Characterisation of quality of service parameters for DTV reception in Singapore

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Characterisation Of Quality Of Service Parameters For DTV Reception In Singapore

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School of Electrical and Electronic Engineering

A thesis submitted to the Nanyang Technological University
in fulfillment of the requirement for the degree of
Master of Engineering

2005

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Statement of Originality

I hereby certify that the content of this thesis is the result of work done by me and has not been submitted for a higher degree to any other University or Institution.

18th August 2005

Date

A handwritten signature in black ink, appearing to read 'Peh Beng Yeow', with a long horizontal line extending to the right.

Peh Beng Yeow

Abstract

Digital data transmission has revolutionized the communication arena. The launch of mobile digital television (DTV) service in Singapore has demonstrated the capability of COFDM technique for mobile reception. Singapore is a small island with many high-rise buildings, the environment is different from most of the European countries, which has much bigger land and can afford to build low rise buildings. Hence, there is a need to verify the recommendation provided by Chester 97 report [1] or ITU. The present work undertaken is to study the fixed DTV reception in Singapore. The QoS parameter like field strength, Bit-Error-Rate (BER), Modulation Error Rate (MER), Signal to Noise Ratio (SNR) has been identified as prime parameters for measurement. Extensive measurement campaign has been undertaken to study these parameters in different environments. A noble approach of using fish-eye lens to capture 360° of the environment to calculate the mean angle of elevation and the standard deviation at the points where the signal strength were measured has been incorporated to characterize the clutter loss. Necessary software has been developed to process the fish-eye photographs. The gain associated with rising the receiving antenna (or height gain) for fixed DTV reception in Singapore was also studied via a van with an extendable antenna mast. Recommendation on the QoS parameters has been given for the fix reception of DTV services in Singapore.

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List of Abbreviations

ATSC	Advanced Television System Committee
BER	Bit Error Rate
C/N	Carrier to Noise Ratio
cdf	cumulative distribution function
COFDM	Coded Orthogonal Frequency Division Multiplexing
DTV	Digital Television
DVB	Digital Video Broadcasting
ETSI	European Telecommunications Standards Institute
ERP	Effective Radiated Power
HDB	Housing and Development Board
ISDB	Integrated Services Digital Broadcasting
ISI	Inter-Symbol Interference
MER	Modulation Error Rate
MES	mobile earth station
MPEG	Moving Picture Experts Group
Mux	Multiplexer
pdf	probability density function
PRBS	Pseudo Random Binary Sequence
SDM	satellite diversity mitigation
SNR	Signal to Noise Ratio
STB	Set-top-box

Chapter One - Motivation

1.1 Background

In January 2000, Singapore Broadcasting Authority, SBA (now known as Media Development Authority of Singapore, MDA) commissioned a UK transmission company, ntl for a consultancy service on frequency planning [2]. The recommended Digital Video Broadcasting Terrestrial (DVB-T) configuration for mobile DTV services was two thousand carriers (2k), Quadrature Phase Shift Keying (QPSK), $\frac{1}{2}$ code rate and $\frac{1}{4}$ guard interval with minimum required median field strength of 69dB μ V/m at 10m height. The configuration requirement set by MDA for mobile application is 2k, 16 Quadrature Amplitude Modulation (QAM), $\frac{1}{2}$ code rate and $\frac{1}{4}$ guard interval and the minimum median field strength required at 10m height was decided to be 77dB μ V/m. With this configuration, it is possible to squeeze in minimum 2 video services in one RF channel of 7-8 MHz bandwidth with a total bit rate of 9.95 Mbit/s. However DVB-T standard was not originally developed for mobile reception. Later laboratory and field trial confirmed that mobile reception of DVB-T was feasible [3]. On Valentine's Day 2001, MediaCorp launched the world first mobile TV service, namely TVMobile (Ch37, centre frequency of 602MHz, 8 MHz of band width) [4]. The technology is based on DVB-T, and the configuration is 2k, QPSK, $\frac{1}{2}$ code rate, $\frac{1}{4}$ guard interval. Today, about 1,500 buses and 50 taxis were installed with DVB-T set-top-

boxes. For the first time, it is possible to watch good quality TV programs on the move.

Initial field trials were carried out by ntl to confirm the coverage predictions. 10 gap-fillers were identified and a comprehensive Single Frequency Network (SFN) was established to cover the entire island for mobile service. However no efforts were focused on the assessment of the picture quality as it was generally agreed that electrical field strength is the only parameter that will affect the reception quality. Studies were carried out in countries like UK, Spain etc under the EU VALIDATE program [5] to determine the Quality of Service (QoS) parameter for DVB-T. But all these studies were computer simulated and needs to be verified experimentally. It is therefore proposed to under take a detailed study of the QoS requirements for DTV reception in Singapore. The QoS parameters of interest are the minimum field strength required for error free picture reception, the Bit Error Rate (BER), Modulation Error Rate (MER) and carrier-to-noise ratio (C/N). The main objective is to measurement these parameters at 10m above ground level (agl), to speed up the measurement process, 2m agl, which the receiving antenna was placed on top of the reception van was used. The 2m agl is a more realistic height for mobile reception test too. In all case, especially for a Single Frequency Network (SFN), the impulse response is also equally important to understand the multi path and 'artificial echoes' from the repeaters.

The QoS issues pertaining to DTV mobile reception are more complex for two main reasons. Firstly, the receiving antenna on the vehicle is situated at lower heights and the receiver is moving. Another reason is the blockage of the transmitted signals from the high-rise buildings in Housing Development Board (HDB) estates in the urban area. The empirical prediction models like Hata [6] and ITU-R [7] overestimate the field strengths due to the fact that they do not consider the clutter losses in detail. The Urban definition given by ITU-R may not be applicable to Singapore. The dense urban area was defined with a building height of 30 m. However, in Singapore 75% of the population lives in high rise (40-50 meters) housing apartments which are clustered together in large estates. Models based on Uniform Theory of Diffraction (UTD) are needed to predict the exact field strength at a given location [8]. The Walficsh-Bertoni [9] model also underestimates the field strength. Hence, some innovative techniques are sought for the prediction of QoS parameters in a hostile environment. The predictions, measurements and analyses of the Quality of Service for DTV especially for mobile DTV are relatively new that require detailed studies.

This project work is focused on the area of QoS for DTV fixed reception i.e. the minimum field strength required to see error free pictures and the associated MER, BER(pre Viterbi) and SNR values in different clutter environments. In this report, brief review of QoS parameters and results of the outdoor measurements conducted at some places are presented.

1.2 Objectives

The main objective of the thesis is to define and recommend appropriate guidelines for DVB-T reception in Singapore. This includes picture quality assessment, gain vs height of receiving antenna measurements and characterization of the environmental (clutter) losses for DVB-T in high rise Housing Development Board (HDB) estates and low rise landed property.

Fig. 1.1 shows a typical block diagram of a DVB-T receiving system.

Fig. 1.1 Typical DVB-T receiver

There are no existing guidelines on the picture quality assessment. The BER of 2×10^{-4} after the Viterbi-Decoder was fixed in the DVB-T specification as a reference for the quasi error free (QEF) state of picture [1]. QEF means less than one uncorrected error event per hour, corresponding to $\text{BER} = 1 \times 10^{-11}$ at the input of the MPEG-2 demultiplexer. This failure point is mainly used for system simulation and laboratory measurement in stationary and portable

channels. The definition of QEF is 1 uncorrectable transport packet per hour. This might not be very realistic as it means very few errors and it takes too long to measure the QEF too. Hence Subjective Failure Point (SFP) [3] might be a faster way of determining the picture quality. This method states that a sufficient picture quality is achieved if no error is visible in a picture sequence of 20 seconds. However this method is based on the visual observations and depends mostly on the individual perception. Therefore it is necessary to quantify the picture failure in terms of minimum acceptable signal strength, C/N ratio, BER and MER. Hence the study is undertaken to quantify the QoS parameters. In Singapore, MediaCorp's way of judging picture quality in mobile reception is "a break is considered only if it lasts more than 3 seconds". The other objective is to verify the suitability of Chester 97 recommendations to the existing network. Chester 97 [1], which is adopted by European Telecommunications Standards Institute (ETSI) [10] has defined the minimum median equivalent electrical field strength and C/N ratio required for various configurations of the DVB-T network. For Ch37 of 2k, QPSK, $\frac{1}{2}$ code rate and $\frac{1}{4}$ guard interval to operate in a Rayleigh channel, the required C/N is 5.4dB (@ the receiver input) for Non-hierarchical transmission to achieve a BER = 2×10^{-4} after the Viterbi decoder. Unfortunately, there is no mention of minimum median equivalent field strength for the mobile DVB-T configuration in Chester report because DVB-T was not designed originally for mobile platform. Furthermore, the minimum median equivalent field strength specified for various configurations at 10 m level by the Chester

report is not from the experimental values but taken from the ITU-R Recommendations [11]. A more detail calculation of the minimum median equivalent field strength can be found in section 3.3.2.3.

Keeping in view the above mentioned issues, the thesis concentrates on 3 major areas and provides some recommendations. Putting in a nut shell, the objectives are:

- QoS study of DVB-T at

Ch37: 602MHz, 2k, QPSK, $\frac{1}{2}$ code rate, $\frac{1}{4}$ guard interval and

Ch29: 538MHz, 8k, 16QAM, $\frac{3}{4}$ code rate, $\frac{1}{8}$ guard interval

That is to correlate between the various QoS parameters and picture quality.

- Characterization of clutter using fish-eye lens
- Investigation of the height gain characteristic.

1.3 Major contribution of the Thesis

There are three major contributions of this project:

1.3.1 Quality of Service (QoS) parameter of DVB-T in Singapore

Singapore launched digital TV service, namely TVMobile in the year 2001[4]. Initial study was based on Chester 97 report [1], which recommended the field strength requirement and C/N for good quality DTV reception using software simulation. This project proposed a procedure to measure the parameters (receiver input voltage, BER, SNR, MER etc) in the actual field condition with single (Ch29) and multiple (Ch37) transmission sites. It recommends the QoS parameters requirement for DVB-T fixed reception in Singapore.

1.3.2 Characterisation of clutter loss using fish-eye lens

Clutter loss has been very difficult to quantify, it depends very much on the definition of density of the terrain. To make things more complicated, the urban area in certain country might be considered as rural area to another country. This report discusses the possibility of quantifying the micro-terrain density using fish-eye lens photo, which captures the 360° view of the surrounding.

1.3.3 Gain with respect to the height of the receiving antenna characteristic

According to ITU-R P370-7 [7], there is always signal strength gain when the receiving antenna is raised to a higher location. The measurement conducted in this project showed that this is not always the case in Singapore terrain. There are cases, when the signal strength decreases as the receiving antenna height increases.

1.4 Organization of the Thesis

The thesis has been organized in six chapters. The objectives and organization of the present work are described in Chapter One.

A detailed introduction of the DVB-T network in Singapore, data transmission and modulation techniques are presented in Chapter Two. Theoretical concepts of some of the QoS parameters pertaining to DVB-T reception are described.

Chapter Three provides detailed results about the picture quality assessment, required C/N ratio, field strength, BER and MER values for error free picture reception.

Chapter Four investigates the effect of the environment building condition contributes to the clutter loss using a fish-eye lens.

Chapter Five describes the height vs gain (of receiving antenna) characteristics. The electrical field strength received with the receiving antenna placed at 2m and 10m above ground level (agl) are reported.

Summary and conclusions are given in Chapter Six.

Chapter Two - Background of DVB-T

2.1 Introduction to digital television

Currently, the three major digital transmission systems for digital television are [12]:

- Advanced Television Systems Committee (ATSC), which was introduced by the United States and being adopted by other countries such as Canada and South Korea.
- Digital Video Broadcasting (DVB), which originated in Europe. Countries adopting this system include European Union, Australia, New Zealand, Hong Kong, Taiwan and Singapore.
- Integrated Services Digital Broadcasting (ISDB), which is similar to DVB in many ways and is designed by the Japanese.

Our focus was on DVB-T since it has been selected for Singapore. The standards for the terrestrial transmission (ETSI 300 744) [10] specifies a system design to deliver high quality video over 7MHz (for VHF band) and 8MHz (for UHF) channels. With the adoption of Single Frequency Network (SFN), all the stations are transmitting with 3 conditions:

- Same frequency
- Same modulation
- Same data

To make it flexible in designing a television network compared to the constraint in the analogue system, areas that are not covered by one transmitter will be filled up by another transmitter.

2.2 Functional block diagram of DVB-T system (non-hierarchical)

Fig 2.1 illustrates the DVB-T system as the functional blocks of equipment performing the adaptation of the baseband TV signals from the output of the MPEG-2 transport multiplexer, to the terrestrial channel characteristics [10].

The following processes are applied to the data stream:

- Transport multiplex adaptation and randomization for energy dispersal
- Outer coding (i.e. Reed Solomon code)
- Outer interleaving (i.e. convolutional interleaving)
- Inner coding (i.e. punctured convolutional code)
- Inner interleaving
- Mapping and modulation
- Orthogonal Frequency Division Multiplexing (OFDM) transmission.

Fig 2.1 Block diagram of DVB-T transmission system

2.2.1 Multiplexer (Mux) adaptation and energy dispersion

The output of the multiplexer has a fixed length packet of 188 bytes including the synchronisation byte (47Hex). In order to ensure adequate binary transitions, the data at the input of the MPEG-2 mux shall be randomized in accordance with the configurations depicted in Fig 2.2. The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be [10]:

$$1+X^{14}+X^{15} \dots\dots\dots (2.1)$$

Fig 2.2 Scrambler/descrambler schematic diagram

2.2.2 Reed Solomon coding (Outer coding)

Reed-Solomon coding is applied to the packets in the outer coder. The Reed-Solomon has length 204 bytes, dimension 188 bytes. There are 16 parity bytes, which mean that the error correction is up to 8 bytes.

Fig 2.3 Outer Reed-Solomon code

2.2.3 Outer interleaver

Referring to Fig 2.1, the outer coder is followed by a byte-wise outer interleaver. The principle of the outer interleaver is to transmit horizontal codewords in vertical format.

Fig.2.4 Outer interleaver principle

Say t_x is the length of the horizontal code words of row x , Fig 2.5 shows the original sequence of the data, and Fig 2.6 shows the transmitting sequence of the data..

Fig 2.5 Original sequence (horizontal codewords)

Fig 2.6 Transmitted sequence (vertical codewords)

In the receiver, the transmitter vertical codewords are assembled back to horizontal codewords again. In this case, when there is a burst noise, which destroyed a vertical codeword (refer to Fig 2.8), after reassembly back at the receiver to horizontal codeword, the error reduces to one byte per code (refer to Fig 2.9) instead of whole horizontal codeword being destroyed. Thus, the burst error can be rectified after error correction. Fig 2.8 shows the vertical codeword was destroyed by burst noise. Fig 2.9 shows that the error has reduced to one byte per horizontal codeword, which can be corrected to the original codeword.

Fig 2.7 Demonstration: Original sequence (horizontal codewords)

Fig 2.8 Demonstration: Transmitted sequence (vertical codewords) with burst error

Fig 2.9 Demonstration: Received sequence

2.2.4 Inner coding

Following the outer interleaver is the inner coding, which consists of a convolutional encoder and puncturer.

Fig 2.10 convolutional encoder and puncturing

The convolutional code is based on mother code of $\frac{1}{2}$ and 64 states with generator, $G_1=171_{oct}$ for X output and $G_2=133_{oct}$ for Y output.

Fig 2.11 Mother convolutional code of rate $\frac{1}{2}$

For the X output, $G_1(x) = 1 + x + x^2 + x^3 + x^6$ or in vector form is 1111001_b, which is 171_{oct} [9].

For the Y output, $G_2(x) = 1 + x^2 + x^3 + x^5 + x^6$ or in vector form is 1011011_b, which is 133_{oct} [9].

The encoder output $c(x)$ is the interlace of $d(x).G_1(x)$ with $d(x).G_2(x)$, where $d(x)$ being the input.

For example: $d(x) = 1 + x^2 + x^3$

$$\begin{aligned} d(x).G_1(x) &= (1 + x^2 + x^3) \cdot (1 + x + x^2 + x^3 + x^6) \\ &= 1 + x + x^5 \end{aligned}$$

$$\begin{aligned} d(x).G_2(x) &= (1 + x^2 + x^3) \cdot (1 + x^2 + x^3 + x^5 + x^6) \\ &= 1 + x^3 + x^4 + x^5 \end{aligned}$$

$$\text{encoded sequence} = (1,1) + (1,0)x + (0,0)x^2 + (0,1)x^3 + (0,1)x^4 + (1,1)x^5$$

and the transmitted sequence is 11 10 00 01 01 11, Hence, it has a code rate of $\frac{1}{2}$.

The mother code imposed by DVB standard is 1/2. However, higher code rate such as 2/3, 3/4, 5/6 and 7/8 can be achieved from the mother code by puncturing. Puncturing is the deleting of certain number of bits in the encoded stream according to perforation patterns, which indicate the deleting bit positions [13]. (Please refer to Table 2.1). Puncturing increases the capacity of the transmission channel at the expense of a reduction of the free distance, which is a measure of the correction efficiency of the convolutional code. In another words, it makes the channel less robust [14].

Table 2.1 Puncturing pattern and transmitted sequence after parallel-to-serial conversion

Code rates	Puncturing pattern	Transmitted sequence
$\frac{1}{2}$	X: 1 Y: 1	$X_1 Y_1$
$\frac{2}{3}$	X: 1 0 Y: 1 1	$X_1 Y_1 Y_2$
$\frac{3}{4}$	X: 1 0 1 Y: 1 1 0	$X_1 Y_1 Y_2 X_3$
$\frac{5}{6}$	X: 1 0 1 0 1 Y: 1 1 0 1 0	$X_1 Y_1 Y_2 X_3 Y_4 X_5$
$\frac{7}{8}$	X: 1 0 1 0 1 0 1 Y: 1 1 0 1 0 1 0	$X_1 Y_1 Y_2 X_3 Y_4 X_5 Y_6 X_7$

Guard interval and OFDM will be explained in the next section.

2.3 Theory on RF transmission

2.3.1 Orthogonal Frequency Division Multiplexing (OFDM)

In digital TV system, data rate of at least few Mbps is required. This implies that the symbol duration is less than 1 μ s. Outdoor wireless channels introduced multipath delays can be as long as 20 μ s. Thus the multipath delay can be as much as 20 symbol duration resulting in severe Inter-Symbol Interference (ISI) problems.

Coded Orthogonal Frequency Division Multiplexing (COFDM) is a method of transmitting high data digital signals over radio channel. The idea of COFDM is to divide the single bit-stream into a number of parallel bit-streams and to transmit all these lower bit-rate streams on a very large number of carriers side by side within one channel. Orthogonality means each sub-carrier can be demodulated without interference from any of the others [15]. Fig 2.12 shows the spectrum of an OFDM signal. The chances for each sub-carrier to experience flat fading is much higher as compared to a single carrier of wider band width and equalisation can be performed easily in the frequency domain by the multiplication of a scaling vector for each sub-carrier.

Fig. 2.12 Spectrum of OFDM signal [16]

For orthogonality, the sub-carrier spacing must be such that [17]:

$$f_n = f_o + n\Delta f \dots\dots\dots(2.2)$$

where

$$\Delta f = \frac{1}{NT} \dots\dots\dots(2.3)$$

- N = total number of sub-carriers
- n = sub-carrier number
- f_n = frequency of that sub-carrier
- f_o = frequency of the first sub-carrier
- $1/T$ = symbol rate

An ideal environment is assumed and the received signal over a period of NT in the absence of noise is given by [17]:

$$x(t) = \sum_{n=0}^{N-1} d_n e^{j2\pi(f_0 + n\Delta f)t} \quad 0 \leq t \leq NT \quad \dots\dots\dots (2.4)$$

To obtain the i^{th} desired symbol, the equation is multiplied by $e^{-j2\pi f_i t}$ and integrate over the period NT .

$$\begin{aligned} \hat{d}_i &= \frac{1}{NT} \int_0^{NT} x(t) e^{-j2\pi f_i t} dt \\ &= \frac{1}{NT} \int_0^{NT} x(t) e^{-j2\pi(f_0 + i\Delta f)t} dt \\ &= \frac{1}{NT} \sum_{n=0}^{N-1} d_n \int_0^{NT} e^{j2\pi(n-i)\Delta f t} dt \\ &= \frac{1}{NT} \sum_{n=0}^{N-1} d_n \int_0^{NT} e^{j2\pi(n-i)t/(NT)} dt \\ &= d_i \end{aligned}$$

Take note of the term:

$$\int_0^{NT} e^{j2\pi(n-i)t/(NT)} dt,$$

which is equal to NT if $n = i$, otherwise zero. Hence, all other sub-carriers have zero value for cross-correlation. This implies that all the carriers are orthogonal to each other.

2.3.2 Guard interval

Although the symbol rate of each carrier is moderate, ISI would still occurs if no special measures were taken. To avoid the ISI, a guard interval, g is inserted before each symbol. The guard interval consists of a cyclic continuation of the useful symbol. This is to ensure the orthogonality of the carriers can be achieved for the received signal in the presence of echoes, as long as the echoes are within the guard interval. In DVB-T, there are two modes, which are usually referring to 2k or 8k mode. There is an option of choosing 4 sets of guard interval too. Table 2.2 shows the possible values of N and T in DVB-T system.

Table 2.2 The value of N and T in DVB-T system

Parameter		8k mode	2k mode
Number of carriers, N		6817	1705
Duration of each carrier, T_{usable}		896 μsec	224 μsec
Guard interval duration, T_g	1/4 g	224 μsec	56 μsec
	1/8 g	112 μsec	28 μsec
	1/16 g	56 μsec	14 μsec
	1/32 g	28 μsec	7 μsec
$T = T_{\text{usable}} + T_g$	1/4 g	1120 μsec	280 μsec
	1/8 g	1008 μsec	252 μsec
	1/16 g	952 μsec	238 μsec
	1/32 g	924 μsec	231 μsec

Fig 2.13 shows the superposition of the multipath signals detected at the receiver. T_g is the guard interval portion, which is not use in decoding the signal. T_{useable} is the portion, which we are interested and it preserves to certain extend the original waveform.

Fig 2.13 Superposition of multipath signals arrived within guard interval [18]

In DVB-T single frequency network (SFN), there are many transmitters transmitting at the same frequency with the same content and same modulation. This creates many artificial multipaths. The receiver encounters relatively long time delay between the various signals. For it to operate properly in SFN mode, the guard interval must be long enough. However, long guard interval will reduce the capacity of the network. The mobile television

system in Singapore uses $\frac{1}{4}$ guard interval and 2k mode. This corresponds to guard interval of $56\mu\text{sec}$ or 16.8km ($=56\mu\text{sec} \times 3 \times 10^8 \text{ m/sec}$) (Please refer to Appendix B for the map of Singapore island). More possible values of guard interval can be found in Table 2.2.

Fig 2.14 Impulse response at the receiving location

Fig 2.14 shows an example of received impulse response. Carrier 1, 2 and 3 arrived at the receiver within the guard interval; they will have a positive contribution to the signal. Whereas Carrier 4 falls outside the guard interval, the receiver treats it as noise and thus it has a negative impact on the signal. The effect of this is generally to increase the required Carrier to Noise ratio (C/N), and hence the field strength threshold. In extreme cases, where a carrier of relatively strong signal strength as compared to the main carrier falls outside guard interval, the receiver will not operate at any signal level. In

order for most (if not all) of the signals to arrive at the receiver within the guard interval, the firing time of the transmitters become very critical.

2.3.3 Rayleigh channels

The Rayleigh distribution has a probability density function (pdf) given by [19]:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) & (0 \leq r \leq \infty) \\ 0 & (r < 0) \end{cases} \dots\dots\dots(2.5)$$

Where

σ is the rms value of the received voltage signal before envelope detection.

σ^2 is the time-average power of the received signal before envelope detection.

The probability that the received signal does not exceed a specific value R is given by the corresponding cumulative distribution function (cdf) [19]

$$P(R) = P_r(r \leq R) = \int_0^R P(r)dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \dots\dots\dots(2.6)$$

The mean value r_{mean} is of the Rayleigh distribution is given by [19]:

$$r_{mean} = E[r] = \int_0^\infty rp(r)dr = \sigma \sqrt{\frac{\pi}{2}} = 1.2533\sigma \dots\dots\dots(2.7)$$

The variance of the Rayleigh distribution is given by σ_r^2 [19]

$$\begin{aligned} \sigma_r^2 &= E[r^2] - E^2[r] = \int_0^\infty r^2 p(r)dr - \frac{\sigma^2 \pi}{2} \\ &= \sigma^2 \left(2 - \frac{\pi}{2}\right) = 0.4292\sigma^2 \end{aligned} \dots\dots\dots(2.8)$$

In the planning of a DVB-T on mobile or portable platform, Rayleigh channel is assumed as the mobile (or portable) receivers will not have the luxury of orientating the antenna to optimize for the best signal condition. It is treated that there is no dominating signal. It can be observed from Table 2.3 that the signal requires a higher C/N value in a Rayleigh channel as compared to a Gaussian or Ricean channel.

2.3.4 Ricean Channel

The small scale fading envelope distribution is considered Ricean when there is a dominant stationary signal component present in the channel. In Ricean channel, the random multipath signals arriving at different angle are superimposed on a stationary dominant signal. [19]

As the dominant component become weaker, the composite signal resembles a noise signal, which has an envelope with a Rayleigh distribution.

The Ricean distribution is given by [19]:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{(r^2 + A^2)}{2\sigma^2}} I_0\left(\frac{Ar}{\sigma^2}\right) & \text{for } (A \geq 0, r \geq 0) \\ 0 & \text{for } (r < 0) \end{cases} \dots\dots\dots(2.9)$$

The parameter A is the peak amplitude of the dominant signal and $I_0(.)$ is the modified Bessel function of the first kind and zero-order. K is defined as the ratio between the deterministic signal power and the variance of the multipath signals, it is given by $K=A^2/2\sigma^2$ or in term of dB:

$$K(dB) = 10 \frac{A^2}{2\sigma^2} \text{ dB} \dots\dots\dots(2.10)$$

The parameter K is known as the Ricean factor. In DVB-T standard, the Ricean channel is based on K=10 dB [5]

Fig 2.15 Probability density function of Ricean distributions: K = -∞ dB (Rayleigh) and K = 6dB.

As $A \rightarrow 0$, $K \rightarrow -\infty \text{ dB}$, and as the dominant path decrease in amplitude, the Ricean distribution approaches to Rayleigh distribution. In the planning of a fixed reception DVB-T network, Ricean channel is assumed as the viewers will have the opportunity to adjust the receiving antenna until the best picture is received, there is normally a dominating signal in this case.

2.3.5 Chester 97 specification on C/N

The required C/N(dB) for non-hierarchical transmission to achieve a BER= 2×10^{-4} after the Viterbi decoder for all combinations of coding rate and modulation types are presented in Chester 97 [1] .

Table 2.3 C/N required for different configurations [1]

			Required C/N for BER= 2×10^{-4} after Viterbi (quasi error-free after Reed- solomon)			Net bit rate (Mbit/s)			
System variant	Modulation	Code rate	Gaussian Channel	Ricean Channel	Rayleigh Channel	D/Tu =1/4	D/Tu =1/8	D/Tu =1/16	D/Tu =1/32
A1	QPSK	1/2	3.1	3.6	5.4	4.98	5.53	5.85	6.03
A2	QPSK	2/3	4.9	5.7	8.4	6.64	7.37	7.81	8.04
A3	QPSK	3/4	5.9	6.8	10.7	7.46	8.29	8.78	9.05
A5	QPSK	5/6	6.9	8.0	13.1	8.29	9.22	9.76	10.05
A7	QPSK	7/8	7.7	8.7	16.3	8.71	9.68	10.25	10.56
B1	16QAM	1/2	8.8	9.6	11.2	9.95	11.06	11.71	12.06
B2	16QAM	2/3	11.1	11.6	14.2	13.27	14.75	15.61	16.09
B3	16QAM	3/4	12.5	13.0	16.7	14.93	16.59	17.56	18.10
B5	16QAM	5/6	13.5	14.4	19.3	16.59	18.43	19.52	20.11
B7	16QAM	7/8	13.9	15.0	22.8	17.42	19.35	20.49	21.11
C1	64QAM	1/2	14.4	14.7	16.0	14.93	16.59	17.56	18.10
C2	64QAM	2/3	16.5	17.1	19.3	19.91	22.12	23.42	24.13
C3	64QAM	3/4	18.0	18.6	21.7	22.39	24.88	26.35	27.14
C5	64QAM	5/6	19.3	20.0	25.3	24.88	27.65	29.27	30.16
C7	64QAM	7/8	20.1	21.0	27.9	26.13	29.03	30.74	31.67

From Rohde&Schwarz’s application note [20], the C/N is related to Eb/No with the following formula:

$C/N = Eb/No + K_{FEC} + K_{QPSK/QAM} + K_p \text{ dB} \dots\dots\dots(2.11)$

Where K_{FEC} is the factor of FEC to Reed Solomon:

$K_{FEC} = 10 * \log \frac{188}{204} = -0.3547 \text{ dB} \dots\dots\dots(2.12)$

$K_{QPSK/QAM}$ is the factor for QPSK/QAM mode

$K_{QPSK/QAM} = 10 * \log(m) , m \text{ is the number of bit for each mode } ..(2.13)$

Table 2.4 Values of $K_{QPSK/QAM}$

Mode	m	$K_{QPSK/QAM}$ dB
QPSK	2	3.0103
16QAM	4	6.0206
64QAM	6	7.7815

K_p is the factor for the puncturing rate (p=1 for QAM)

$K_p = 10 \times \log(p) \dots\dots\dots(2.14)$

Table 2.5 Value of K_p

Mode	p	K_p dB
QPSK	$\frac{1}{2}$	-3.0103
	$\frac{2}{3}$	-1.7609
	$\frac{3}{4}$	-1.2494
	$\frac{5}{6}$	-0.7918
	$\frac{7}{8}$	-0.5799
QAM	1	0

The relationship of BER vs E_b/N_0 is given by:

Fig. 2.16 Diagram for QPSK modulation [19]

The value $BER = 2 \times 10^{-4}$ before Reed Solomon corresponds to the point, where the FEC Reed Solomon is able to correct errors to the Quasi Error Free (QEF) data stream. From Fig.2.16, the E_b/N_0 required for $1/2$ code rate under Gaussian condition is 3.4 dB, using equations (2.11),(2.12),(2.13) and (2.14)

$$\begin{aligned} C/N &= E_b/N_0 + K_{FEC} + K_{QPSK/QAM} + K_p \text{ dB} \\ &= 3.4 - 0.3547 + 3.0103 - 3.0103 \\ &= 3.045 \text{ dB (the value shown in Table 2.3 is 3.1dB)} \end{aligned}$$

Take another example, the E_b/N_0 required for $3/4$ code rate is 4.4dB (refer to Fig. 2.15) at QEF condition, the C/N requirement is thus:

$$\begin{aligned} C/N &= E_b/N_0 + K_{FEC} + K_{QPSK/QAM} + K_p \text{ dB} \\ &= 4.4 - 0.3547 + 3.0103 - 1.2494 \\ &= 5.8062 \text{ dB (the value shown in Table 2.3 is 5.9dB)} \end{aligned}$$

The two examples shown that the above (i.e. $C/N|_{QPSK, \text{code rate}=1/2, \text{ gaussian}}$ and $C/N|_{QPSK, \text{code rate}=3/4, \text{ gaussian}}$) match quite well with Table 2.3. For Ricean and Rayleigh channels, the requirements for C/N are higher as there are more interferences.

In this project, the configuration of 2k, QPSK, $1/2$ code rate and $1/4$ guard interval is used as it is a commercially available service in Singapore.

2.3.6 Some Popular Propagation Models

Unlike wired channels, which are stationary and predictable, radio channels of wireless communication are extremely random and difficult to analyse. The mechanism behind electromagnetic wave propagation are diverse, but can be generally attributed to reflection, diffraction and scattering. Propagation models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation are useful in estimating the radio coverage area of a transmitter. Two very popular models (Okumura Hata Model and Walfisch and Bertoni model) were studied. Unfortunately, both models did not take clutter loss into consideration.

2.3.6.1 Okumura Hata Model [6]

The original Hata model was introduced in 1980 by Masaharu Hata [6]. The limitation of Hata models are limited path length and frequency range. The Hata equation for propagation loss in urban area is [6]:

$$L_p = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) * \log(d) \dots\dots\dots(2.15)$$

For medium to small city:

$$a(h_m) = (1.1 \log(f) - 0.7) * h_m - (1.56 \log(f) - 0.8) \dots\dots\dots(2.16)$$

The adjustment for propagation loss in suburban area is:

$$L_{ps} = L_p(urban\ area) - 2 * (\log(f / 28))^2 - 5.4 \dots\dots\dots(2.17)$$

The adjustment for propagation loss in open area is:

$$L_{po} = L_p(\text{urban area}) - 4.78(\log(f))^2 + 18.33\log(f) - 40.94 \quad \dots(2.18)$$

Where

h_m is the height of the mobile or receiver in meter

h_b is the base station height in meter

f is the frequency in MHz and

d is the distance in km

Take note that the clutter loss is not taken into detail consideration in this case.

Part of the aim for this project is to characterise the clutter loss using fish-eye photos.

2.3.6.2 Walfisch and Bertoni model [9]

This is a model developed by Walfisch and Bertoni, which considers the impact of rooftops and building height by using diffraction to predict average signal strength at street level [9].

In Bertoni model, the rows or blocks of building is viewed as diffraction cylinders lying on the earth. By assuming that the building as absorbing screens, the propagation process reduces to multiple forward diffraction through a series of screen [9]. Fig 2.17 shows the various ray paths travel to the receiver in the present of buildings.

Fig 2.17 Various ray paths for UHF propagation in presence of buildings

$$L_{ex} = 57.1 + A + \log f_c + 18 \log R_k - 18 \log H - 18 \log \left[1 - \frac{R_k^2}{17H} \right] \quad \text{.....(2.19)}$$

$$A = 5 \log \left[\left(\frac{d}{2} \right)^2 + (h - h_m)^2 \right] - 9 \log d + 20 \log \{ \tan^{-1} [2(h - h_m) / d] \} \quad \text{.....(2.20)}$$

The overall path loss, L_p can be found by adding L_{ex} to the free space loss L_o for isotropic antennas. Received signal strength can be found by subtracting L_p from the radiated power plus antenna gain in dB . Again, the clutter loss is not specified. It gives this project a motivation to look into how the environment contributes to the clutter loss.

2.3.7 ITU-R specification of clutter loss [21]

Environment condition, e.g. buildings, vegetation etc can contribute to addition diffraction losses on the ground [21]. This ITU-R model, the additional loss due to protection from local clutter is given by the expression [21]:

$$A_h = 10.25 x e^{-d_k} \left(1 - \tanh \left[6 \left(\frac{h}{h_a} - 0.625 \right) \right] \right) - 0.33 \quad \text{.....(2.21)}$$

Where

d_k is the distance (km) from nominal clutter point to the antenna

h is the antenna height (m) above local ground level

h_a is the nominal clutter height (m) above local ground level.

ITU-R also provides a table for different category of clutters:

Table 2.6 Category of clutters

Category	Nominal height, h_a (m)	Nominal distance, d_k (km)
Open	0	--
Rural (sparse vegetation and occasional isolated buildings)	4	0.1
Coniferous trees	20	0.05
Deciduous trees	15	0.05
Suburban	9	0.025
Urban	20	0.02
Dense urban	25	0.02

Singapore is a country where the land area is very small and congested with many tall buildings. Take the situation of public housing estate in Singapore, the building is easily 20 to 30 stories, which is about 50 to 75m, it does not feed into any category mentioned above. Hence, a study on the clutter loss in Singapore is proposed.

Chapter Three - Quality of Service (QoS)

Unlike analogue television, where a broadcast can often be viewed even under adverse conditions, such as a heavy "snow" effect, a digital receiver either manages to recognise the digital data streams, or it doesn't. If it does, you get a "perfect" picture. If it doesn't, there is no TV reception. This is also commonly known as "cliff effect". In some marginal cases "pixelation" occurs (blocky squares similar to that used to deliberately mask faces on the news). This occurs when the receiver can decode some part of the data but not others. The severity depends on the broadcast method used.

Chester 97 [1] (also in ETSI EN300744 [10]) defined the required C/N ratios for BER threshold of 2×10^{-4} after Viterbi decoder. Above this BER threshold would be Quasi Error Free (QEF) after Reed Solomon decoder. This BER threshold is mainly used for computer simulation purpose. A study on the field measurement was carried out in several typical locations in Singapore to verify the parameters (including signal strength, MER etc) to decode an error free video.

In this project, the threshold level is defined as the receiver signal power level or signal to noise (S/N) ratio when the picture started to pixelate - the marginal case.

3.1 Definition of MER

A new QoS parameter, which has become popular recently, known as Modulation Error Ratio (MER) will be defined. It represents the overall degree of impairment of the signal, regardless of the nature of impairment(s) affecting the signal. It was defined by the DVB Measurement Group [22]. The overall net effect of the ability to decode the modulated signal can be determined by MER measurement with a single performance target value.

MER is defined as the sum of squares of the magnitudes of the ideal symbol vectors divided by the sum of the squares of the magnitudes of the error vectors [22], [23].

Fig 3.1 Constellation of 64QAM

Fig 3.1 Error vector

$$MER = 10 \log_{10} \left(\frac{\sum_{j=1}^N (I_j^2 + Q_j^2)}{\sum_{j=1}^N (\partial I_j^2 + \partial Q_j^2)} \right) \text{ dB} \dots\dots\dots(3.1)$$

Where N is the number of symbols over which the measurement is taken. Although the figure, N is not part of the definition of MER, it should be as large as possible. Some manufacturers recommend N should be at least 10 times the number of points in the constellation [23].

The Tektronix MTM400 employs 512 sample (or N=512) to calculate MER.

3.2 Equipmental setup

In this project, the signal strength and MER are the main parameters that are of interest. The main equipment used is a Rohde and Schwarz’s EFA. Fig 3.3 shows the experimental setup of the measurement. In the later part of this project, the PixelMetrix’s DVStation is used instead of EFA since the DVStation is able to give log data and it can present several parameters in a single screen.

Fig 3.3 Measurement equipment setup

The signal is received by the antenna via an attenuator. The attenuation is normally set to 0dB unless we are measuring the minimum receiver input power and MER. In this case, the attenuator will be varied until the point where the set-top-box (STB) is just able to decode a good picture. The splitter is used to split the signal into two paths. One path is passed to a STB to decode pictures; the other path is passed to the EFA for measuring receiver input voltage and MER. As the splitter introduced loss, an amplifier is inserted to compensate for this loss. The personal computer (PC) is used as a data

logger. The video output from the PC is then combined with the signal decoded by the set-top-box using a quad split. The final video signal is passed into a video cassette recorder (VCR) for recording before passing the signal to the TV monitor.

This set of equipment is installed in a van, which has an antenna mast that can be extended up to 10m above the ground (refer to Fig 3.4) to conduct measurement. In this way, the signal strength at different height can also be measured and the height vs gain/loss characteristics can be obtained.

Fig 3.4 Measurement van

3.3 Measurement results

3.3.1 Measurement for QoS

Measurements were conducted in several selected representative locations with different clutter environments for the minimum receiver input voltage and MER of a decodable signal using the R&S's EFA. The Minimum receiver input voltage and MER are defined at the point, which the maximum attenuation are added to the received signal and it is still able to decoded error free picture for **at least 1 min**. The results are tabulated in Table 3.1a to Table 3.1c.

To minimize the effect of spatial variation of received signals (fading), the vehicle is moved forwards or backwards very slowly so that the received signal is maximum. This is to ensure that measurements are repeatable. Over a small vehicle movement the signal could change from a maximum value to a low level several dBs lower. It should be noted that the DVB-T system configuration is 2k, QPSK, $\frac{1}{2}$ code rate and $\frac{1}{4}$ guard interval, which is the configuration for TVMobile network in Singapore.

The receiving antenna used in this project has measured gain of 5 dBi and cable loss of 2.04dB (for the whole length of cable) at Ch37 frequency (602MHz). Using the formula [24]:

$$E(\text{dB}\mu\text{V/m}) = \text{Power}(\text{dB}\mu\text{V}) - \text{Gr}(\text{dBi}) + 20\log_{10} F(\text{MHz}) - 31.8 \dots\dots\dots(3.1)$$

The measured field strength, $E(\text{dB}\mu\text{V/m})$ at the various locations are tabulated in Table 3.1a to Table 3.1c. Table 3.1a is the minimum receiver input voltage and MER required to receive an error free picture at the open area and low rise

buildings (2 to 3 storey buildings). Table 3.1b is the minimum receiver input voltage and MER required to receive an error free picture at the Public Housing Estates (Housing Development Board, HDB). Table 3.1c is the minimum receiver input voltage and MER required to receive an error free picture at the Central Business District and indoor.

Table 3.1a minimum receiver input voltage and MER required for QPSK, 2k, 1/4g, 1/2r, at 602MHz (Ch37) for open to low rise area.
(Appendix B-1 shows the locations on Singapore map)

S/no	Location	Minimum receiver input voltage (dBμV)	Equivalent min field strength (dBμV/m)	Minimum MER (dB)	Location classification
1	Tuas Lamp Post 12	23.0	43.83	3.7	Open area
2	Juying Primary School, at Gate 2	25.6	46.43	3.8	Low rise beside public housing
3	Mosque Street, opposite car park Lot 40/40A	28.7	49.53	6	Low rise 2 to 3 stories
4	Bournemouth Road, opposite Unit 11	25	45.83	5.1	Low rise 2 to 3 stories
5	Mandai, Upper Seletar Reservoir	20	40.83	5.3	Open area

Table 3.1b minimum receiver input voltage and MER required for QPSK, 2k, 1/4g, 1/2r, at 602MHz (Ch37) for Public Housing Estate.
(Appendix B-2 shows the locations on Singapore map)

S/no	Location	Minimum receiver input voltage (dB μ V)	Equivalent min field strength (dB μ V/m)	Minimum MER (dB)
1	Cashew Road	23.6	44.43	3.8
2	Toh Yi, car park Lot 323	23.3	44.13	3.7
3	Blk345, car park Lot23 Jurong East	23.2	44.03	5.7
4	Blk306, car park Lot16, Jurong East Street 32	20.5	41.33	4.4
5	Blk173, car park Lot139 Bt Batok West Ave 8	20.7	41.53	4.6

Table 3.1c minimum receiver input voltage and MER required for QPSK, 2k, 1/4g, 1/2r, at 602MHz (Ch37) for Central Business District (very high and dense buildings) and indoor.
(Appendix B-3 shows the locations on Singapore map)

S/no	Location	Minimum receiver input voltage (dB μ V)	Equivalent min field strength (dB μ V/m)	Minimum MER (dB)	Location classification
1	Sungei Road car park Lot 52	24.6	45.43	4.0	Central Business District
2	Dalhousie Obelisk, Victoria Theatre	25.8	46.63	4.7	Central Business District
3	NTU, indoor	42	62.83	7	Indoor

Measurement in the public housing (HDB) areas in Table 3.1b refers to clutter with buildings of average 12 to 16 stories (or 26m to 48m). It can be observed that for indoor and outdoor propagation (refer to Table 3.1c), the required MER and receiver input voltage values are quite different. Hence, there is a need to separate these two cases. For this project, only outdoor measurements are considered. These propagation measurements consider the received power and they have different modulation parameters for the DVB-T system.

From the result of the preceding tables, to achieve an error free fixed out door decoding of QPSK, 2k, 1/2r, 1/4g at 602 MHz, the minimum receiver input voltage ranges from 20 dBμV to 28.7dBμV (or field strength from 40.83 dBμV to 49.53 dBμV/m) and min MER is 6dB.

The equivalent minimum field strength at receiving location (dBμV/m) is worked out using the method detailed in Chester 97. As the receiving antenna is omni directional, Rayleigh channel is assumed. The C/N requirement for Ch37 (QPSK, 2k, 1/2r, 1/4g) is thus 5.4dB, (Please note that C/N can be obtained from Table 2.3)

Chester 97 recommended the receiver noise figure to be 7dB.

Hence, the receiver noise input power, P_n [1]:

$$\begin{aligned} P_n &= KTB + NF \dots\dots\dots(3.2) \\ &= (1.38 \times 10^{-23}) (290) (7.61 \times 10^6) + 7 \\ &= 3.0455 \times 10^{-14} + 7 \\ &= -135.2 \text{ dBW} \\ &= -128.2 \text{ dBW} \end{aligned}$$

Hence,

$$\begin{aligned} P_{\text{min},37}, \text{ minimum receiver input power (Ch37)} &= C/N + P_n \dots\dots\dots(3.3) \\ &= 5.4 - 128.2 \\ &= -122.8 \text{ dBW} \end{aligned}$$

$$\text{Minimum power flux density, } \Phi_{\text{min}} \text{ (dBW/m}^2\text{)} = P_{\text{min}} - A_a + L_f, \dots\dots\dots(3.4)$$

where

$$A_a = -13.3 \text{ dBm}^2 \text{ (Effective antenna aperture: as given in Chester 97 for Omni direction antenna)}$$

$$L_f = 0 \text{ dB (it is the feeder loss. As given in Chester 97, it is assumed to have no feeder loss)}$$

$$\begin{aligned} \Phi_{\text{min},37} &= P_{\text{min},37} - A_a + L_f \dots\dots\dots(3.5) \\ &= -122.8 + 13.3 \\ &= -109.5 \text{ dBW} \end{aligned}$$

$$\begin{aligned} E_{\text{min}} &= \Phi_{\text{min}} + 120 + 10 \log_{10} (120\pi) \text{ (the equivalent minimum field strength at receiving place, dB}\mu\text{V/m)} \dots\dots\dots(3.6) \\ &= \Phi_{\text{min}} + 145.8 \end{aligned}$$

$$\begin{aligned} E_{\text{min},37} &= \Phi_{\text{min},37} + 145.8 \\ &= -109.5 + 145.8 \\ &= \mathbf{36.3 \text{ dB}\mu\text{V/m}} \end{aligned}$$

A location correction factor is calculated by the formula [1]:

$$C_l = \mu \times \sigma$$

Where μ is the distribution factor, being 0.52 for 70% and 1.64 for 95%)

σ is the standard deviation, which is 5.5dB as recommended by Chester 97.

For planning purpose, μ shall be taken as 95%. Take note that Ch37 was targeted to be covered 99% in Singapore island-wide.

$$E_{\text{med}} = E_{\text{min}} + C_1 \dots\dots\dots(3.7)$$

$$\begin{aligned} E_{\text{med},37} &= E_{\text{min},37} + C_1 \\ &= 36.3 + 5.5 \times 1.64 \\ &= 45.32 \text{ dB}\mu\text{V/m} \end{aligned}$$

The data provided in Chester 97 referred to frequency of 500MHz. Ch37 being 602 MHz would need some conversion:

Conversion from 500MHz to 602MHz:

$$\begin{aligned} \text{Antenna Gain conversion} &= 10 \log_{10}(602/500) = 0.81\text{dB} \\ \text{Min. median equivalent} &= 20 \log_{10}(602/500) = 1.62\text{dB} \\ \text{Field strength conversion} & \end{aligned}$$

$$\text{Hence, } E_{\text{med},37} = 45.32 + 0.81 + 1.62 = 47.75 \text{ dB}\mu\text{V/m}$$

Chester 97 recommended 3dB margin to be added, and the final $E_{\text{med},37}[1]$:

$$E_{\text{med},37} = 50.75 \text{ dB}\mu\text{V/m}$$

Take note that the measured minimum field strength is 49.53 dB μ V/m. Hence, although the measured field strength is within the recommended field strength in Chester 97, there is not much margin that the system is able to tolerate. Moreover, the QoS is based on visual assessment only, any error happen in the audio is not taken into consideration. In certain occasion, it is hard to judge picture quality by naked eyes. For example, a problem with the insufficient bit rates (which is not a transmission issue) could be mistaken as insufficient field

strength. Hence, in the later part of the project, a PixelMetrix's DVStation is used instead of EFA. PixelMetrix's DVStation is able to log all the parameter so that all the error (or uncorrected packets) can be recorded for future analysis.

The minimum receiver input voltage and MER are also measured for different QPSK configurations on another occasion. The measurement van is parked at Jubilee Road beside AYE (Ayer Rajah Expressway), where there is very high volume of traffic. The vehicle speed on AYE is typically 80km/h. As this measurement involved some network configuration changes at the DVB-T multiplexer, which is an operating service, the logistic arrangement is very complicated. Any change in the network configuration can only be done after mid-night, when the TVMobile network shut down. The results for different QPSK configurations are shown in Table 3.2.

Table 3.2 Minimum receiver input voltage and minimum MER required for different configuration of QPSK modes.

S/no	Configuration		Min. Receiver input voltage (dB μ V) for 2k	Min. Receiver input voltage (dB μ V) for 8k	Min. MER (dB) for 2k	Min. MER (dB) for 8k
1	QPSK, $\frac{1}{2}$ code rate	1/4 g	25.4	25.4	5.5	3.5
2		1/8 g	25.1	25.7	5.5	3.7
3		1/16 g	24.8	24.4	5.5	3.4
4		1/32 g	24.5	25.7	5.2	3.8
5	QPSK, $\frac{3}{4}$ code rate	1/4 g	29.1	29.7	7.7	5.4
6		1/8 g	29.9	30.3	8.7	6.0
7		1/16 g	29.7	31.2	8.1	6.5
8		1/32 g	31.0	30.7	8.2	6.8
9	QPSK, $\frac{7}{8}$ code rate	1/4 g	32.8	33.5	10.4	8.1
10		1/8 g	33.6	33.5	10.5	8.0
11		1/16 g	33.9	33.9	10.9	8.8
12		1/32 g	35.7	33.8	10.6	8.4

It can be seen from the above table (Table 3.2) that the minimum receiver input voltage required for 2k and 8k modes are fairly similar for fixed reception (or stationary measurements). However, there is an improvement of about 2dB in MER if 8k mode is chosen as compared to 2k mode. This implies that one cannot use signal strength as the only parameter to judge the capability of decoding good video. It is also suggested that as far as possible, 8k mode should be selected for fixed services. Another advantage of choosing 8k mode is that the synchronisation timing in Single Frequency Network (SFN) will be easier as the symbol duration is 4 times longer than 2k mode, which results in longer guard interval. The trade-off in selecting 8k mode over 2k mode is the capability to handle doppler effect. For 8k mode, the carrier separation is closer as compared to 2k mode, it will have greater impact on mobile receivers. The results of tests of mobile reception using 8k mode on TVMobile network with the van driving at about 60 km/h were not very satisfactory. There was hardly any area that a good decodable picture could be received as compared to 2k mode. For 2k, about 99% of the area in Singapore can decode with error free pictures in the moving van. The result in Table 3.2 also suggested that there might be some other parameters, which affect the decodability of the DVB-T signal on top of just the signal strength. For example, compare the minimum criteria for the two configurations listed in Table 3.3:

Table 3.3 Comparison of two different configurations

	Min. Receiver input voltage (dBμV)	Min. MER (dB)
QPSK 1/2r 1/4g, 2k	25.4	5.5
QPSK 1/2r 1/4g, 8k	25.4	3.5

The two different configurations might need the same receiver input voltage to decode good picture, but the 2k mode needs a higher MER than the 8k mode.

A separate measurement was done using PixelMetrix's DVStation.

The setup in Fig 3.3 was modified to that in Fig 3.5.

Fig 3.5 Equipment setup for DVStation and QMM

The advantage of the newer DVStation as compared to EFA is that it is able to display many parameters (e.g. Signal power, SNR, MER uncorrected packet etc) into one screen and all the data is logged in the PC. Therefore, any relation between these parameters with the decodable of the pictures can be investigated. Here, it is suggested to use the uncorrected packet as the guide to good signal quality as compared to just used the decoded picture mentioned previously. The reason being that the uncorrected packets can hit anywhere in

the video, audio or headers portion, one might not be able to know that there exists a problem by just looking at the picture.

Some attenuation of the signal is deliberately introduced to make the situation worst. Signal measurement is done in three typical locations in Singapore:

Location A- Open car park at Old Jurong Road, Car park Lot number 533 (Appendix B-4 shows Location A on Singapore map). At this location, we are fortunate to receive Ch29 (538MHz, 8k, 16QAM, $\frac{3}{4}$ code rate, $\frac{1}{8}$ guard interval) in addition to TVMobile (Ch37). This is due to the closer distance from the transmission centre. Ch29 is a test channel only transmitted at the main transmitting station at Bukit Batok. This is also the main transmitting station for Ch37. A snap shot of PixelMetrix's DVStation is captured in Fig 3.6a (for Ch37) and Fig 3.7a (for Ch29). The equipment was left to acquire data for a while and it is represented in Fig 3.6b (for Ch37) and Fig 3.7b (for Ch29).

A snap shot of the equipment was captured in Fig 3.8a beside Blk 243, Jurong East Street 24 (**Location B**) (Appendix B-4 shows Location B on Singapore map). This is the public housing estate, which about 75% of residents in Singapore are staying in this environment. Surrounding building height is about 16 stories (or 48m). The data acquired was represented in Fig 3.8b.

A snap shot of the equipment is captured in Fig 3.9a beside Subordinate Court (**Location C**) (Appendix B-4 shows Location C on Singapore map). This represents the edge of Singapore's Central Business District in which the

surrounding buildings are typically more than 30 stories (or 90m). The data acquired is represented in Fig 3.9b.

In both the figures mentioned in the preceding figures, the top left quadrant is the spectrum of the 8MHz bandwidth. The channel number and the received power (dBm) are indicated. The carrier confidence showed any interference on individual carrier. A Level 7 in this chart means no interference to that particular carrier.

The top right quadrant is the constellation diagram with various parameters (frequency, mode, modulation, SNR, MER BER, uncorrected packet (RS Uncorrected)). The uncorrected packet is an interesting parameter, all the data will be corrupted if it hit the header of the DVB stream.

The bottom left quadrant is the subjective picture quality monitor provided by Tandberg's Quality Monitor Module (QMM). Unfortunately, it sometime gives the wrong indication. For example, it cannot differentiate a still picture from frozen pictures, which is due to decoding issue. Hence, the QMM will not be studied for this project. The bottom right column is the impulse response of the measured channel. DVB-T is able to work under some echoes, as long as all the impulse responses are kept within the tolerable limit (that is the guard interval).

Location A – Open Car Park Lot 533 at Old Jurong Road (Ch37)

The parameters recording at Old Jurong Road Car Park Lot 533 is presented in Fig 3.6b, showing the time series for receiver input power, BER (Pre- and Post-Veterbi), MER, SNR, frequency offset and the number of uncorrected packets.

Note that for the bit error rate (BER) in the table (Pre- and Post-Veterbi), 00E00 BER means there is no error.

Fig 3.6a Snap shot of PixelMetrix's DVStation at Old Jurong Car Park on Ch37

Fig 3.6b Ch37 parameter at Old Jurong Road Car Park Lot 533

Location A – Open Car Park Lot 533 at Old Jurong Road (Ch29)

The snap shot from the PixelMetrix’s DVStation for Old Jurong Road Car Park for Channel 29 is shown in the following figure (Fig 3.7a), together with the time series for the QoS parameters (Fig 3.7b).

Fig 3.7a Snap shot of PixelMetrix’s DVStation at Old Jurong Car Park on Ch29

Fig 3.7b Ch29 parameter at Old Jurong Road Car Park Lot 533

Location B (HDB) – Beside Blk 243, Jurong East Street 24 (Ch37)

The snap shot from the PixelMetrix’s DVStation for Jurong East Street 24 Channel 37 is shown in the following figure (Fig 3.8a), together with the time series for the QoS parameters (Fig 3.8b).

Fig 3.8a Snap shot of PixelMetrix’s DVStation at Jurong East Street 24 on Ch37

Fig 3.8b Ch37 signal parameter at Jurong East Street 24

Location C – Beside the Sub-ordinate Court at the Edge of the Central Business District (Ch37)

The snap shot from the PixelMetrix's DVStation besides the Subordinate Courts Channel 37 is shown in the following figure (Fig 3.9a), together with the time series for the QoS parameters (Fig 3.9b).

Fig 3.9a Snap shot of PixelMetrix's DVStation at Subordinate Court on Ch37

Fig 3.9b Ch37 signal parameter at Subordinate Court

From the impulse response windows shown in Fig 3.6a, 3.8a and 3.9a, for the three locations, all the multipath signals received at the receiving antenna are within the guard interval of $56\mu\text{s}$ (or $56 \times 10^{-6} \times 3 \times 10^8 = 16.8\text{km}$). The worst case has been at Location C (refer to Fig 3.9a), where there are many tall buildings, which causes many reflected signal in the Central Business District. The longest delay is about 8km away (which is corresponding to $26.67\mu\text{sec}$). It is observed that the trend of BER (post Viterbi) do not always follow the BER (pre Viterbi). There are times, when the BER (pre Viterbi) is reducing but the BER (post Viterbi) is still going up (please refer to Fig 3.8b as an example). The reason being that the BER(pre Viterbi) recorded is the average data for 1sec. If there is an impulse noise (lasted 1ms), the effect will not be very obvious, but the error caused by this impulse noise is still exist and shown in BER (post Viterbi).

Example:

Ch37's system bit rate is 4.98Mbit/s, environment noise causes BER(pre Viterbi) to be 1×10^{-2} . An impulse noise lasted 1ms and it make the instantaneous BER(pre Viterbi) to 1×10^{-1} . The effect of impulse noise after average will make the BER(pre Viterbi) to 1×10^{-4} ($= 1 \times 10^{-1} \times 1\text{ms}/1\text{s}$). The environmental noise (BER(pre Viterbi) = 1×10^{-2}) in this case overwhelmed the impulse noise. Hence, the BER(pre Viterbi) do not always shows the effect of impulse noise.

3.3.2 Improvement in Experimental Procedure

The results of the measurement presented so far in this chapter have some short comings. It is difficult to observe any relation between one QoS parameter and another. On top of this, the attenuator introduces some impulse noise during transition and hence, it is decided to improve the procedure. After every step of change in attenuation (attenuation resolution was set to 2dB), the system is left to acquire the data for 5 min. The data acquired during the first half of a minute is not used for analysis; the period can be regarded as the stabilisation period. The system is then left to acquire data for 4 minutes and the average data (receiver input power, BER, MER etc) is calculated. The data during the last half a minute before a change of another attenuation is not used for analysis too. This is to eliminate any inconsistency between the DVStation's clock and the PC's clock. The system is first attenuated until the decoding is not possible. Thereafter, the attenuation is decreased by 2 dB step until a complete "good" signal can still be decoded. After the previous round of measurements, it is decided that the data of BER (post Viterbi) is not necessary as it vary between receivers, the data of frequency offset (kHz) is left out too as it do not have major impact due to static measurement only. During the time when the new improved measurement procedure is implemented, MediaCorp changes Ch37's code rate from 1/2 to 2/3. The aim is to increase the capacity of the network from 4.98Mbit/s to 6.64Mbit/s. During the 4 min (or 240 sec) of stablised duration, a signal is considered "good" if there are less than 2.4 sec of error, this is correspond to 99% of the

time, the equipment is able to decode good picture as recommended by Chester 97. As the equipment acquired data at 1 sec interval, there should be less than 3 spots (or 3 sec) in the “uncorrected packets” charts for the duration of 4 min.

3.3.2.1 Reference QoS Measurements (Direct From Transmitter)

It is always useful to have a good set of measurements for reference. The new equipment set-up is directly connected by a high quality co-axial cable to a coupled port of the transmitter in the transmitter room and the new procedure is employed to acquire QoS parameters for Ch29 and Ch37. The results are shown in the following table (Table 3.4) and figures (Fig 3.10 and Fig 3.11).

Fig 3.10 QoS parameter directly acquired from Ch37 transmitter

Fig 3.11 QoS parameter directly acquired from Ch29 transmitter

From Fig 3.10 and Fig 3.11, the QoS parameter measured directly from the transmitters can be tabulated as below:

Table 3.4 Summary of Ch29 and Ch37 QoS parameters measured directly at the transmitter

	Ch29 16QAM, 8k, 3/4r, 1/8g	Ch37 QPSK, 2k, 2/3r, 1/4g
Minimum receiver input power	-80.21 dBm	-80dBm
Minimum SNR	0.0959	0.0256
Minimum MER	12.91dB	7.91dB
Minimum BER (pre Viterbi)	14.79dB	8.77dB

Table 3.4 shows that Ch37 needs a higher signal-to-noise ratio (SNR) to decode good picture. This does not seem to be quite right as Ch37 is QPSK modulated and Ch29 is 16QAM modulated. Ch37 is supposed to be a more robust system. On investigation, it is found that there are multi-path signals entering the measuring receiver in addition to the signal conducted directly from the transmitter; there is another radiated signal from the transmitting antenna outside. Looking at the impulse responses (refer to Fig 3.12 and Fig 3.13) of the two channels, despite of using a very high quality (RG 213, double shielded) cable, a second multi-path signal is detected for Ch37.

However the Ch29 transmitter is located in a better shielded room so that the signal leaking into the transmitter room from the transmitter room is lower. The Ch37 transmitter is located in an older room, which does not have good shielding from the measurement room.

Fig 3.12 Impulse response of Ch37 measured directly at the transmitter

Fig 3.13 Impulse response of Ch29 measured directly at the transmitter

Fig 3.14 Measurement equipment picking up Ch37 interference

3.3.2.2 Measurements for representative locations

Again, several locations are chosen. These are listed in Table 3.5. Note that Ch29 cannot be received at all the locations as it is not a full network (only one transmitter at Bukit Batok). The results at various locations are shown in the following pages.

Table 3.5 Locations where the new measurement is done

(Appendix B-5 shows the locations on Singapore map)

S/no	Locations	Ch37, QPSK, 2k, 2/3r, 1/4g	Ch29, 16QAM, 8k, 3/4r, 1/8g	Clutter classification
1	NTU S2 Lot 29	√	X	Open
2	River Valley Lot 73	√	X	CBD
3	Bugis	√	√	CBD
4	Subordinate Court Lot 85	√	√	CBD
5	Bishan Lot 25A	√	X	HDB
6	Toh Yi Lot 307	√	√	HDB
7	Toh Yi Lot 670	√	√	HDB

Fig 3.15 Ch37 parameter at NTU S2 Lot 29

Fig 3.16 Ch37 parameter at River Valley Lot 37

Fig 3.17 Ch37 parameter at Bugis

Fig 3.18 Ch37 parameter at Subordinate Court Lot 85

Fig 3.19 Ch37 parameter at Bishan Lot 25A

Fig 3.20 Ch37 parameter at Toh Yi Lot 307

Fig 3.21 Ch37 parameter at Toh Yi Lot 670

Nanyang Technological University

Fig 3.22 Ch29 parameter at Bugis

Fig 3.23 Ch29 parameter at Subordinate Court Lot 85

As can be seen from Fig 3.23, Ch29 cannot be decoded at the Subordinate Court as the equipment detected more than 3 sec of error (14:09:30hr to 14:14:30hr) in all the 4 min of time slots..

Fig 3.24 Ch29 parameter at Toh Yi Lot 307

Fig 3.25 Ch29 parameter at Toh Yi Lot 607

The summary of Fig 3.15 to Fig 3.25 is tabulated in Table 3.6.

Table 3.6 Summary of Ch37 and Ch29 QoS parameter
(Appendix B-5 shows the locations on Singapore map)

Locations	Minimum receiver input power (dBm)	Minimum BER (pre Viterbi)	Minimum MER (dB)	Minimum SNR (dB)
Ch37				
NTU S2 Lot 29	-78.13	0.0302	7.50	8.40
River Valley Lot73	-77.01	0.033	8.68	9.54
Bugis	-73.18	0.0347	8.63	9.50
Subordinate Court Lot 85	-72.42	0.0163	11.50	12.37
Bishan Lot 25A	-77.0	0.0469	7.57	8.43
Toh Yi Lot 307	-76.63	0.0164	10.22	11.08
Toh Yi Lot 670	-76.82	0.0446	8.53	9.40
Ch29				
Bugis	-76.04	0.0196	14.80	18.47
Subordinate Court Lot 85	Not decodable	Not decodable	Not decodable	Not decodable
Toh Yi Lot 307	-73.77	0.00251	17.43	19.33
Toh Yi Lot 670	-73.61	0.0179	15.87	17.76

3.3.2.3 Comparing measurement with Chester 97's recommendation

The procedure of Chester 97 is adopted to work out the equivalent minimum field strength at receiving place (dBμV/m).

As the receiving antenna is omni directional, Rayleigh channel is assumed.

The C/N requirement for Ch37 (QPSK, 2k, 2/3r, 1/4g) is thus 8.4dB, and the C/N requirement of Ch29 (16QAM, 8k, 3/4r, 1/8g) is 16.7dB. (Please note that C/N can be obtained from Table 2.3)

Chester 97 recommended the receiver noise figure to be 7dB.

Hence, the receiver noise input power, P_n :

$$\begin{aligned}
 P_n &= KTB + NF \\
 &= (1.38 \times 10^{-23}) (290) (7.61 \times 10^6) + 7 \\
 &= 3.0455 \times 10^{-14} + 7 \\
 &= -135.2 \text{ dBW} \\
 &= -128.2 \text{ dBW}
 \end{aligned}$$

Hence,

$$\begin{aligned}
 P_{\text{min},37}, \text{ minimum receiver input power (Ch37)} &= C/N + P_n = 8.4 - 128.2 \\
 &= -119.8 \text{ dBW}
 \end{aligned}$$

$$\begin{aligned}
 P_{\text{min},29}, \text{ minimum receiver input power (Ch29)} &= C/N + P_n \\
 &= 16.7 - 128.2 \\
 &= -111.5 \text{ dBW}
 \end{aligned}$$

$$\text{Minimum power flux density , } \Phi_{\text{min}} (\text{dBW/m}^2) = P_{\text{min}} - A_a + L_f, \text{ where}$$

$$\begin{aligned}
 A_a &= -13.3 \text{ dBm}^2 \text{ (Effective antenna aperture: as given in Chester 97 for} \\
 &\quad \text{Omni direction antenna)}
 \end{aligned}$$

$L_f = 0$ dB (it is the feeder loss. As given in Chester 97, it is assumed to have no feeder loss)

$$\begin{aligned}\Phi_{\min,37} &= P_{\min,37} - A_a + L_f, \\ &= -119.8 + 13.3 \\ &= -106.5 \text{ dBW}\end{aligned}$$

$$\begin{aligned}\Phi_{\min,29} &= P_{\min,29} - A_a + L_f, \\ &= -111.5 + 13.3 \\ &= -98.2 \text{ dBW}\end{aligned}$$

$E_{\min} = \Phi_{\min} + 120 + 10\log_{10}(120\pi)$ (the equivalent minimum field strength at receiving place, dB μ V/m)

$$= \Phi_{\min} + 145.8$$

$$\begin{aligned}E_{\min,37} &= \Phi_{\min,37} + 145.8 \\ &= -106.5 + 145.8 \\ &= \mathbf{39.3 \text{ dB}\mu\text{V/m}}\end{aligned}$$

$$\begin{aligned}E_{\min,29} &= \Phi_{\min,29} + 145.8 \\ &= -98.2 + 145.8 \\ &= \mathbf{47.6 \text{ dB}\mu\text{V/m}}\end{aligned}$$

A location correction factor is calculated by the formula:

$$C_l = \mu \times \sigma$$

Where μ is the distribution factor, being 0.52 for 70% and 1.64 for 95%)

σ is the standard deviation, which is 5.5dB as recommended by Chester 97.

For planning purpose, μ shall be taken as 95%. Take note that Ch37 is targeted to be covered 99% in Singapore island-wide.

$$E_{\text{med}} = E_{\text{min}} + C_1$$

$$\begin{aligned} E_{\text{med},37} &= E_{\text{min},37} + C_1 \\ &= 39.3 + 5.5 \times 1.64 \\ &= 48.32 \text{ dB}\mu\text{V/m} \end{aligned}$$

$$\begin{aligned} E_{\text{med},29} &= E_{\text{min},29} + C_1 \\ &= 47.6 + 5.5 \times 1.64 \\ &= 56.62 \text{ dB}\mu\text{V/m} \end{aligned}$$

The data provided in Chester 97 referred to frequency of 500MHz. Ch37 being 602 MHz and Ch29 being 538MHz would need some conversion:

Conversion from 500MHz to 602MHz:

$$\text{Antenna Gain conversion} = 10 \log_{10}(602/500) = 0.81\text{dB}$$

$$\text{Min. median equivalent} = 20 \log_{10}(602/500) = 1.62\text{dB}$$

Field strength conversion

$$\text{Hence, } E_{\text{med},37} = 48.32 + 0.81 + 1.62 = 50.75 \text{ dB}\mu\text{V/m}$$

Chester 97 recommended 3dB margin to be added, and the final $E_{\text{med},37}$:

$$\mathbf{E_{\text{med},37} = 53.75 \text{ dB}\mu\text{V/m}}$$

Conversion from 500MHz to 538MHz:

$$\text{Antenna Gain conversion} = 10 \log_{10}(538/500) = 0.32\text{dB}$$

$$\text{Min. median equivalent} = 20 \log_{10}(538/500) = 0.64\text{dB}$$

Field strength conversion

$$\text{Hence, } E_{\text{med},29} = 56.62 + 0.32 + 0.64 = 57.58 \text{ dB}\mu\text{V/m}$$

Chester 97 recommended 3dB margin to be added, and the final $E_{\text{med},37}$:

$$E_{\text{med},29} = 60.58 \text{ dB}\mu\text{V/m}$$

The receiving antenna used in this project is measured to have 5 dBi gain and 2.04dB cable loss (for the whole length of cable) at Ch37 frequency (602MHz) and 4.5 dBi gain and 1.90dB cable loss (for the whole length of cable) at Ch29 (538MHz). Using the formula:

$$E(\text{dB}\mu\text{V/m}) = \text{Power (dBm)} - \text{Gr (dBi)} + 20\log_{10} F \text{ (MHz)} + 77.2$$

We are able to calculate the measured field strength, E(dBμV/m) at the 11 locations in Table 3.7.

Table 3.7 Minimum field strength measured at 11 locations

Locations	Measured minimum receiver input power (dBm)	Measured minimum field strength, E(dBμV/m)
Ch37 (602MHz)		
NTU S2 Lot 29	-78.13	51.7
River Valley Lot73	-77.01	52.83
Bugis	-73.18	56.65
Subordinate Court Lot 85	-72.42	57.41
Bishan Lot 25A	-77.0	52.83
Toh Yi Lot 307	-76.63	53.20
Toh Yi Lot 670	-76.82	53.01
Ch29 (538MHz)		
Bugis	-76.04	53.17
Subordinate Court Lot 85	Not decodable	-
Toh Yi Lot 307	-73.77	55.44
Toh Yi Lot 670	-73.61	55.6

Table 3.7 is translated into graphical forms (Fig 3.26 and Fig 3.27).

The measured values are compared with the theoretically calculated minimum median equivalent field strength obtained from Chester 97's recommendation. Separate comparisons are made for Ch29 and Ch37 which employed two different modulation parameters.

Fig 3.26 Ch37: compare measured with Chester 97's field strength

Fig 3.27 Ch29: compare measured with Chester 97's field strength

From Fig 3.26, the measured field strength at the 7 locations are within +3.66dB to -2.09dB from the calculated Chester 97's field strength. Taking into account that Ch37 is a Single Frequency Network (SFN) with 10 transmitters whereas Chester 97's calculation takes care of only single transmitter network. The result in Fig 3.26 shows that in the worst case, additional 3.66dB (round up to 4dB) of implementation margin is required for Ch37, which is covered by SFN. The mean of minimum field strength at the 7 locations is 53.95 dB μ V/m, which is very close to the theoretical calculated value using Chester 97 method (53.75 dB μ V/m). However, for planning purpose, the worst case has to be assumed.

From Fig 3.27, the calculated field strength according to Chester 97's recommendation is consistently higher than the measured field strength with a minimum difference of 4.98dB. Note that Ch29 has only one transmitter in the network and Chester 97's recommendation on the required field strength serves as a very good estimation. Chester 97 includes an implementation margin of 3dB. The calculated and the measured field strength difference is only 1.98dB if we take this into account. On top of this, the attenuation resolution while acquiring the data is 2dB. (Note that it is not useful to reduce to 1dB attenuation resolution as the signal fluctuation can be as high as 3dB.) Hence, this project agreed closely with Chester 97 recommendation for single transmitter network. The mean of minimum field strength at the 3 locations is 54.74 dB μ V/m, which are quite close to all the minimum field strength at all the three locations.

Similarly, the minimum SNR required at various locations for Ch37 and Ch29 were summarised in Fig 3.28 and Fig 3.29.

Fig 3.28 Ch37: compare measured with Chester 97's SNR

Fig 3.29 Ch29: compare measured with Chester 97's SNR

The PixelMetrix DVStation’s SNR is measuring the SNR in the channel and it is equivalent to C/N. When comparing the SNR measured with Chester 97, which specified C/N for Ch37 to be 8.4dB and C/N for Ch29 to be 16.7dB, the measured SNR (or C/N in this case) can be 3.97dB higher for Ch37 and 2.63dB higher for Ch29. The Chester 97’s recommendation does not take into account of the implementation margin associated with a practical channel equalizer, which was included in the measured result. If we take this into account, the measured SNR and theoretically calculated C/N are very close [25].

The MER and BER (pre Viterbi) requirement are presented in the graphical forms (refer to Fig 3.30, Fig 3.31, Fig 3.32 and Fig 3.33).

Fig 3.30 Ch37 minimum MER requirement at various locations

Fig 3.31 Ch29 minimum MER requirement at various locations

Fig 3.32 Ch37 minimum BER (pre Viterbi) requirement at various locations

Fig 3.33Ch29 minimum BER (pre Viterbi) requirement at various locations

For planning purpose, worst case scenario must be assumed and hence, the QoS parameter required for Ch37 (602MHz, QPSK, 2k, 2/3r,1/4g)and Ch29 (538MHz, 16QAM, 3/4r, 1/8g) are suggested as shown in Table 3.8.

Table 3.8 QoS parameter for Ch37 and Ch29

	Ch37	Ch29
Minimum median equivalent field strength (dBμV/m)	57.41	60.58
Minimum C/N (dB)	12.37	19.33
Minimum MER	11.50	17.43
Minimum BER (pre Viterbi)	1.63x10 ⁻²	2.51x10 ⁻³

Chapter Four

4. Characterisation of clutter loss using fish-eye lens

4.1 Fish-eye lens

A fish-eye lens is a wide angle lens in which the correction of curvilinear distortion is sacrificed in order to give an extreme angle of view [26]. It can take the 360° in azimuth and 90° in elevation of the environment. In order to achieve this, image magnification varies greatly across the picture.

Fig 4.1 Viewing on top of fish-eye lens

Fig 4.2 Viewing from back of fish-eye lens

Fig 4.3 Fish-eye lens
attached to Nikon camera,
view 1

Fig 4.4 Fish-eye lens
attached to Nikon camera,
view 2

Fig 4.5 Wide angle fish-eye lens

By using fish-eye lens, the surrounding can be captured in one single photo.

The fish-eye lens was placed to face vertically upward as shown in Fig 4.3.

Fig 4.6 shows an example of a fish eye photo taken.

Fig 4.6 Example of a fish-eye photo

Take note that the captured photo can only be used to interpret the angle of elevation but not the height of the buildings. In Fig 4.7, although Building A and Building B are of different height with Building B being much taller, they appear to be the “same height” in a fish-eye photo. Both Building A and B have the same angle of elevation as far as fish-eye lens is concerned.

Fig 4.7 Appearance in fish eye photo depend on the angle of elevation

To analyze the link budget, we normally consider free space loss, multipath loss, large scale diffraction loss and clutter loss etc. Clutter loss depends very much on the surrounding and it is very difficult to determine unfortunately. One of the ways to know the surrounding environment is to capture it with a fish-eye lens. The main limitation as mentioned above in the empirical Hata [6] and Walfisch and Bertoni model [9], [19] is the clutter loss. An alternate approach to fill the gap is by using the fish-eye lens.

Fish-eye lens was used to quantify satellite diversity mitigation (SDM) [27]. In the modeling of satellite diversity, the performance of personal and mobile satellite communication systems is limited by the environment in the vicinity

of the mobile earth station (MES). There are three possible paths in a mobile satellite link.

Fig 4.8 Three possible paths in a mobile satellite link

With clear line-of-site (LOS) path, the received signal is affected by:

- Diffuse scatter of the object near the MES
- Reflection from the ground near the user at any elevation angle
- Reflection from inclined smooth terrain in the direction of the satellite at low elevation angle.

When signal is shadowed by trees, the received signal is weakened by the scattering of incident energy from the limbs in all directions. The signal power reaching the user is diminished by scatter and the scatter components produce constructive and destructive interference to each other.

When the LOS is blocked by a building, the signal is contributed by the diffuse scatter from the environment near the MES, diffraction over and around buildings, reflection from the illuminating visible surface and reflection from building edges.

This project intends to use the fish-eye lens technique with modification in the processing of the photos to characterize the surrounding condition at the points, where the signals were received. The fish-eye lens was positioned as in Fig 4.9 at the point of the receiving antenna.

Fig 4.9 Fish-eye lens

4.2 Measurement for field strength

Measurements are carried out in several locations to characterise the clutter loss. The field strength values recorded are given in the Table 4.1. The fish eye photos taken at the same locations are also shown in Section 4.3.4. The signal strength was taken by moving the measurement van slightly such that the maximum signal strength is captured. This is to prevent the equipment from measuring the deep fading signal and ensure the measurement results are repeatable.

Table 4.1 Field strength measured at various locations with omni-directional antenna

(Appendix B-6 shows the locations on Singapore map)

Location	Location description	Field strength (dBμV)	Clutter classification
1	Yunnan Cres 1	54.5	Low rise
2	Yunnan Cres 2	47.5	Low rise
3	Yunnan Cres 3	46.4	Low rise
4	Yunnan Cres 4	43.3	Low rise
5	Yunnan Cres 5	43.7	Low rise
6	Yunnan Cres 6	43.1	Low rise
7	Yunnan Cres 7	41.3	Low rise
8	Yunnan Cres 8	42.3	Low rise
9	Yunnan Road 1	46.2	Low rise
10	Yunnan Road 2	45.6	Low rise
11	Yunnan Road 3	40.4	Low rise
12	Yunnan Cres 9	57.2	Low rise
13	Tuas Lamp Post 12	49.9	Open area
14	Cashew Road	50.2	HDB estate
15	Toh Yi, car park Lot 323	54.0	HDB estate
16	Sungei Road car park Lot 52	52.1	Low rise

The field strength is dependent on:

- Free Space Loss, which is due to the distance between the transmitter and the receiver. These are known losses.
- Large scale losses if present. Eg. Hills which cause diffraction loss.
- Clutter loss, which is the interest of this chapter, it depends on the local environmental condition.

The first 12 locations in Table 4.1 are very close to each other, but the measured signal strengths fluctuate due to the local environmental condition. We will see how this environmental factor affects the received signal strength.

4.3 Processing of fish-eye photo

4.3.1 Adobe photo shop

The pictures captured were firstly processed with Adobe Photoshop. There were mainly two steps in processing the photos:

- Step One
Clear the sky (mainly were the uneven cloud colour) and trees and replaced them with pure white. Refer to Fig 4.11.
- Step Two
Resize the photo to 200 x 200 pixels. Refer to Fig 4.15. In this case the centre of the fish-eye photo is (100,100)

All the processing mentioned above can be done easily with Adobe Photoshop.

Fig 4.10 Original fish-eye photo

Fig 4.11 Clear the sky and trees

Fig 4.12 Resize the photo to 200x200 pixels

The resultant photo (refer to Fig 4.12) is ready to be used for calculation of angle of elevation.

4.3.2 Algorithm of the software and flow chart

Now, these fish-eye photos are ready to be processed with Visual Basic program, written to calculate the mean, standard deviation and variance of the distance from the centre of the photo to the rim of the structures/buildings.

The centre of the fish-eye photo is at the coordinate (100,100). An invisible vertical line (at 0 degree) extending from (100,100) to the rim of the photo. Search is performed along this line to detect the starting “non white” portion along this line. This line is then turned clockwise to the next angle (1 degree) and performed the same search. Hence, when this invisible line turned one round, it will collect 360 sets of data. These 360 sets of data are related to the

angle of elevation at different direction. Imagine that Fig 4.13 is opened up into rectangular form, it will be transformed to Fig 4.14.

Fig 4.14 Rectangular presentation of the fish-eye photo

The red cross at the centre of Fig 4.13 is now transformed to be the red line on top of Fig 4.14. The blue line in Fig 4.14 is the skyline. The angle of elevation to this skyline (viewing from the ground level) is what we are interested. Take note that wanted mean is measured from the ground level and not from the red line although the algorithm seems to be implying that. Hence, certain adjustment will have to be made as explained in Section 4.3.3.

The algorithm to make the invisible line to turn clockwise is as follow:

Fig 4.15 Making the angle, θ to increase from 0° to 359°

As θ increases by 1° , the y-coordinate follow a cosine curve pattern and the x-coordinate follow a sine curve pattern. In this case, there are 360 imaginary lines with angular space of 1° .

$$y = 100 - 100\cos\theta$$

$$x = 100 + 100\sin\theta$$

(Take note that the centre of the fish-eye photo is at 100, 100)

The direction of the imaginary lines stretch from (100,100) to (x,y) in Fig 4.13. Along these imaginary lines, the program counts from the centre of the fish-eye photo (which is the red cross) to the point, where the pixel starts to be non-white (note that for white pixels, all the R, G, B components have the value of 255, 255, 255 in decimal).

Once it detected a non-white pixel along these lines, the coordinate of these points are recorded and the distance from the centre of the fish-eye photos to these points are calculated as:

$$distance[\theta] = \sqrt{(x[\theta] - 100)^2 + (y[\theta] - 100)^2}$$

Hence, there is an array of 360 members of distance[θ]. These distance[θ]s are used to calculate the mean, variance and standard deviation of the angle of elevation of the terrain. (take note that this is not the true angle of elevation yet as it correspond to the angle started from vertical {or from the red cross} instead of from the ground level). To get the true angle of elevation, calibration of the fish-eye lens is required. It is discussed in Section 4.3.3. Fig 4.16 shows the flow of the program.

Fig 4.16 Flow chart for calculating mean, variance and standard deviation of the angle of elevation

4.3.3 Calibration of fish-eye lens

Fisheye lens photo can show us the angle of elevation of the buildings but not the actual height. Hence, beside the heights of the buildings, the distances between these buildings to the fish-eye lens are important too.

Fig 4.17 Picture taken using fish-eye lens

Fig 4.17 shows that although Building A is shorter than Building B, but they appear to be the same “height” in the fisheye photo.

The calibration was done with a HDB block. Fig 4.18 shows the fish-eye photo of the block that was used for the calibration.

Fig 4.18 fish-eye photo for calibration purpose

The blue and red marks in Fig 4.18 are the known heights of the HDB block. These marks are denoted as Y in Fig 4.19. The “thickness” of these blue and red marks is measured to be 63cm, the height of each story is measured to be 223cm accept the void deck height, which is measured to be 305cm. As the tripod of the camera is 100cm, the first point presented in Table 4.2 become 205cm (=305cm-100cm).

Fig 4.19 Calibration of the fish-eye lens

The distance, X is fixed at 2m with Y being variable (Y is the height at the blue and red marks). Table 4.2 is the summary of X, Y, ψ , and the distance from the centre of the fish-eye photo to the corresponding red or blue marks.. The angle, ψ , which is the inverse tangent of vertical height, Y over the horizontal distance, X. Note that the calculated angle of elevation is $90-\psi$ in

the software and what we are interested is ψ . Hence, certain adjustment is necessary.

By varying Y and keeping X fixed in Fig 4.19, we are able to tabulate the relationship between the angle ψ and the pixel distance on the fish-eye photo.

Refer to Table 4.2.

Table 4.2 Angle, ψ versus distance of the red/blue spots in the fisheye photo

Height, Y (cm)	Angle of elevation, ψ degree	Result obtained in the fish-eye photo		
		Coordinates (x,y) of the red/blue marks in the fish-eye photo (pixel)		Distance of the red/blue spots from the centre of photo (pixel)
205	45.70	109	148	49
268	53.26	108	140	41
491	67.83	105	127	27
554	70.14	104	124	24
777	75.56	103	118	18
1063	79.33	102	114	14
1635	83.02	101	110	10
3128	86.33	101	105	5

The graphical form of Table 4.2 can be represented in Fig 4.20.

Fig 4.20 Relationship between the angle of elevation, ψ (vertical axis) and the pixels from the centre of fish-eye photo (horizontal axis).

Hence, the actual mean of the angle of elevation can be calculated using the formula shown in Fig 4.20.

4.3.4 Result of various locations

The field strengths at various locations were measured (refer to Table 4.1).

Fish-eye pictures were taken at the same locations too. With the Visual Basic programme, the mean variance and standard deviation of the angle of elevation is as follow:

The screenshot shows a Visual Basic form titled 'Form1'. On the left, there is a fish-eye image of a circular object. Below the image is an 'exit' button. To the right of the image, there are several input fields and labels. The labels and their corresponding values are as follows:

Label	Value
X-coordinate	128
Y-coordinate	108
Mouse colour	16777215
debug purpose	10.194
debug purpose	94
Mean	84.0472222222
Variance	171.2949922839
Standard Deviation	13.08797128220
Actual Mean	18.64390833333
Actual Variance	123.4696017332
Actual standard deviation	11.1168761859

Fig 4.21 Yunnan Cres 1

Fig 4.22 Yunnan Cres 2

Fig 4.23 Yunnan Cres 3

Fig 4.24 Yunnan Cres 4

Fig 4.25 Yunnan Cres 5

Fig 4.26 Yunnan Cres 6

Fig 4.27 Yunnan Cres 7

Fig 4.28 Yunnan Cres 8

Fig 4.29 Yunnan Road 1

Fig 4.30 Yunnan Road 2

Fig 4.31 Yunnan Road 3

Fig 4.32 Yunnan Cres 9

Fig 4.33 Tuas Lamp Post 12

Form1

exit

X-coordinate	86	Mean	63.5472222222
Y-coordinate	85	Variance	365.9477700617
Mouse colour	16777215	Standard Deviation	19.12976136970
debug purpose	49.248	Actual Mean	36.0484083333
debug purpose	48	Actual Variance	263.7755186082
		Actual standard deviation	16.24116740287

Fig 4.34 Cashew Road

Form1

exit

X-coordinate	108	Mean	52.9694444444
Y-coordinate	69	Variance	837.3796219135
Mouse colour	16777215	Standard Deviation	28.93751236567
debug purpose	77.265	Actual Mean	45.02894166666
debug purpose	15	Actual Variance	603.5840688549
		Actual standard deviation	24.56794799845

Fig 4.35 Toh Yi, car park Lot 323

Fig 4.36 Sungei Road Car park Lot 52

The summary of the calculation is as follow:

Table 4.3 Actual mean, variance and standard deviation of the angle of elevation at various locations

Location	Actual		
	Mean	Variance	Std dev
1	18.64	123.47	11.11
2	19.39	163.52	12.79
3	23.19	116.44	10.79
4	26.58	68.52	8.28
5	23.85	44.79	6.69
6	25.2	44.48	6.67
7	23.5	41.13	6.41
8	21.35	15.67	3.96
9	24.22	37.44	6.12
10	24.52	35.47	5.96
11	24.74	39.92	6.32
12	15.94	129.94	11.4
13	12.92	5.78	2.4
14	36.05	263.78	16.24
15	45.03	603.58	24.57
16	20.15	47.54	6.89

4.3.4.1 Field strength prediction

As the fish-eye photos characterize the local environment, part of this research project is to find out the effect of local environment on the clutter loss.

To minimize the uncertainty of the transmitter power, free space loss and transmitting antenna pattern etc, the first 12 locations indicated in Table 4.1 are chosen as they are very close to each other. Assuming at this point of time that the multipath and diffraction loss are constant for all these 12 locations.

Fig 4.37 Distance between the transmitter and the reception van

The frequency of the test channel is 602MHz, wavelength is 0.498m. The path loss from the transmitter to these 12 points is:

$$\begin{aligned} &\approx 20\log\left(\frac{4 \times \pi \times d}{\lambda}\right) \\ &= 20\log\left(\frac{4 \times \pi \times 8500}{0.498}\right) \\ &= 106.6dB \end{aligned}$$

From data sheet, the transmitted power in the direction of these 12 locations is about 178.15 dBμV.

By using the relationship

$$\text{received signal strength} = \text{transmitted power} - \text{path loss} - \text{clutter loss} - X \text{ loss}$$

or it can be arranged as:

$$\text{clutter loss} + X \text{ loss} = \text{transmitted power} - \text{path loss} - \text{received signal strength}$$

$$\text{clutter loss} + X \text{ loss} = 178.15 - 106.6 - \text{received signal strength}$$

$$\text{clutter loss} + X \text{ loss} = 71.55 - \text{received signal strength}$$

Take note that the X loss is referring to diffraction loss, reflection loss etc, which are assumed to be constant for the 12 locations chosen.

With the measured signal strength mentioned in Section 4.2 (referring to Table 4.1), the clutter loss + X loss can be calculated. Table 4.4 shows the summary of received signal strength, clutter loss + X loss at the 12 locations chosen.

Table 4.4 Clutter loss +X loss

Point	Location description	Received signal strength (dBμV)	Clutter loss + X loss (dB)
1	Yunnan Cres 1	54.5	23.05
2	Yunnan Cres 2	47.5	30.05
3	Yunnan Cres 3	46.4	31.15
4	Yunnan Cres 4	43.3	34.25
5	Yunnan Cres 5	43.7	33.85
6	Yunnan Cres 6	43.1	34.45
7	Yunnan Cres 7	41.3	36.25
8	Yunnan Cres 8	42.3	35.25
9	Yunnan Road 1	46.2	31.35
10	Yunnan Road 2	45.6	31.95
11	Yunnan Road 3	40.4	37.15
12	Yunnan Cres 9	57.2	20.35

The relationship of Clutter loss + X loss with the mean and standard deviation of the angle of elevation is as follow: (Table 4.5)

Table 4.5 Clutter loss +X loss vs mean and standard deviation of angle of elevation

Locations	Clutter loss + X loss (dB)	Actual mean angle of elevation	Actual standard deviation of angle of elevation
1	23.05	19.96	11.11
2	30.05	20.36	12.79
3	31.15	30.91	10.79
4	34.25	28.41	8.28
5	33.85	24.58	6.69
6	34.45	26.17	6.67
7	36.25	25.28	6.41
8	35.25	23.08	3.96
9	31.35	26.06	6.12
10	31.95	26.31	5.96
11	37.15	26.27	6.32
12	20.35	16.98	11.4

Fig 4.38 and Fig 4.39 are the graphical representations of Table 4.3.4.1.2

Fig 4.38 Clutter loss +X loss vs mean angle of elevation

Fig 4.39 Clutter loss +X loss vs standard deviation of the angle of elevation

Fig 4.38 and Fig 4.39 represent the characterization of clutter loss in a low rise residential area, which the houses are 2 to 3 storeys. It can be shown in Fig 4.38 that as the mean angle of elevation of the environment increases, the clutter loss increases. The result demonstrated that when the buildings are taller and closer together, the clutter loss is higher. It can also be shown that in Fig 4.39, when the standard deviation is higher, the clutter loss is lower.

4.3.5 Result at Jurong West New Town

Another measurement was done at Jurong West New Town (Appendix B-7 shows the locations on Singapore map). This is the typical public housing estate in Singapore. The average building height is 16 stories. Similarly, field strength and fish-eye photos were collected along the line indicated in Fig 40.

Fig 4.40 Locations, where field strength and fish-eye photos were collected in Jurong West New Town

The signal strength measured on 17 locations is as follow:

Table 4.6 Signal strength measured at 17 locations
along the red line indicated in Fig 4.40

Location	Received signal strength (dBμV)
1	40.2
2	39.4
3	35.7
4	39.5
5	39.7
6	40.2
7	37.4
8	34.2
9	34.6
10	36.2
11	34.7
12	34.5
13	37.5
14	34.68
15	39
16	39.6
17	41.4

From the data sheet of the transmission system. The transmitted power in the direction of this 17 point is about 183.98 dB μ V, the path loss is 106.32dB.

Using the same relationship mentioned in Section 4.3.4.1:

$$\text{clutter loss} + X' \text{ loss} = \text{transmitted power} - \text{path loss} - \text{received signal strength}$$

$$\text{clutter loss} + X' \text{ loss} = 183.98 - 106.32 - \text{received signal strength}$$

$$\text{clutter loss} + X' \text{ loss} = 77.66 - \text{received signal strength}$$

Hence, the clutter loss + X' loss can be calculated as (Table 4.7). Take note that X' loss is referring to diffraction loss, reflection loss etc, which are assumed to be constant for the 17 locations.

Table 4.7 Clutter loss + X' loss

Locations	Received signal strength (dBμV)	Clutter loss + X' loss (dB)
1	40.2	37.46
2	39.4	38.26
3	35.7	41.96
4	39.5	38.16
5	39.7	37.96
6	40.2	37.46
7	37.4	40.26
8	34.2	43.46
9	34.6	43.06
10	36.2	41.46
11	34.7	42.96
12	34.5	43.16
13	37.5	40.16
14	34.68	42.98
15	39	38.66
16	39.6	38.06
17	41.4	36.26

The mean, variance and standard deviation of the fish-eye photo taken at these 17 points are as follow:

X-coordinate	127	Mean	60.975
Y-coordinate	106	Variance	453.2854861111
Mouse colour	16777215	Standard Deviation	21.29050225126
debug purpose	38.211	Actual Mean	38.232225
debug purpose	61	Actual Variance	326.7286316743
		Actual standard deviation	18.07563641132

exit

Fig 4.41 Jurong West location 1

Fig 4.42 Jurong West location 2

Fig 4.43 Jurong West location 3

Fig 4.44 Jurong West location 4

Fig 4.45 Jurong West location 5

Fig 4.46 Jurong West location 6

Fig 4.47 Jurong West location 7

Form1

exit

X-coordinate	112	Mean	41.897222222222
Y-coordinate	94	Variance	435.48110339501
Mouse colour	16777215	Standard Deviation	20.868183998491
debug purpose	41.607	Actual Mean	54.429258333333
debug purpose	57	Actual Variance	313.89521480821
		Actual standard deviation	17.71708821472

Fig 4.48 Jurong West location 8

Form1

exit

X-coordinate	103	Mean	45.902777777777
Y-coordinate	84	Variance	490.6988811728
Mouse colour	16777215	Standard Deviation	22.15172411287
debug purpose	40.758	Actual Mean	51.028541666666
debug purpose	58	Actual Variance	353.69624424821
		Actual standard deviation	18.80681377182

Fig 4.49 Jurong West location 9

Fig 4.50 Jurong West location 10

Fig 4.51 Jurong West location 11

Fig 4.52 Jurong West location 12

Fig 4.53 Jurong West location 13

Fig 4.54 Jurong West location 14

Fig 4.55 Jurong West location 15

Form1

exit

X-coordinate	99	Mean	56.7972222222
Y-coordinate	91	Variance	404.4561033950
Mouse colour	16777215	Standard Deviation	20.11109403774
debug purpose	59.436	Actual Mean	41.7791583333
debug purpose	36	Actual Variance	291.5323637832
		Actual standard deviation	17.07431883804

Fig 4.56 Jurong West location 16

Form1

exit

X-coordinate	98	Mean	58.3777777777
Y-coordinate	94	Variance	467.0183950617
Mouse colour	16777215	Standard Deviation	21.61060839175
debug purpose	14.439	Actual Mean	40.4372666666
debug purpose	89	Actual Variance	336.6273261788
		Actual standard deviation	18.34740652459

Fig 4.57 Jurong West location 17

The relationship of clutter loss + X' loss with the mean and standard deviation of the angle of elevation is tabulated as shown in Table 4.8.

Table 4.8 Clutter loss + X' loss vs mean and standard deviation of the angle of elevation

Locations	Clutter loss + X' loss (dB)	Actual mean angle of elevation	Actual standard deviation of angle of elevation
1	37.46	38.23	18.08
2	38.26	46.53	16.48
3	41.96	47.55	15.65
4	38.16	49.82	20.77
5	37.96	48.99	19.43
6	37.46	49.33	16.76
7	40.26	50.77	17.88
8	43.46	54.43	17.72
9	43.06	51.03	18.81
10	41.46	47.61	17.52
11	42.96	47.1	17.05
12	43.16	46.62	16.54
13	40.16	45.08	18.03
14	42.98	47.33	17.33
15	38.66	45.78	20.12
16	38.06	41.78	17.07
17	36.26	40.44	18.35

Fig 4.58 and Fig 4.59 are the graphical representation of Table 4.8.

Fig 4.58 Clutter loss + X'loss vs mean angle of elevation

Fig 4.59 Clutter loss + X' loss vs standard deviation of angle of elevation

Both Fig 4.38 and Fig 4.58 have a positive gradient. Both Fig 4.39 and Fig. 4.59 have a negative gradient. The result shows that in low rise residential and public housing estate, the clutter behavior is very similar. As the mean angle of elevation of the environment increases, the clutter loss increases. And also the higher the standard deviation of angle of elevation, the lower the clutter loss.

4.4 Suggested improvement for Okumura Hata Model

The result in Section 4.3.4 and 4.3.5 are used to compare with Okumura Hata model (referring to section 2.3.6.1). If Singapore is classified as “medium to small” city, the propagation loss can be calculated with Okumura Hata mode using Equation 2.15 and Equation 2.16.

$$L_p = 69.55 + 26.16\log(f) - 13.82\log(h_b) - a(h_m) + (44.9 - 6.55\log(h_b)) * \log(d) \dots\dots\dots(2.15)$$

$$a(h_m) = (1.1\log(f) - 0.7) * h_m - (1.56\log(f) - 0.8) \dots\dots\dots(2.16)$$

- With f = 602 MHz : frequency in MHz
- h_m = 12 m : Height of receiver in meter
- h_b = 300 m : Height of base station in meter
- d = 8.5 km for Yunnan : Distance in km
- = 8.2 km for Jurong West

The Effective Radiated Power (ERP) toward Yunnan is 178.15dBμV and the ERP toward Jurong West is 183.98 dBμV. Using Equation 2.15 and Equation 2.16, the received signal strength at Yunnan is calculated to be 68.22 dBμV and the received signal strength at Jurong West is calculated to be 74.50 dBμV. Referring to Table 4.4 and Table 4.5, if the clutter loss is treated as the difference between the calculated received signal strength (using Okumura Hata model) and the field measured received signal strength, we are able to

tabulate the relationship between the clutter loss and actual mean angle of elevation (referring to Table 4.9).

Table 4.9 Relationship between clutter loss and actual mean angle of elevation at Yunnan

Point	Received signal strength (dBμV)	Clutter Loss (dB)	Actual mean angle of elevation (degree)
1	54.4	13.72312103	19.36
2	47.5	20.72312103	20.36
3	46.4	21.82312103	30.91
4	43.3	24.92312103	28.41
5	43.7	24.52312103	24.58
6	43.1	25.12312103	26.17
7	41.3	26.92312103	25.28
8	42.3	25.92312103	23.08
9	46.2	22.02312103	26.06
10	45.6	22.62312103	26.31
11	40.4	27.82312103	26.27
12	57.2	11.02312103	16.98

Similarly, referring to Table 4.7 and Table 4.8, if the clutter loss at Jurong West can be tabulated in Table 4.10.

Table 4.10 Relationship between clutter loss and actual mean angle of elevation at Jurong West

Point	Received signal strength (dB μ V)	Clutter Loss (dB)	Actual mean angle of elevation (degree)
1	40.2	34.30059426	38.23
2	39.4	35.10059426	46.53
3	35.7	38.80059426	47.55
4	39.5	35.00059426	49.82
5	39.7	34.80059426	48.99
6	40.2	34.30059426	49.33
7	37.4	37.10059426	50.77
8	34.2	40.30059426	54.43
9	34.6	39.90059426	51.03
10	36.2	38.30059426	47.61
11	34.7	39.80059426	47.1
12	34.5	40.00059426	46.62
13	37.5	37.00059426	45.08
14	34.68	39.82059426	47.33
15	39	35.50059426	45.78
16	39.6	34.90059426	41.78
17	41.4	33.10059426	40.44

Table 4.9 is transformed to Fig 4.60.

Fig 4.60 Clutter loss (dB) vs actual mean angle of elevation (degree) at Yunnan

Table 4.10 is transformed to Fig 4.61

Fig 4.61 Clutter loss (dB) vs actual mean angle of elevation (degree) at Jurong West

From Fig 4.60 and Fig 4.61, it is suggested to modify Equation 2.15 to Equation 4.1a (for Yunnan, which the building height is 2 to 3 stories) and Equation 4.1b (for Jurong West, which the building height is 16 stories)

$$L_p = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) * \log(d) + 0.91X \quad \dots\dots\dots(4.1a)$$

$$L_p = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) * \log(d) + 0.36X + 16 \quad \dots\dots\dots(4.1b)$$

Where X is the mean angle of elevation (degree) at the points, where the signal measurement are conducted.

Chapter Five

5 Height vs gain/loss study

In Recommendation ITU-R P370-7, “VHF AND UHF PROPAGATION CURVES FOR THE FREQUENCY RANGE FROM 30MHz TO 1000MHz” [3], the change in the receiving antenna height is given by [7]

$$Height\ gain(dB) = \frac{c}{6} \cdot 20 \log_{10} \left(\frac{h_2}{10} \right)$$

Where height gain factors, c is given by

Table 5.1 ITU specification of c

Zone	VHF (dB)	UHF (dB)
Rural	4	4
Suburban	5	6
Urban	6	8

And h_2 is the change in receiver height.

Judging from the height gain formula given above, it suggests that if a receiving antenna is placed at a higher position, there should always be some gain in the received field strength. This gain is higher in urban than rural area. In this chapter, which measurement was carried in various locations, the result shows that the height gain do not follow what is recommended in ITU. In fact, there are some places, where the received signal strength is stronger when the receiving antenna is placed at 2m above ground level (agl) as compared to 10m agl.

In the analogue TV system, the signal parameter is always measured at 10m above ground level (agl) as specified in ITU. Field measurement engineers normally go from point to point to do static measurement, which is very time consuming. With the introduction of DVB-T, which TV programme can be received in a moving vehicle at lower height, the measurement process can be automated. In that way, more data can be collected with much shorter time as compared to the past. While doing so, it is important to correlate the measurement at 2m agl, which is very close to the receiving antenna to 10m agl. Take note that the ETSI EN300744 [10] specification is still referring to 10m agl.

5.1 Measurement for height gain/loss

The measurement campaign is conducted using a van, which has a hydraulic mast that is extendable to 10m level. The field strength values are recorded using the equipment setup as shown in Section 3.2. Omni directional antenna is used to record the field strength at 2m and 10m levels. Beside the public housing estate, where population density is high, measurements are also carried out in other locations, which represent low rise and industrial estates. Results are given in Table 5.2a and Table 5.2b. The locations are so selected to cover different clutter types. It is interesting to note that the height-gain is different for different locations. In some locations, where there is no line-of-sight with the transmitter, the field strength at 2m level can be higher than at

10m level. In locations like Tuas and Serangoon, which are quite open with low-rise buildings, a height gain of 6 to 9.8 dB is seen.

Table 5.2a Comparison of signal received at 2m and 10m agl with omni directional antenna for open to low rise areas
(Appendix B-8 shows the locations on Singapore map)

Locations	Description of the location	Clutter classification	Received field strength, dBuV at		
			2m agl	10m agl	Gain/loss ?
1.	NTU car park	Small area surrounded by 7 story buildings	49	43	Height loss 6dB
2.	Nanyang Hill	Open area	78	75.8	Height loss 2.2dB
3.	Tuas	Low rise, 2 to 3 storeys	54.2	64	Height gain 9.8dB
4	Bukit Timah	Low rise, 2 to 3 storeys	54	55	Height gain 1dB
5.	Serangoon Road	Low rise, 2 to 3 storeys	52.1	58.1	Height gain 6dB
6.	Juying .Primary School, at Gate 2	Low rise beside public housing	44.5	48.6	Height gain 4.1dB
7.	Mosque Street, opposite carpark Lot 40/40A	Low rise 2 to 3 storeys	57	55.8	Height loss 1.2dB
8.	Bournemouth Road, opposite Unit 11	Low rise 2 to 3 storeys	47	58	Height gain 11dB
9.	Mandai, Upper Seletar Reservoir	Open area	82	70	Height loss 12dB
10.	Alexandra Road, in front of Dawson Place	Fairly open, average of 5 to 6 storeys	45.8	46	Height gain 0.2dB

Table 5.2b Comparison of signal received at 2m and 10m agl with omni directional antenna for public housing and Central Business District

(Appendix B-9 shows the locations on Singapore map)

Locations	Description of the location	Clutter classification	Received field strength, dBuV at		
			2m agl	10m agl	Gain/loss ?
1.	Cashew road	Public housing	50.2	53.2	Height gain 3dB
2.	Dalhousie Obelisk, Victoria Theatre	Central business district	61.4	61.7	Height gain 0.3dB
3.	Blk345, carpark Lot23 Jurong East	Public housing	35.2	43.7	Height gain 8.5dB
4.	Blk306, carpark Lot16, Jurong East Street 32	Public housing	52.3	53.5	Height gain 1.2dB
5.	Blk173, carpark Lot139 Bt Batok West Ave 8	Public housing	49.9	49.6	Height loss 0.3dB
6	Holland Close	Public Housing	43.2	42.9	Height loss 0.3dB
7	Holland Drive	Public Housing	43.7	44.2	Height gain 0.5dB
8	Jurong West Blk 654B	Public Housing	41.6	41.8	Height gain 0.2dB

The public housing in Table 5.2b refers to clutter of building with average height of 12 to 16 storeys (or 26m to 48m).

A more detail measurement is done in a public housing estate at Jurong West (Appendix B-10 shows the locations on Singapore map). The locations chosen consist of Line-Of-Sight (LOS), partial LOS and completely blocked case.

Fig 5.1 Locations of Jurong West estate, where signal strength is measured for height gain/loss analysis

Table 5.3 Signal strength measured at 2m and 10m at Jurong West estate

Locations	Descriptions	Avg. Signal Strength (2m) dB μ V	Avg. Signal Strength (10m) dB μ V	Height gain (dB) @ 10m agl as compared to 2m agl
1	Line of sight	62.55	65.68	3.13
2	Line of sight	62.55	65.68	3.13
3	Line of sight	68.66	65.85	-2.81
4	Partial Line of sight	46.45	42.79	-3.66
5	Partial Line of sight	38.51	40.06	1.55
6	Partial Line of sight	35.19	32.59	-2.6
7	Completely blocked	28.68	29.80	1.12
8	Completely blocked	29.62	30.52	0.9
9	Completely blocked	27.30	28.72	1.42
10	Completely blocked	28.47	31.81	3.34
11	Completely blocked	30.72	31.04	0.32

Table 5.3 can be represented graphically in Fig 5.2.

Fig 5.2 Signal strength (dBuV) measured at 2m and 10m agl at the 11 locations at Jurong West estate

From Fig 5.2, those locations with LOS and partial LOS with the transmitting antenna exhibit inconsistency in the height gain. The last 5 locations, which are completely blocked, have a height gain of 0.32 dB to 3.34dB. Fig 5.3 to Fig 5.6 show the impulse response recorded at Location 1, 3, 5 and 10 respectively.

Fig 5.3 Impulse response at Location 1

Fig 5.4 Impulse response at Location 3

Fig 5.5 Impulse response at Location 5

Fig 5.6 Impulse response at Location 10

The impulse responses Fig 5.3 to Fig 5.6 indicate that the multipaths reach the receiving antenna within the guard interval of 56μsec, hence, they add up constructively. The multipaths in Location 1 and 3 were quite low and thus

they have much lesser effect on the signal strength. Take note that Location 1 and 3 have LOS with the transmitting antenna and Location 5 has partial LOS with the transmitting antenna. They received stronger main signals. As the blockage from the transmitting antenna getting higher, the effect of multipaths becomes more significant. This can be seen in Fig 5.5. The environment in Location 10 has completely blocked the receiving antenna from the transmitting antenna and the signal bounced within the clutter of 16 storeys HDB blocks. As the main signal is weak, the resultant signal strength in Location 10 depends very much on the multipaths.

Fig 5.7 to Fig 5.9 show the instantaneous signal strength measured when raising the receiving antenna from 2m to 10m above ground level (agl).

Fig 5.7 Field strength measured at Location 1, 2, 3 while raising the receiving antenna

The signal strength at Location 1, 2 and 3 follows more or less an average line (refers to Fig 5.7). This is the result of superposition of multipath reflected from the ground and the main signal.

Fig 5.8 Field strength measured at Location 4, 5, 6 while raising the receiving antenna

Location 4, 5 and 6 have partial LOS with the transmitting antenna.

The initial part of the curves in Fig 5.8 follow an average curve, which are very much like that of Fig 5.9. As the antenna raise further, the signal become random, which is very much like Location 10 and 11 (refer to Fig 5.9).

Fig.5.9 Field strength measured at Location 10 and 11 while raising the receiving antenna

Fig 5.7 to Fig 5.9 show that the signal strength does not always increase as the height of the receiving antenna rises. The slow variation in signal strength is likely due to the superposition of all the signals.

Chapter Six

6 Conclusion and Recommendations

6.1 Conclusion

6.1.1 Conclusion on the QoS

The table (referring to Table 2.3) in Chester 97 [1] serves only as a guide line for the required carrier-to-noise ratio (C/N) with different configurations under different receiving channels (i.e. Gaussian, Rayleigh and Ricean {with $k=10\text{dB}$ } channels). However, in a practical situation, a receiving channel is not purely Gaussian, Rayleigh or Ricean (with $k=10\text{dB}$). Hence, the Quality of Service (QoS) parameters must be characterized to optimize the number of transmitters/gap-fillers required to provide an acceptable service.

The QoS parameters required for indoor and outdoor propagation is different and they should be studied separately.

From the measurement conducted in Chapter Three, it shows that field strength is not the only parameter that is required to quantify QoS, other parameter such as BER, MER, SNR are important too.

Table 3.8 suggests the QoS parameters of Ch37 (602MHz, QPSK, 2k, 2/3r, 1/4g,) and Ch29 (538MHz, 16QAM, 8k, 3/4r, 1/8g) in Singapore to be as follow:

Table 3.8 QoS parameter for Ch37 and Ch29

Channel number	Ch37	Ch29
Minimum median equivalent field strength (dBμV/m)	57.41	60.58
Minimum C/N (dB)	12.37	19.33
Minimum MER	11.50	17.43
Minimum BER (pre Viterbi)	1.63×10^{-2}	2.51×10^{-3}

This project has shown that the theoretically calculated minimum median equivalent field strength (according to Chester 97's calculation [1]) of Ch29, which uses only one transmitter agree very well with the measured data. For Single Frequency Network (SFN) like Ch37, an additional of 4dB implementation margin on top of Chester 97's calculation is required.

When comparing the SNR measured with Chester 97, which specified C/N for Ch37 to be 8.4dB and C/N for Ch29 to be 16.7dB, the measured SNR (or C/N in this case) can be 3.97dB higher for Ch37 and 2.63dB higher for Ch29. The Chester 97's recommendation does not take into account of the implementation margin associated with a practical channel equalizer, which is included in the measured result. If we take this into account, the measured SNR and theoretically calculated C/N are very close [25].

6.1.2 Comment on the height gain

The height gain is different in different locations. In some places, where there are no line of site and the buildings are quite crowded, there are reduction in received signal strength when the antenna is risen. For example, there is rarely any received signal strength gain associated with the risen of receiving antenna when the measurement is conducted in HDB blocks. The specification in ITU-R [7] on gain vs antenna height does not apply for this project. In an environment, where there are many reflected signals, the superposition of these signals cause the signal strength to varies. This is different from the simple idea that as long as the receiving antenna is raised, the field strength will be increased.

6.1.3 Comment on the characterisation of clutter

The clutter loss can be characterized using fish-eye lens at selected locations. The clutter loss is higher when the receiver is situated in a highly dense environment as compared to a more open area. Two clutters of locations, where signal strength are measured and fish-eye photos are taken.

The graph (Fig 4.38), which is generated in Yunnan area (low rise residential area) has a higher gradient (1.4 dB/degree) than that of a public housing estate (refer to Fig 4.58, gradient = 0.43 dB/degree) at Jurong West. It shows that the clutter loss is more sensitive to the change in the angle of elevation in a low rise area as compared to a 16 stories pubic housing area.

Fig 4.38 Clutter loss +X loss vs mean angle of elevation (low rise area)

Fig 4.58 Clutter loss + X'loss vs mean angle of elevation (public housing 16 stories)

On the other hand, from Fig 4.39 and Fig 4.59, the clutter loss seems to be more sensitive to the change in the standard deviation in a 16 stories housing area as compared to a low rise area.

Fig 4.39 Clutter loss +X loss vs standard deviation of the angle of elevation (low rise area)

Fig 4.59 Clutter loss + X loss vs standard deviation of angle of elevation (public housing, 16 stories)

A better way to analyze the effect of standard deviation of the angle of elevation to the clutter loss + X loss would be to keep the mean angle of elevation fixed. However, that will require a very large amount of data, which is not sufficient for this project.

The project further suggests including the clutter loss in the propagation loss calculation (referring Equation 2.15) in the Okumura Hata model. The modified equations are:

$$L_p = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) * \log(d) + 0.91A \dots\dots\dots(4.1a)$$

(For Yunnan, where the building height is 2 to 3 stories)

$$L_p = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) * \log(d) + 0.36A + 16 \dots\dots\dots(4.1b)$$

(For Jurong West, where the building height is 16 stories)

Where A is the mean angle of elevation (degree) at the points, where the signal measurement are conducted. Take note that original Okumura Hata model do not take clutter loss into consideration and the

6.2 Recommendations for further research

It has been some forty years since television was introduced in Singapore. Although there are some improvements with the conventional analogue system. Example,

- Introduction of colour system
- Introduction of stereo sound system
- Introduction of teletext etc.

These changes were minor, they involved adding on modules to the existing system.

This is the first time TV broadcasting industry is applying digital transmission technique and there are many new areas, which need detail understanding.

6.2.1 Indoor coverage

In the conventional way, terrestrial TV is always received with fixed antenna. With the introduction of digital TV, multipaths issue is minimized and it is possible to receive TV programmes in the car, indoor etc. Unfortunately, there are very few documents available to quantify indoor coverage. Parameter such as building penetration loss, which has a very large impact on the planning of indoor coverage can hardly been found in any technical paper. There is a new technology known as DVB-H (H stands for handheld), which Nokia is leading many trial world wide to provide video services on a handheld set. Indoor reception will be particularly important. Hence, detail studying of indoor coverage is suggested.

6.2.2 Diversity receiver

It is possible to receive DVB-T signal in vehicle. As the vehicles are moving, there is absolutely no chance to optimize the receiving antenna. Diversity receiver for this case is very helpful such that the decoder can either select the best signal from all the branches or combine them up. The placing of the receiving antennae is very crucial, improper position will not give an effective result. Topic on how much a diversity receiver can improve the decodability of the video/audio signal remains very important.

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Appendix A

```
Private Sub Command1_Click()  
End  
End Sub
```

```
Private Sub picture1_MouseDown(button As Integer, shift As Integer, x As  
Single, y As Single)
```

```
Dim x_co, y_co, x1, y1, pi, radius, angle, colour, count  
Dim sum_mycheck, i, j, mean, std_deviation, variance, sum_mycheckactual,  
meanactual, sum_actual_var  
Dim actual_var, std_actual_deviation  
Dim mycheck(360), mycheckactual(360) As Variant
```

```
pi = 3.14159  
x1 = 100  
y1 = 100
```

```
For angle = 0 To 359 Step 1  
count = 0
```

```
*****
```

```
For radius = 0 To 100 Step 1  
x_co = x1 + radius * Sin(angle * pi / 180)  
y_co = y1 + radius * Sin((angle - 90) * pi / 180)  
colour = Picture1.Point(x_co, y_co)  
  
'x_next = x_co + radius * Sin(angle * pi / 180)  
'y_next = y_co + radius * Sin((angle - 90) * pi / 180)  
'colour = Picture1.Point(x_next, y_next)
```

```
If (colour = 16777215) Then  
Picture1.Line (x1, y1)-(x_co, y_co), RGB(255, 0, 0)  
' Picture1.Circle (x_co, y_co), 0.1, 255  
count = count + 1  
End If  
*****
```

```
Next radius
```



```
*****
    mycheck(angle) = count
    mycheckactual(angle) = 90 - (0.849) * (count)
Next angle

*****
'this part uses mouse location to indicate the colour
Wcolour = Picture1.Point(x, y)
Text1.Text = (x)
Text2.Text = (y)
Text3.Text = Wcolour
*****

Text4.Text = mycheckactual(200)
Text5.Text = mycheck(200)

sum_mycheck = 0
sum_mycheckactual = 0

'this part calculate the mean

For i = 0 To 359
    sum_mycheck = sum_mycheck + mycheck(i)
    sum_mycheckactual = sum_mycheckactual + mycheckactual(i)

Next i
    mean = sum_mycheck / 360
    Text6.Text = mean
    meanactual = sum_mycheckactual / 360
    Text9.Text = meanactual

'this part calculate the standard deviation
'note that variance is the square of standard deviation

sum_variance = 0
sum_actual_var = 0

For j = 0 To 359
    sum_variance = sum_variance + ((mycheck(j) - mean) * (mycheck(j) -
mean))
    sum_actual_var = sum_actual_var + ((mycheckactual(j) - meanactual) *
(mycheckactual(j) - meanactual))
```

Next j

```
variance = sum_variance / 360  
std_deviation = Sqr(variance)
```

```
actual_var = sum_actual_var / 360  
std_actual_deviation = Sqr(actual_var)
```

```
Text7.Text = variance  
Text8.Text = std_deviation
```

```
Text10.Text = actual_var  
Text11.Text = std_actual_deviation
```

End Sub

Appendix B

B-1 Location map of Table 3.1a

ISLAND-WIDE GRID

B-2 Location map of Table 3.1b

ISLAND-WIDE GRID

B-3 Location map of Table 3.1c

ISLAND-WIDE GRID

B-4 Location map of Location A, B and C

ISLAND-WIDE GRID

ISLAND-WIDE GRID

B-6 Location map of Table 4.1

ISLAND-WIDE GRID

B-7 Location map of Fig 4.10

ISLAND-WIDE GRID

B-8 Location map of Table 5.2a

ISLAND-WIDE GRID

ISLAND-WIDE GRID

B-10 Location map of Jurong West

ISLAND-WIDE GRID