 2 ASI Independent outputs
- ASI input packet length 188/204 bytes Self-adapting
- Output packet length 188/204 bytes optional.
- SI/PSI automatic regeneration or manual re-mapping
- Service and PID packet filtering and re-multiplexing

3.2.1.4.1.3 Scrambler

The scrambler is also a multiplexer and the multiplexer type is ES6081 DVB Multiplexer. The scrambler has two inputs:

- An input to receive the combined signal of the seven programs to be scrambled
- An input to receive the signals of the five free-on-air programs directly from their encoders

The scrambler encrypts the signal of the seven programs so that only Skyy Digital's set-top box can receive these programs. The scrambling software is called the Enigma System. This is Skyy Digital's Conditional Access (CA) system. Each of its set-top boxes has a unique number. These numbers are entered into the Enigma System and enabled before the receivers are sold. Therefore a particular receiver can be disabled in the Enigma System.

The combined scrambled signal and the free-on-air signals are combined into a single signal so that only one signal leaves the scrambler. The signal up to this point is in the Asynchronous Serial Interface (ASI) format.

3.2.1.4.1.4 Converter (CircLoop)

The signal from the scrambler passes through a converter called CircLoop. The CircLoop converts the format of the signal from ASI to DS3 (Digital Signal 3).

This is done because the signal is to be passed through a microwave link to the transmitter located at a different location (McCarthy Hill).

3.2.1.4.1.5 IDU/ODU

A microwave link is used to send the signal to the transmitter site for onward transmission. The band of link is 7/8GHz.

The microwave link equipment type is: PASOLINK NEO NEC/NLite [46]

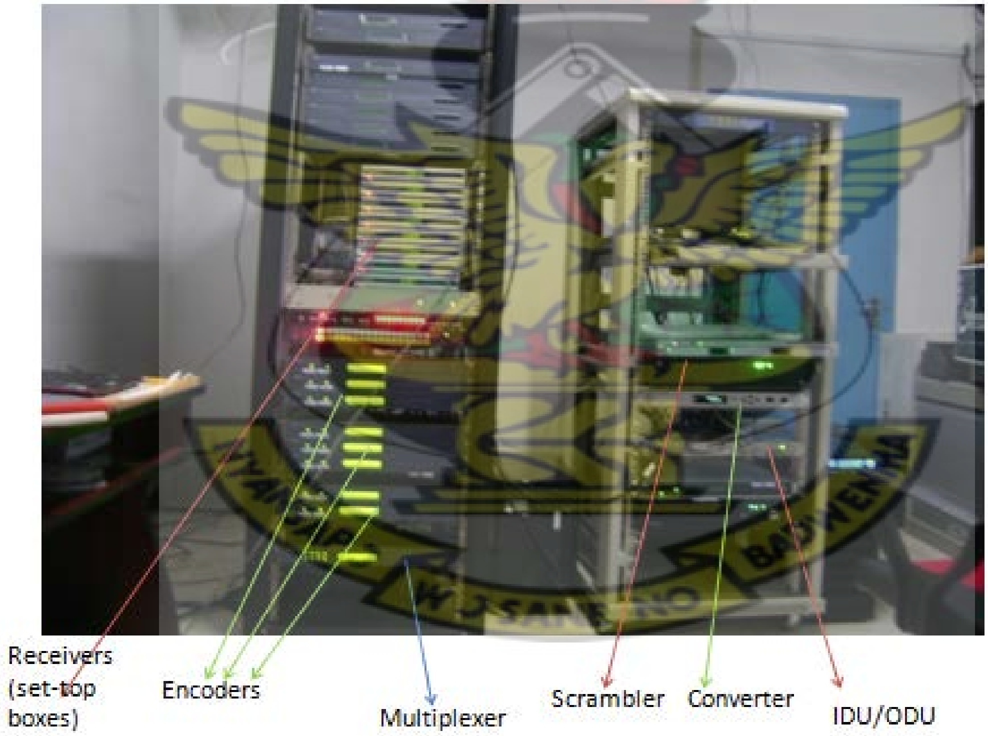

Figure 3.5 Skyy Digital’s Headend

3.2.1.4.1.6 Modulator

There is a modulator responsible for modulating the signals for transmission

The modulator type is: PBI DCH-4000PM Processor and Modulator. It has the following features [47]:

- RF output options, DVB-C/QAM or DVB-T/COFDM
- 2K mode for DVB-T/COFDM
- Multicast or Unicast on IP, up to 32 independent addresses
- CI equipped supports various Conditional Access systems
- Compatible with Multiple De-encrypt CI modules

3.2.1.4.1.7 Transmitter Sites

There are four (4) transmitter sites.

- The main transmitter (with 1KW power) is located at McCarthy Hill in the Greater Accra Region.
- There is a 1KW power transmitter in Kumasi
- There is a 200W power transmitter in Takoradi
- There is a 200W power transmitter in Koforidua

The main transmitter site at McCarthy Hill has the following main equipments:

1. IDU/ODU to receive the signal through the microwave link from the Skyy House in Abelemkpe in Greater Accra Region.
2. CircLoop which coverts the signal from DS3 back to ASI format
3. Multiplexer that breaks the single signal up into the individual signals
4. A Modulator.
5. Transmitter

The three other transmitter sites have all the above equipments except the modulator.

3.2.1.4.1.8 Drop and Add services

The main transmitter in Accra supplies all the other coverage areas. There is however a special feature called the Drop and Add service. The set-up at the transmitter site in Takoradi has this feature.

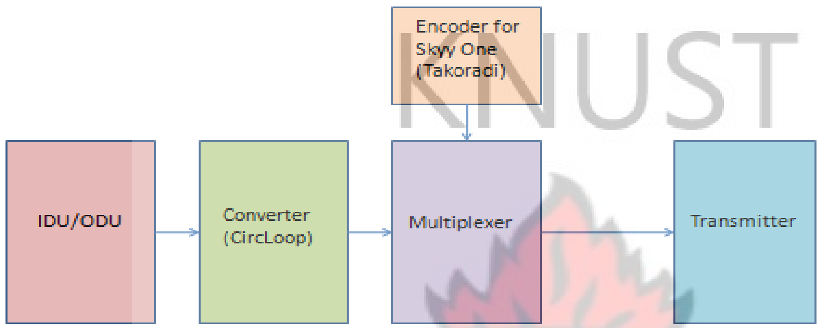

Figure 3.6 Set-up at the Transmitter site in Takoradi

This feature is implemented in the following way as shown in Figure 3.6:

(a) There is one encoder in addition to all the other equipments that the other subsidiary transmitter sites have. The function of this encoder is to carry out the Drop and Add service.

(b) The received signal from the main transmitter after it has gone through the multiplexer is split into the individual programs.

(c) Skyy Takoradi produces its own Skyy One program. Therefore, the Skyy One program from the main studio in Accra is "dropped" for the local Skyy One program.

(d) The signal from the local Skyy One will be encoded by the encoder and then fed to the multiplexer

(e) The multiplexer combines the local Skyy One with the other eleven programs. The signal is then transmitted. This is possible with the special feature of the multiplexer called Re-multiplexing.

(f) This phenomenon is what is termed Drop and Add. Thus the Original Skyy One program from Accra is "dropped" while the local Skyy One program is "added". This flexible system therefore makes it possible for subsidiaries of Skyy Digital in the regions to add their own programs.

3.2.1.5 Multiplex Capacity and Technical Issues Involved

The total capacity of Skyy Digital's multiplex was 27.14Mbps but currently is 30.160 Mbps [48]. Each program is encoded at 2.5Mbps [43]. The multiplex allocations for the twelve programs can be seen in Appendix B1.1

3.2.2 GBC (Ghana Broadcasting Cooperation) DVB-T System (Pilot)

The GBC DVB-T multiplex was assigned in 2008 by the NCA. The frequency assigned was 478-486 MHz and thus the bandwidth is 8MHz. It was a partnership between GBC and Next Generation Broadcasting (NGB), a Swedish-based broadcaster in collaboration, with five broadcasting TV stations in Ghana. The multiplex also had two international channels. The multiplex was being run on a pilot basis in Accra.

The multiplex thus had seven (7) programs. The local broadcasters on the multiplex were as can be seen in Figures 3.7 and 3.8 [18]:

- 1024 GTV
- 2048 Net2 Television
- 3072 TV3
- 4096 TV Africa
- 5120 Viasat1

The international programs included [18]:

- 6145 CNBC Africa
- 7168 KidsCo

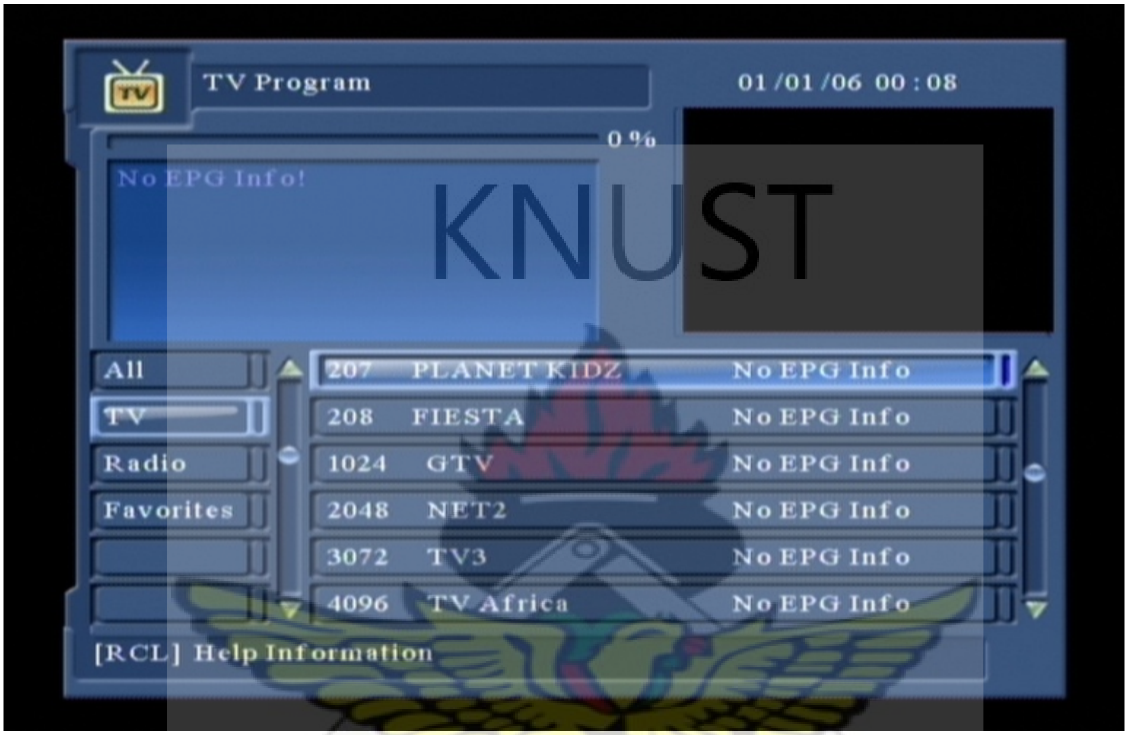

Figure 3.7 Set-up showing some of the TV programs on the GBC multiplex

Figure 3.8 Set-up showing some of the TV programs on the GBC multiplex

3.2.2.1 Set-up of GBC DVB-T system

- Content for the system was from the local analog TV networks and from the two international networks.
- There were three ways of getting the signals into the Headend for multiplexing as shown in figure 3.9. Since the Headend was located at GTV, the signal from GTV was fed in directly into its encoder for digitization. Four of the programs- TV Africa, Viasat1, CNBC Africa, KidsCo were received with a Ku-band satellite receiver and fed to their encoders while TV3 was received on a C-band satellite receiver. Net2 TV was picked off-air with a tuner and then fed to its encoder.
- The signals from the TV stations were encoded and multiplexed at the Headend located at GTV. The transmitter was at the same location.

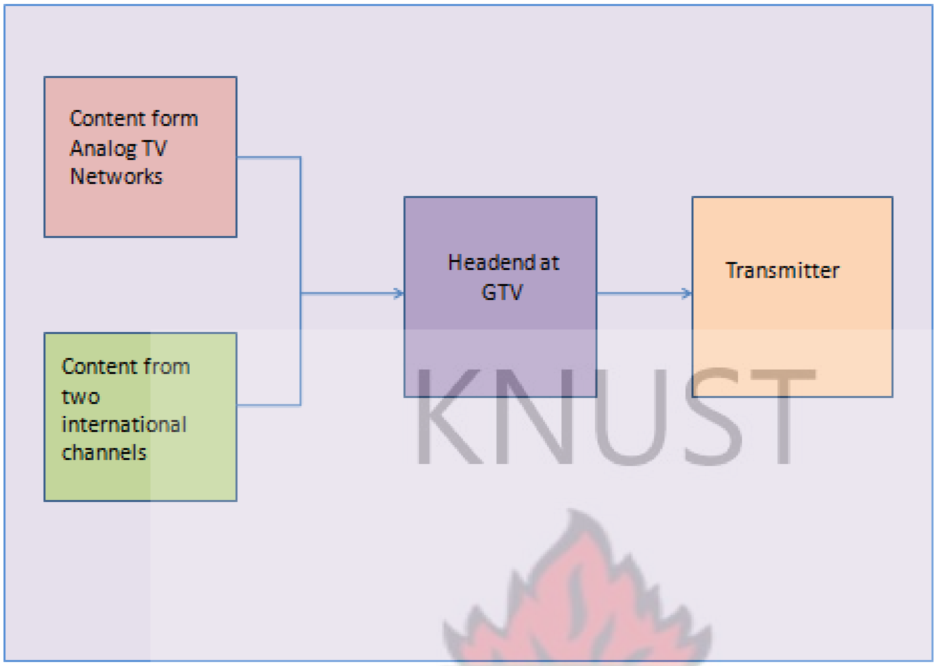

Figure 3.9 GBC DVB-T system set-up

3.2.2.2 Content Generation

Content was generated in two ways and the standard used for content generation can be seen in Table 3.6:

- TV signals from the already transmitting five analog TV stations.
- Satellite rebroadcast of the two international stations

Table 3.6 Standard for content generation for GBC multiplex (pilot) [48]

Parameters	Standard
Video Compression Algorithm	MPEG-2
Video Standard	PAL
Video format	4:3
Video Resolution	720×576
Audio Coding Layer	MPEG-1

3.2.2.3 Multiplexing

Multiplexing of the signals took place in the Headend at GTV. The Headend had the Encoders, Multiplexer, Scrambler, Modulator and Transmitter.

1. The encoders encode the video part of the programs with MPEG-2 compression and audio parts with MPEG-1 compression. There were two types of encoders used. First Encoder type: TLDC-3 SD Encoder. This encoder had the following specifications [49]:
    - Supports every standard video and audio signal, including analog S-VIDEO, analog composite video, and mono/analog stereo signal etc.
    - The format of the output of compressed data was ASI/SPI

    Second Encoder type: 4 in 1 Encoder (TLDC-41). This encoder had the same specifications as the first one, however it could encode four programs at the same time [50].

2. From the encoders the signals were combined by the multiplexer. The multiplexer type was: DVB Re-multiplexer TRS 180 TERRA. The multiplexer had the following specifications [51]:
    - automatic or manual PID remapping
    - remultiplexing of encrypted programs
    - compatible with EIT servers
    - ASI inputs: 8 channels, ASI outputs: 2 channels (parallel)

3. The combined signal went through a Sumavision SMSX 10K571 Stand-alone Scrambler. The scrambler had the following specifications [52]:
    - Based on 3.0 DVB simulcrypt standard
    - Scrambling of selected programs
    - Scrambling of audio/video/data separated or combined

4. The signal was then modulated and transmitted. The status of the TV programs as at the time of implementation is shown in Table 3.7.

Table 3.7 Status of the seven (7) programs on the GBC multiplex (pilot) [48]

Programs	Status
GTV	Free-on-air
TV3	Free-on-air
TV Africa	Free-on-air
Net2 TV	Free-on-air
Viasat1	Free-on-air
CNBC Africa	Scrambled
KidsCo	Scrambled

3.2.2.4 Multiplex Capacity

The total multiplex capacity of the multiplex was 22.118 Mbps. Table showing the allocations of the multiplex capacity for the seven programs is shown in Appendix B1.2

3.2.3 GBC DVB-T system (New multiplexes, Mux1 and Mux2)

The frequency assigned is 478-486 MHz (channel 22) for Multiplex 1 and 486-494 MHz (channel 23) for Multiplex 2. Currently Multiplex 1 has ten (10) TV programs and Multiplex 2 has 8 programs.

3.2.3.1Content Generation

Content is generated in two ways:

- TV signals from the already transmitting analog TV stations.
- Satellite rebroadcast of some international sources

The standard used for content generation can be seen in Table 3.8.

Table 3.8 Standard for content generation for GBC new multiplexes (Mux1 and 2) [48]

Parameters	Standard
Video Compression Algorithm	MPEG-4
TV format	SDTV
Video Standard	PAL
Video format	4:3
Video Resolution	544×576
Audio Coding Layer	HE AAC

3.2.3.2 Multiplexing

The multiplex capacity of each of the two multiplexes is 22.118 Mbps. The multiplexes use statistical multiplexing hence bit rate per program is assigned dynamically by a statistical multiplexer based on the content being aired at a particular time as can be seen in Table 3.9.

Table 3.9 Bit rate per program assigned on the multiplexes at one instance

Multiplex1		Multiplex2	
Multiplex Capacity	**Allocations (Mbps)**	**Multiplex Capacity**	**Allocations (Mbps)**
Total Multiplex Capacity	22.118	Total Multiplex Capacity	22.118
(1) Capacity for GTV (video)	1.1	(1) Capacity for ASN(video)	1.9
(2) Capacity for Net2 (video)	0.9	(2) Capacity for Homebase(video)	2.2
(3) Capacity for eTv(video)	1.7	(3) Capacity for Hi(video)	2.8
(4) Capacity for TV(video)	1.6	(4) Capacity for Fox Entertainment(video)	1.7
(5) Capacity for Viasat(video)	1.5	(5) Capacity for Showtime(video)	1.0
(6) Capacity for GTV Sports Plus(video)	1.7	(6) Capacity for BBC(video)	2.8
(7) Capacity for Music(video)	1.1	(7) Capacity for DayStar TV(video)	1.4
(8) Capacity for News(video)	1.2	(8) Capacity for KidsCo(video)	1.4
(9) Capacity for Sports1(video)	1.6		
(10) Capacity for Entertainment(video)	1.7		
Total Capacity Used	14.1	Total Capacity Used	15.2
Total Capacity left	8.018	Total Capacity left	6.918

3.2.4 Comparison of DVB-T systems in Ghana with systems around the world

Table3 3.10 below compares the DVB-T variants used by the systems used in Ghana and the variants used in the United Kingdom and Germany. This results in different multiplex capacities for the systems.

Table 3.10 DVB-T variants of systems in Ghana compared to those of other countries [32-33, 35]

Parameters	United Kingdom		Germany			Skyy Digital	GBC (Pilot, Multiplex1 and2)
Multiplexes	1, B,C and D	2 and A	Mux1	Mux2 &3	Mux4	Mux1	Mux 1 & 2
Modulation	16-QAM	64-QAM	16-QAM	16-QAM	64-QAM	64-QAM	64-QAM
Guard Interval	1/32	1/32	1/8	1/8	1/8	1/32	1/8
FEC rate	3/4	2/3	½	2/3	2/3	¾ (Previous) 5/6(Current)	2/3
Total Multiplex Capacity (Mbps)	18.10	24.13	11.06	14.75	22.12	27.144 (30.160)	22.118

Table 3.11 compares the bit rate per program used by Skyy Digital and the GBC multiplexes with that used by multiplexes in other countries.

Table 3.11 Bit rate per program comparison [32, 35, 53]

Countries	**Bit rate per program (Mbps)**	**Video Compression Algorithm**	**Video Resolution**	**TV format**
U.K	3.2	MPEG-2	720 ×576	SDTV
Germany	3.6	MPEG-2	720 ×576	SDTV
France	3.9	MPEG-2	720 ×576	SDTV
Skyy Digital multiplex	2.9(now 2.5)	MPEG-2	720 ×576	SDTV
GBC multiplex (Pilot)	2.6	MPEG-2	720 ×576	SDTV
GBC Multiplex1	1.4 (Average)	MPEG-4	544 ×576	SDTV
GBC Multiplex2	1.9(Average)	MPEG-4	544 ×576	SDTV

Table 3.12 compares the parameters used by the Skyy Digital system and the GBC systems and the effects it has on the multiplex capacities of the systems.

Table 3.12 Comparison of parameters determining multiplex capacity [43, 48]

Parameters	Skyy Digital	GBC (Pilot and new multiplexes)	Remarks
Modulation technique	COFDM	COFDM	-
Number of carriers	8K	8K	-
Inner modulation scheme	64-QAM	64-QAM	-
Coding rate	¾ (Previously) 5/6 (Currently)	2/3	The GBC multiplex's coding rate is less than that of the Skyy multiplex and hence it has a lower total multiplex capacity
Guard Interval	1/32	1/8	A wider guard interval will result in a more robust signal. However the signal does not travel far. Thus the GBC multiplex has a more robust signal but the coverage area is less than that of the Skyy multiplex.
Total Multiplex Capacity (Mbps)	27.14 (Previously) 30.160(Currently)	22.118	-

3.2.5 Proposed System for Skyy Digital

The following proposals are made to improve the Skyy Digital system:

- The use of MPEG-4/AVC encoders which can generate SDTV at 1.5 Mbps will increase it's coding efficiency by 40.0%
- This will generate 12.0 Mbps (40.0% of 30.0)
- The introduction of Statistical multiplexing will increase the coding efficiency by 27% based on the 12 TV programs on the Skyy multiplex as can be seen in Figure 3.10
- Thus with statistical multiplexing the 12 TV programs with MPEG-2 encoding will require 21.9 Mbps instead of 30.0 Mbps. With MPEG-4 encoding the 12 programs will require 13.14 Mbps instead of 18.00 Mbps
- The introduction of DVB-T2 can increase the multiplex capacity to as high as 50.03 Mbps [30]

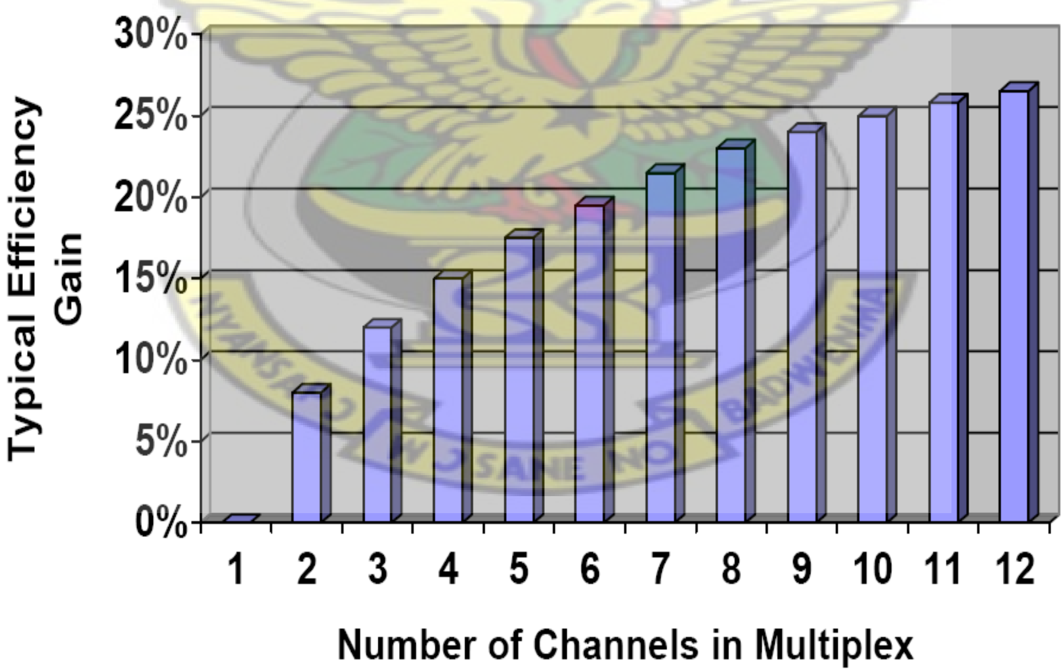

Figure 3.10 Typical Coding Efficiency Benefit due to Statistical Multiplexing [53]

The proposed system will have certain implications as can be seen in Table 3.13

Table 3.13 TV programs that can be accommodated on Skyy Digital multipex based on the proposals

Parameters	Multiplex Allocations (Mbps)	Number of TV programs
Total Multiplex Capacity	30.160	12 SDTV programs
MPEG-4 Encoding at 1.5 Mbps	30.160/1.5 = 20.1	20 SDTV programs
Statistical Multiplexing with about 30% efficiency	(30/100) × 30 = 9	6 SDTV programs 20 + 6 = 26 programs
MPEG-4 Encoding at 8 Mbps	30.160/8 =3.77	3 HDTV programs

3.2.6 Proposed System for GBC multiplexes (Mux1 and 2)

The following proposals are made to improve the GBC multiplexes (Mux1 and 2):

- The DVB-T variants can be optimized to increase net capacity.
- The following variant is proposed:
  (i) Continuous use of 64-QAM
  (ii) Decrease of the guard interval to 1/32
  (iii) Increase code rate to ¾
- This will increase multiplex capacity by 22.72%
- The new multiplex capacity will be 27.144 Mbps an increase of 5.026 Mbps which can accommodate **three** SDTV programs
- Increasing the code rate to 5/6 will increase the capacity by 36.36% giving a new multiplex capacity of 30.160
- The bit rate used to encode one TV program on Mux2 is over specified and hence exceeds MPEG-4 encoding rate of 1.5 Mbps. If this is brought to 1.5 Mbps more TV programs can be accommodated.

- The introduction of DVB-T2 here also can generate a multiplex capacity of 50.03 Mbps [30]

The proposed system will have certain implications as can be seen in Table 3.14

Table 3.14 TV programs that can be accommodated on GBC multiplexes based on the proposals [53]

Parameters	Multiplex Allocations (Mbps)	Number of TV programs	
		Mux1	Mux1
Total Multiplex Capacity	22.118	10 SDTV programs	8 SDTV programs
DVB-T variant of 64-QAM, 1/32 guard interval and ¾ code rate	27.144	18 SDTV programs	
DVB-T variant of 64-QAM, 1/32 guard interval and 5/6 code rate	30.160	20 SDTV programs	
DVB-T2 variant of 256-QAM, 1/128 guard interval and 5/6 code rate with Scattered Pilot Pattern 3 and 4	50.03	33 SDTV programs	

3.3 Conditional Access Systems used by digital multiplex systems in Ghana

Skyy Digital DVB-T system previously used the Simulcrypt technique of the DVB CA standards as seen in Table 3.15. Thus the the video stream is decoded within the installed circuitry of the set-top box. The CA system of Skyy Digital is called the Enigma System. Each of the Skyy Digital set-top boxes has unique numbers and these numbers are entered into the Enigma system. The set-top boxes are thus enabled in the Enigma system before the boxes are sold out. Skyy Digital (now Skyy Plus) is currently implementing the Multicrypt technique.

The video stream of the GBC DVB-T multiplexes (pilot and new multiples) is decoded in a removable smartcard. Thus the Multicrypt technique of DVB CA standard is used. The programs on the multiplex are not always scrambled. When the programs are not scrambled, the Skyy Digital set-top box is able to receive the programs.

Table 3.15 CA System Description of digital multiplexes in Ghana

Parameters	**Skyy Digital DVB-T multiplex**	**GBC DVB-T multiplex (Pilot)**	**GBC DVB-T multiplexes (Mux1 and Mux2)**
Encoder compression standard	MPEG-2	MPEG-2	MPEG-4
Set-top box Type	DTR-1000	SmartBox	SmartBox
DVB CA technique	Simulcrypt (Now using Multicrypt)	Multicrypt	Multicrypt
CA system	Enigma System	Sumavision	Sumavision

3.4 Valued Added Services on digital multiplexes in Ghana

The Skyy Digital DVB-T system provides no valued added services on its multiplex whilst the GBC DVB-T systems (pilot and new multiplexes) provide only “Now and Next” programming schedule as can be seen in Table 3.16.

Table 3.16 Valued Added Service of digital multiplexes in Ghana

Provider	Valued Added Service
Skyy Digital (Skyy Plus)	No Valued Added Service
GBC	EPG

3.5 Observations and Findings

The content and multiplexing components of the broadcast value chain of three (3) systems have been the subject of this study. A number of observations and findings have been made as a result of the study and they include:

3.5.1 Stage of Migration

As regards to the stage of digital broadcasting migration, it has been established that Ghana is currently in what experts call dual illumination stage of the digital migration. This means there are both analog and digital television transmissions.

The dual illumination will be generally expensive for networks such as GTV which already have a large number of analog transmission systems that cannot be switched-off until it is able to migrate all its viewers to the digital receiving platform.

3.5.2 New Definition of the Broadcast value chain

With digitization, the broadcast value chain has changed from the two distinct components, namely content generation per program, broadcast on one television channel, to that of many content generated, multiplexed and transmitted over one television channel.

3.5.3 Video Format

LDTV, SDTV, EDTV, HDTV are the video formatting standards for handheld, standard TV viewing on 4:3 monitors, enhanced viewing, and high definition view of TV signals.

Content on the studied digital multiplexes are all in the Standard Definition Television (SDTV) format. The video resolution is 720×576 with an aspect ratio of 4:3 for the Skyy multiplex and the GBC pilot while the new GBC multiplexes has 544×576 resolution.

The immediate implementation of HDTV could compromise the number of programs per channel as one HDTV program requires a large multiplex capacity.

3.5.4 Compression standards

The current digital multiplex operators use both the MPEG-2 and MPEG-4 compression standards. It is concluded that MPEG-4 is bandwidth efficient as MPEG-4 produces equal or better quality pictures as MPEG-2 but with less multiplex capacity. MPEG-4 is not reverse compatible with MPEG-2 compression. Therefore MPEG-4 transmissions cannot be received on MPEG-2 receivers.

3.5.5 DVB CA techniques

The two different techniques (Simulcrypt and Multicrypt) defined in the DVB Conditional Access (CA) standards are used in Ghana currently.

3.5.6 Type of video encoding

It is observed that Skyy Digital (now Skyy Plus) and the GBC pilot use Constant Bit Rate video encoding while the new GBC multiplexes use Variable Bit Rate encoding.

3.5.7 One broadcaster operating all three components/services of the value chain

The current broadcasters are responsible for producing content, multiplexing the content and then transmitting to the consumers. That is they operate all the three components of the value chain.

3.5.8 Proposals for operation

The NCA issues out the frequency licenses for digital television transmission without a presentation of the programming on how to fill the multiplex. Content on the already issued digital licenses are not monitored by the NMC. No policy is in place to promote the development of local content.

3.5.9 Multiplex capacity per program

TV programs that have a lot of action and movements are allocated more multiplex capacity.

3.5.10 Drop and Add feature of digital broadcasting

Parts of the network can receive a bouquet of programs, drop and add some. This creates the possibility of operating varied programs on national and regional multiplexes. This is seen on the Skyy Digital multiplex.

3.5.11 Equipments for content generation and multiplexing

The equipments for digital content generation (cameras, microphones, audio mixers, video mixers) and multiplexing (encoders, multiplexers, modulators) are up to international standards.

3.5.12 Cost of Programs on Digital broadcast multiplex

Multiplex providers have their own cost per program. This may make it difficult for potential users/customers to participate in providing programs on the multiplex in keeping with the new definition of the broadcast value chain.

3.5.13 DVB and MPEG Implementations

DVB-T with MPEG-2 compression system implementations occurred from 2008 to 2009. DVB-T with MPEG-4 compression system implementations occurred from 2010 to 2011. DVB-T2 with MPEG-4 compression system implementations will occur from 2011 to 2012 [31].

3.6 Recommendations

Based on the above observations and findings the following recommendations are made:

3.6.1 Stage of Migration

It is recommended that to reduce or minimize the cost of dual illumination, right policies should be put in place to migrate all viewers on analog services of the national broadcaster, GTV to digital in the shortest possible time since it has a lot of viewers.

3.6.2 New Definition of the Broadcast value chain

With the new digital broadcast value chain where many programs can be transmitted on a single channel, policies should be put in place to take full advantage whereby many content providers can share multiplex and transmitting resources efficiently.

3.6.3 Video Format

To ensure that enough space is available for current incumbent analog stations on a digital multiplex, SDTV should be the video format choice before analog switch-off. HDTV is recommended for after analog switch-off since it requires more bandwidth capacity. More SD programs can be accommodated on a digital multiplex as compared to HD programs. Hence SDTV will save scarce spectrum resulting in a larger digital dividend. Also most of the television sets used in Ghana may not be able to receive HDTV programs currently.

The thematic operation of SDTV and HDTV should be considered during content production planning and implementation.

3.6.4 Compression standards

The latest version of MPEG-4, H.264/AVC/MPEG-4 (part 10) and Advanced Audio Coding (AAC) is recommended since it is more bandwidth efficient. MPEG-4 should be adopted as the compression technique because it allows for more programs on a digital multiplex since it is more bandwidth efficient.

3.6.5 DVB CA techniques

The Multicrypt DVB CA solution is recommended since it the best and widely adopted solution around the world. It allows a user to access several networks by manually switching the Common CI module (smartcard) to the networks' used CA system.

3.6.6 Malleability/Flexibility of digital bandwidth allocation

The flexibility that can be obtained through digital signal processing by the perturbation of coding rate, guard interval, modulation technique could be used to optimize the number of programs on a digital channel.

3.6.7 Type of video encoding

Constant picture quality could be achieved with the use of Variable Bit Rate (VBR) video encoding through the use of a statistical multiplexer.

3.6.8 Separation of the broadcast value chain into three components/services

The Digital Television Broadcast Value Chain should be separated into the three services: Content Production, Multiplexing and Transmission. Each of these services should be provided by a different entity. The entities responsible for multiplexing (multiplex operator) and transmission should be assisted by government to put the multiplexing and transmission infrastructure together. This will free individual broadcasters to concentrate on content creation.

3.6.9 Proposals for operation

Multiplex operators should submit proposals to the NCA, showing that they can fill a multiplex. This should be a prerequisite for multiplex allocation.

3.6.10 Different Allocations of bandwidth (Mbps) per program

The bandwidth allocation policies of multiplex operators should be as efficient as possible to carry more programs as a further boost to the realization of the digital dividend.

More multiplex capacity (bit rate) should be allocated to programs with lots of action and movement (example live football match) to produce quality pictures for consumers.

3.6.11 Drop and Add feature of digital broadcasting

The Drop and Add feature should be taken into consideration when planning the digital network to ensure efficiency and effectiveness. The Drop and Add feature can be applied in order to add local programs to a digital multiplex. Programs on a nationwide multiplex can be dropped at regional transmitter centers and then local programs added to the multiplex so that local programs can be enjoyed by local consumers.

3.6.12 EPG service

All set-top boxes should also be able to support all free-to-air digital services. All digital multiplex should also provide an Electronic Program Guide (EPG) service.

3.6.13 Program link between multiplex centres and transmitting sites

During the migration efforts should be exerted to ensure that both fiber and microwave resources are utilized for the distribution of programs around transmitting sites.

3.6.14 Local content development

There should be a policy to promote the development of local content. Broadcasters should be required to reserve a percentage of their programming to local content. This will lead to the creation of jobs and culture conservation. The government should play the lead role while monitoring of the percentage should be done by the NMC in partnership with the NCA.

3.6.15 Monitoring of content

The media department of the NMC should be tasked and equipped to monitor content on the digital multiplexes since the multiplicity of programs will create some challenges, such as inappropriate content from international sources.

3.6.16 Manpower for Content production and multiplexing

Content producers should be willing to invest in more personnel. Multiplex operators should also invest in more personnel with the adequate technical requirements in other to manage their multiplexes effectively.

3.6.17 Cost of Programs on Digital broadcast multiplex

It is recommended that the NCA/NMC ensures pricing of bandwidth on a multiplex are as transparent as possible in keeping with the law (ECA 2008, Act 775, Article 6 Clause b)

3.6.18 Number of multiplexes to be issued

The number of multiplexes that will be issued out by NCA for digital broadcasting should be known. The multiplexes should be issued out one at a time. If a multiplex is not filled, a new one should not be issued out.

3.6.19 Specifications of technical requirements

In order to maintain the ability to receive all the multiplex services, it is necessary to specify certain technical requirements covering common methods of delivering video, audio, text and data applications by the NCA.

3.6.20 Statistical multiplexing

Statistical multiplexing can be used to increase the usable capability of the multiplex capacity. This is done by sharing the multiplex capacity among the programs, giving the most bandwidth at any given moment to the most demanding programs.

3.6.21 Introduction of DVB-T2

The introduction of the more advanced DVB-T2 will provide multiplex operators with higher multiplex capacity. This would increase the digital dividend while also giving consumers more options in programming.

3.7 Summary

The study evaluated the implementation of the content production and multiplexing components/services of the digital television value chain in Ghana.

Digital television migration is reviewed looking at the frequency spectrum assigned so far and the digital television broadcasting standards for Ghana adopted by the NCA is also looked at.

Three DVB-T digital television systems are evaluated in terms of the content production and multiplexing services of the digital television broadcasting value chain.

Observations, findings and recommendations are made based on the study.

Finally it is concluded that digital television broadcasting will provide a lot of opportunities to the Ghanaian broadcasting industry but the various stakeholders must be prepared to invest in order to reap the ensuing benefits.

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APPENDIX A

A1 MPEG Compression standards

A1.1 MPEG-1

The first full-motion compression standard to be produced was MPEG-1, which is aimed at non-broadcast applications like computer CD-ROM and Internet download. It draws from JPEG in the area of image compression using DCT and provides a broad range of options to fit the particular application. For example, there are various profiles to support differing picture sizes and frame rates and it can encode and decode any picture size up to the normal TV with a minimum number of 720 pixels per line and 576 lines per picture. The minimum frame rate is 30 (non-interlaced) and the corresponding bit rate is 1.86 Mbps [19, 54].

A1.2 MPEG-2

The second phase of consumer digital video standards activity took the innovations of MPEG-1 and added features and options to yield an even more versatile system for broadcast TV. The purpose of the MPEG-2 standard was to provide lossy video quality equal to or better than NTSC, PAL, and SECAM, along with the facility to support the lossless performance. The developers of MPEG-2 had in mind the most popular applications in cable TV, satellite DTH, digital VCRs, and terrestrial TV networks as well [19, 54].

MPEG-2's important contribution was not in compression (that was established by JPEG and MPEG-1), but rather as an integrated transport mechanism for multiplexing the video, audio, and other data through packet generation and time division multiplexing. It is an extended version of MPEG-1 and is designed to be backward compatible with it. The definition of the bit structure, called the *syntax*, includes a constant-rate bit stream, a set of coding algorithms, and a multiplexing format to combine video, audio, and data (including Internet Protocol data). New coding features were added to improve functionality and enhanced quality in the conventional video environment of interlaced scanning and constrained bandwidth. The system is scalable for lossless and lossy transmission, along with the ability to support HDTV standards. Robust coding and error correction are available to facilitate a variety of delivery systems including satellite DTH, local microwave distribution (e.g., MMDS), and over-the-air VHF and UHF broadcasting [19, 54].

A1.3 MPEG Audio

The other important element of MPEG-2 is the provision of stereo audio. The audio compression system employed in MPEG-2 is based on the European MUSICAM standard as modified by other algorithms. It is a lossy compression scheme that draws from techniques already within MPEG. MUSICAM works by transmitting only changes and throwing away data that the human ear cannot hear. This information is processed and time division multiplexed with the encoded video to produce a combined bit stream that complies with the standard syntax. This is important because it allows receivers designed and made by different manufacturers to be able to properly interpret the information. However, what the receiver actually does with the information depends on the features of the particular unit [19].

A1.4 MPEG-4

MPEG 4 is an object-oriented standard which has the ability to overcome the limitations in bit rate and interactivity that MPEG-1 and MPEG-2 had offered. MPEG-4 is much more than just data compression. It was primarily aimed at low bit rate communications; however, its extent was expanded further to have a number of different technologies and cover a broad range of applications. MPEG-4 gives the user the ability of manipulating the audiovisual objects in a scene. These objects could be parts of video or computer generated models. The user can actively interact with the objects and modify scenes by adding, removing, or repositioning them in a scene. The standard uses a language called binary format for scenes (BIFS) for scene composition. This language is based on the concepts developed in virtual reality modeling language (VRML), and includes features such as facial animation, native two-dimensional primitives, and streaming protocols. Using BFIS for real-time streaming allows scenes to be built up on the fly with no need to be downloaded in full before their display. Like MPEG-2, MPEG-4 conformance is defined in terms of profiles and levels depending on the visual object types supported and the bit stream parameters [19, 55].

Because MPEG-4 coding is descriptive it also provides standardized elements enabling the integration of production, distribution, and content access paradigms. As descriptive coding is typically an order of magnitude more efficient than DCT coding, MPEG-4 is positioned to achieve for the Internet what MPEG-2 did for broadcasting [19, 55].

MPEG-4 is therefore the successor of MPEG-1 and MPEG-2 and may be used at all bitrates from 10 Kbps to several Mbps. MPEG-4 could be said to combine the best of performance in MPEG-1 and MPEG-2 and the same format can be used for signals having very low as well as very high bitrates. Therefore MPEG-4 is suitable for low bit rate Internet TV as well as standard definition and high definition television. On top of this, MPEG-4 is much more bandwidth efficient that MPEG-2. With MPEG-2, a bit rate from 3 to 5 Mbps is required for standard TV while MPEG-4 can produce an acceptable quality at bitrates down to 1.5 Mbps, if cutting-edge technology is used. Also some European HDTV transmissions are carried out using the MPEG-2 format via satellite. It takes about 16 Mbps per TV program to be able to handle HDTV in this way. Changing to MPEG-4 will require only 6 to 8 Mbps per program. This means that HDTV will no doubt be the most important use of MPEG-4 during the years to come. MPEG-4 is also easier than previous formats to combine with computer graphics [19, 55].

Table 1.1a Comparison of MPEG standards [19]

Parameters	MPEG-1	MPEG-2		MPEG-4	
		SDTV	HDTV	SDTV	HDTV
Bit rate per program (Mbps)	1.86 (for non-broadcast applications)	3-5	16	1.5	6-8
Number of programs for a 24 Mbps DVB-T multiplex	-	5-8	1	16	3-4

A1.5 Relationship between DVB and MPEG

DVB follows the spirit of MPEG-2 and this leads to the specification of a family of DVB standards [19]:

- DVB-S: the satellite DTH (direct-to-home) system for use in the 11/12-GHz BSS (broadcast satellite service) band, configurable to suit a wide range of transponder bandwidths and EIRPs (the standard is also applied in C, Ku, and Ka FSS- fixed satellite service bands). There is a second generation standard DVB-S2 which uses MPEG-4;
- DVB-C: the cable delivery system, compatible with DVB-S and normally used with 8-MHz channels (e.g., consistent with the 625-line systems common in Europe, Africa, and Asia);
- DVB-CS: the satellite master antenna TV (SMATV) system, adapted from DVB-S and DVB-C standards to serve private cable and communities;
- DVB-T: the digital terrestrial TV system designed for 7- to 8-MHz channels. There is a second generation standard DVB-T2 which uses MPEG-4;
- DVB-SI: the service information system for use by the DVB decoder to configure itself and to help the user navigate the DVB bit streams;
- DVB-TXT: The DVB fixed-format teletext transport specification;
- DVB-CI: The DVB common interface for use in CA and other applications;

- DVB-RCS: The return channel by satellite scheme being as a mechanism for two-way interactive services within a general broadcast context.
- DVB-H: digital video broadcasting handheld is for mobile digital transmission

A1.6 Modulation parameters and multiplex capacity

Table 1.2a Available bitrates (Mbps) for a DVB-T system in 8 MHz channels for non-hierarchical modulation [57]

Modulation	Coding rate	Guard Interval			
		1/4	**1/8**	**1/16**	**1/32**
QPSK	1/2	4.976	5.529	5.855	6.032
	2/3	6.635	7.373	7.806	8.043
	3/4	7.465	8.294	8.782	9.048
	5/6	8.294	9.216	9.758	10.053
	7/8	8.709	9.676	10.246	10.556
16-QAM	1/2	9.953	11.059	11.709	12.064
	2/3	13.271	14.745	15.612	16.086
	3/4	14.929	16.588	17.564	18.096
	5/6	16.588	18.431	19.516	20.107
	7/8	17.419	19.353	20.491	21.112
64-QAM	1/2	14.929	16.588	17.564	18.096
	2/3	19.906	22.118	23.419	24.128
	3/4	22.394	24.882	26.346	27.144
	5/6	24.882	27.647	29.273	30.160
	7/8	26.126	29.029	30.737	31.668

Table 1.3a Some available bitrates (Mbps) for DVB-T2 in 8MHz channels [30]

Table A2.1: Capacity in a 8 MHz channel, normal carrier mode, FFT modes: 1k to 32k

		Scattered Pilot Pattern 1 & 2							Scattered Pilot Pattern 3 & 4						
		GIF							GIF						
Modulation	Code rate	1/128 [Mbit/s]	1/32 [Mbit/s]	1/16 [Mbit/s]	19/256 [Mbit/s]	1/8 [Mbit/s]	19/128 [Mbit/s]	1/4 [Mbit/s]	1/128 [Mbit/s]	1/32 [Mbit/s]	1/16 [Mbit/s]	19/256 [Mbit/s]	1/8 [Mbit/s]	19/128 [Mbit/s]	1/4 [Mbit/s]
QPSK	1/2	6.8	6.6	6.5	6.4	6.1	6.0	5.5	7.1	6.9	6.7	6.7	6.4	6.2	5.7
	3/5	8.2	8.0	7.8	7.7	7.3	7.2	6.6	8.5	8.3	8.1	8.0	7.7	7.5	6.9
	2/3	9.1	8.9	8.6	8.5	8.2	8.0	7.3	9.5	9.3	9.0	8.9	8.5	8.3	7.7
	3/4	10.2	10.0	9.7	9.6	9.2	9.0	8.3	10.7	10.4	10.1	10.0	9.6	9.4	8.6
	4/5	10.9	10.7	10.4	10.2	9.8	9.6	8.8	11.4	11.1	10.8	10.7	10.2	10.0	9.2
	5/6	11.4	11.1	10.8	10.7	10.2	10.0	9.2	11.9	11.6	11.3	11.2	10.7	10.4	9.6
16-QAM	1/2	13.6	13.3	12.9	12.8	12.2	12.0	11.0	14.3	13.9	13.5	13.4	12.8	12.5	11.5
	3/5	16.4	16.0	15.6	15.4	14.7	14.4	13.2	17.1	16.7	16.3	16.1	15.4	15.1	13.8
	2/3	18.2	17.8	17.3	17.1	16.4	16.0	14.7	19.1	18.6	18.1	17.9	17.1	16.7	15.4
	3/4	20.5	20.1	19.5	19.3	18.4	18.0	16.6	21.4	21.0	20.4	20.1	19.2	18.8	17.3
	4/5	21.9	21.4	20.8	20.6	19.6	19.2	17.7	22.9	22.4	21.7	21.5	20.5	20.1	18.5
	5/6	22.8	22.3	21.7	21.4	20.5	20.1	18.4	23.9	23.3	22.6	22.4	21.4	21.0	19.3
64-QAM	1/2	20.4	20.0	19.4	19.2	18.3	18.0	16.5	21.4	20.9	20.3	20.0	19.1	18.8	17.2
	3/5	24.6	24.0	23.3	23.1	22.0	21.6	19.8	25.7	25.1	24.4	24.1	23.0	22.5	20.7
	2/3	27.3	26.7	25.9	25.7	24.5	24.0	22.1	28.6	27.9	27.1	26.8	25.6	25.1	23.1
	3/4	30.7	30.0	29.2	28.9	27.6	27.0	24.8	32.1	31.4	30.5	30.2	28.8	28.2	25.9
	4/5	32.8	32.1	31.1	30.8	29.4	28.8	26.5	34.3	33.5	32.5	32.2	30.7	30.1	27.7
	5/6	34.2	33.4	32.5	32.1	30.7	30.0	27.6	35.7	34.9	33.9	33.5	32.0	31.4	28.9
256-QAM	1/2	27.3	26.7	25.9	25.6	24.5	24.0	22.1	28.5	27.9	27.1	26.8	25.6	25.1	23.0
	3/5	32.8	32.1	31.1	30.8	29.4	28.8	26.5	34.3	33.5	32.5	32.2	30.7	30.1	27.7
	2/3	36.5	35.7	34.6	34.3	32.7	32.1	29.5	38.1	37.3	36.2	35.8	34.2	33.5	30.8
	3/4	41.1	40.1	39.0	38.6	36.8	36.1	33.2	42.9	41.9	40.7	40.3	38.5	37.7	34.7
	4/5	43.8	42.8	41.6	41.1	39.3	38.5	35.4	45.8	44.8	43.5	43.0	41.1	40.2	37.0
	5/6	45.7	44.7	43.4	42.9	41.0	40.1	36.9	47.7	46.7	45.3	44.8	42.8	41.9	38.6

A1.7 Bit rate per program allocations for various multiplexes around the world

Table 1.4a Bitrate Allocations for BBC Multiplex in the U.K [58]

Multiplex1 (BBC) Frequency: 778166.067 KHz; Bandwidth: 8 MHz; Constellation: 16-QAM; Coding rate: ¾; GI: 1/32; OFDM mode: 2k; Multiplex bitrate: 18.096 Mbps													
	Service		Video				Audio			Audio Description			Data
	Type	SID	Resolution	Min Bitrate (Mbps)	Avg Bitrate (Mbps)	Max Bitrate (Mbps)	Bitrate (Kbps)	Mode	Rate (kHz)	Bitrate (Kbps)	Mode	Rate (kHz)	Bitrate (Kbps)
BBC NEWS	TV	4415	720×576	1.28		4.68	192	joint	48	-	-	-	-
BBC ONE	TV	4351	720×576	1.69	12.78 (3.20 avg)	5.98	256	stereo	48	64	Mono	48	
BBC THREE	TV	4225	720×576	1.58		7.87	256	stereo	48	64	Mono	48	
BBC TWO	TV	4479	720×576	1.99		6.30	256	stereo	48	64	Mono	48	
BBC Red Button	TV	4679											1138
CBBC Channel	TV	4671											
EIT packets													278
Null packets													2127

Key EIT: Event Information Table – Gives information of the events in the multiplex

Table 1.5a Data rates for terrestrial broadcasting in Berlin-Brandenburg project [35]

Systems	**3 Programs in 11.06 Mbps (16-QAM, CR = ½, GI = 1/8)**		**3 Programs in 14.75 Mbps (16-QAM, CR = 2/3, GI = 1/8)**		**4 Programs in 14.75 Mbps (16-QAM, CR = 2/3, GI = 1/8)**	
Program component	Per Program [Mbps]	Total rate [Mbps]	Per Program [Mbps]	Total rate [Mbps]	Per Program [Mbps]	Total rate [Mbps]
Picture	3.2	9.6	4.4	13.2	3.2	12.8
Sound	0.192	0.576	0.192	0.576	0.192	0.768
Data (Teletext)	0.224	0.672	0.256	0.786	0.256	1.024
Service Information	----	0.128	----	0.128	----	0.128
Total		10.98		14.69		14.72

APPENDIX B

B1.1 Skyy Digital (Now Skyy Plus)

Table 1.1b Bit rate per program on the Skyy Digital (Skyy Plus) multiplex [43]

Multiplex Capacity	Allocations (Mbps)
Capacity for Skyy One (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Skyy World (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Channel D (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for KidsCo (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Cinimax (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Showtime (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Fox Entertainment (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Fiesta (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Hi Holly (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Hi Holly (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for Hi Holly (video rate + audio rate)	2.244 + 0.256 = 2.5
Capacity for BBC (video + audio rate)	

Table 1.2b Multiplex Allocations for Skyy Digital [43]

Multiplex Capacity	**Allocations (Mbps)**
Total capacity	30.160
Capacity for video part of each of the twelve programs	2.244
Total video capacity for the twelve programs	26.928
Capacity for audio part of each of all the twelve programs	0.256
Total audio capacity for all the twelve programs	3.072
Capacity in use	30.00
Capacity left	0.160

B1.2 GBC

Table 1.3b Multiplex Allocation for GBC's multiplex (Pilot) [48]

Multiplex Capacity	**Allocations (Mbps)**
Total multiplex capacity	22.118
Capacity for GTV (video rate + audio rate)	2.544 + 0.256 = 2.8
Capacity for TV3 (video rate + audio rate)	2.344 + 0.256 = 2.6
Capacity for TV Africa (video rate + audio rate)	2.344 + 0.256 = 2.6
Capacity for Net2 TV (video rate + audio rate)	2.344 + 0.256 = 2.6
Capacity for Viasat1 (video rate + audio rate)	2.344 + 0.256 = 2.6
Capacity for CNBC Africa (video rate + audio rate)	2.144 + 0.256 = 2.4
Capacity for KidsCo (video rate + audio rate)	2.144 + 0.256 = 2.4
Total Capacity in use	18.0
Total Capacity left	4.118

APPENDIX C

C1 Specifications for Headend Equipment

C1.1 Encoder

Encoders must provide high quality H.264 (MPEG-4, part 10) compressed video and HE-AAC audio coding [31].

Interfaces: Encoders must support input SDI ITU-R BT. 601-6, SDI SMPTE-292M, SDI SMPTE-259M, SDI SMPTE-296M, SDI SMPTE-424M, as well as output IP and ASI streams [31].

Video:

a. Encoder must support Aspect ratio 4:3, 16:9.

b. Encoder must support Chroma format 4:2:0.

c. Encoder must support Standard Definition and High Definition MPEG 4 part 10 (H.264 AVC) encoding [31].

Audio:

a. Encoder must support Embeded audio SMPTE-299M, Embeded audio SMPTE-272M.

b. Encoder must support audio Encoding MPEG-1 Layer II, Dolby Digital (AC-3), Dolby Digital Plus, AAC/HE-AACv2 including support for ADTS and LOAS/LATM variants [31].

Compliance:

a. Encoder should be modular supporting multiple MPEG4 SD and HD channels.

b. Encoder must support Capped VBR – the stream must not exceed its maximum bandwidth value.

c. Encoder must support Forward Error Correction Pro-MPEG COP3, SMPTE 2022.

d. Encoder must support redundant 2+2 IP output 100/1000 Base-T.

e. Encoder must support 1+1 Encoder redundant configuration.

f. Encoder must support dual redundant hot swappable power supplies [31].

C1.2 DVB-T2 re-multiplexer

The Multiplexer/Re-multiplexer performs re-multiplexing on the PID basis.

Interfaces:

a. Multiplexer must support modular architecture with interfaces.

b. Multiplexer must support ASI to IP conversion and IP to ASI conversion.

c. Multiplexer must support extensive transport stream and program-level analysis.

d. Multiplexer must support MPTS and SPTS.

e. Multiplexer must support PID filter/ PID and service ID remapping capability.

f. Multiplexer must support Multiplexer/demultiplexer, separating, duplicating, recombining digital program streams.

g. Multiplexer must support multiplexing of MPEG4 SD and MPEG4 HD channels.

h. Multiplexer must support 10 ASI interface, each port configurable as input or output.

i. Multiplexer must support ASI interface Input Rate Limiting.

j. Multiplexer must support MPEG over IP/UDP/RTP output.

k. Multiplexer must support IGMP V2/V3.

l. Multiplexer must support QoS IP streaming Diffserv/ToS 802.1p.

m. Multiplexer must support redundant 2+2 IP Gigabit output.

n. Multiplexer must support flexible IP output IEEE 802.3ab (Electrical) or IEEE 802.3z (Optical) [31].

Compliance:

a. Multiplexer must support Forward Error Correction Pro-MPEG CoP3, SMPTE-2022.

b. Multiplexer must support 1+1 redundant configuration.

c. Multiplexer must support dual redundant hot swappable power supplies.

d. Multiplexer must be fully managed by Centralized Management System and Self-based GUI interface.

e. Multiplexer must be fully configurable by Self GUI Interface even if Centralized Management fails [31].

C1.3 T2 Gateway

Compliance:

a. Gateway must support Single PLP handling.

b. Gateway must support SFN Adaptation for DVB-T2 broadcasting.

c. Gateway must support and be fully compliant to the T2-MI protocol.

d. Gateway must support 2 redundant ASI outputs.

e. Gateway must support Redundant power supply.

f. Gateway must support MISO.

g. Gateway must support MPEG over IP/UDP/RTP output.

h. Gateway must support FEC Pro-MPEG COP3, SMPTE-2022.

i. Gateway must have built-in GPS receiver.

j. Gateway must support SNMPv2.

k. Gateway must support 1+1 redundant configuration [31].

C1.4 Acronyms Used in the Report

AAC – Advanced Audio coding as specified in ISO/IEC 14496-3:2009.

ASI – Asynchronous Serial Interface.

AVC – Advanced Video Coding as specified in ISO/IEC 14496-10.

Mbps – Megabits per second.

COFDM – Coded Orthogonal Frequency Division Multiplex.

DCT – Discrete Cosine Transform.

DFT – Discrete Fourier Transform.

DiffServ – Differentiated Services.

DTH – Direct To Home.

DVB – Digital Video Broadcasting.

DVB-T – DVB system for Terrestrial broadcasting Specified in EN 300 744.

DVB-T2 – 2nd Generation DVB-T system specified in EN 302 755.

ETSI – European Telecommunications Standards Institute.

FEC – Forward Error Correction.

FFT – Fast Fourier Transform.

GPS – Global Positioning System.

GUI – Graphic User Interface.

H.264 – ITU-T video coding standard.

HE AAC – High Efficiency Advanced Video Coding.

IGMP – Internet Group Management Protocol.

IP – Internet Protocol.

ISO – International Standards Organizations.

ITU-T – International Telecommunications Union.

JPEG/JFIF – Joint Photographic Experts Group/JPEG File Interchange Format.

LATM – LOAS – Low Overhead MPEG-4 Audio Transport Multiplex.

LCD – Light Emitting Diode.

LOAS – Low Overhead Audio Stream.

MISO – Multiple Inputs, Single Output.

MMDS – Multichannel Multipoint Distribution Service.

MP@ML – Main Profile @ Main Level.

MPTS – Multiple Program Transport Stream.

MUSICAM – Masking pattern adapted Universal Sub-band Integrated Coding And Multiplexing.

NCA – National Communications Authority.

NTSC – National Telecommunications Systems Committee.

PAT – Program Association Table.

PAL – Phase Alternating Line.

PID – Package Identification Data.

PLP – Physical Layer Pipe.

PMT – Program Map Table.

QoS – Quality of Service.

SMPTE – Society of Motion Picture and Television Engineers.

SNMP – Simple Network Management Protocol.

SECAM – Sequential Couleur Avec Memoire.

SPTS – Single Program Transport Stream.

SDI – Serial Digital Interface.

UDP/RTP – User Datagram Protocol/Real-time Transport Protocol.

W×H – Width by Height.