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Original Article

E Model Development for Land Mobile Radio System

Vivekanand Krishnaji Joshi[1], Kavitha[2]

[1, 2] *Electronics and Communication Department, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai, Tamilnadu, India*

[1] *Corresponding Author: vivekanandkjoshi@gmail.com*

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Abstract - *The Land Mobile Radio System provides a radio voice broadcast system in public and private domains. Public Land Mobile Radio System is used by government departments like police, fire, and ambulance to provide security and safety services to the common man. In these services, radio speech quality is the prime factor for evaluating the performance of radio networks. There are different standards laid for speech quality assessment. ITU-T recommendations G.107, named as E model, is the first step, which provides a unique method to calculate speech quality for telephone networks once all related parameters are known. Later its successive model, G.107.1 and G.107.2 were also developed, but those were focused on wideband and full-band telephone networks. With this background, we have analyzed Land Mobile Radio System used by State Police Department. The study aims to develop a general formula to calculate speech quality based on known radio and its network parameters. E model has developed a formula for speech quality, which relates speech quality to Received RF Signal Strength, Signal Noise Ratio, Signal Interference Ratio, Deviation and Frequency Drift. Our model is successfully implemented on different network architectures used in LMRS System. Results are supported by different statistical methods and have proven successful. They are also tested in the field for different geographical conditions and found 90 to 95 accurate. This model can be used as a Speech Quality Design tool for designing and planning an analogue radio network.*

Keywords - *Wireless E model, Objective speech quality, Analogue modulation, Deviation, Link budget, Repeaters, Link repeater, Signal to noise ratio, Signal to interference ration, Channel spacing, Path loss, Frequency drift, Spectrum analyzer, MOS.*

1. Introduction

The number of licensed radio users in the Wireless communication world is increasing daily. In India, the Department of Telecommunication (DoT) has Wireless Planning and Co-ordination Wing (WPC)[1]. WPC is responsible for spectrum allocation and licensing in India. It produces [2] National Frequency Allocation Plan (NFAP). It provides a regulatory framework specifying frequency bands for various wireless services like cellular mobile, emergency communication, amateur service, defense and security services, police, firefighter and ambulance services etc. LMRS [3], [4] (Land Mobile Radio Service) is the licensed band radio service operating in the VHF (150 MHZ to 174 MHZ) and UHF (400 MHZ and 800MHZ band) range of frequency. It allocates RF transmitter power in the range of 0-25 watts for Mobile Radio and 0-5 watts for Portable (Walkie Talkie) Radio. The sensitivity of typical radios is -119dbm[5]–[8]. It allows high gain antenna up to 6dbi. The aim of such services is to provide voice communication in the range of 0 -10 kilometers with an extended range of 0-100 kilometers with the help of Repeater units with transmitter RF power of 40 watts. With this equipment, it is possible to form a small wireless network covering a 0-5 kilometers range with a single repeater[30]. If multiple such wireless repeaters are cascaded together, it is possible to extend its range to 200 kilometers. State Police, Firefighter, and Ambulance department uses this service to provide security and safety to citizens. This paper aims to predict the speech quality of such a network with known radio and radio network parameters.

In the LMRS network, speech quality is affected mainly by Speaker characteristics, Radio device parameters, and Environmental parameters. In LMRS wireless environment, speech degradation factors differ from that of the wired network like a telephone network or wireless networks such as mobile cellular networks or satellite phone networks. Many protocols and services are available to maintain speech quality in mobile cellular networks. LMRS wireless services are cheap, easy and quickly installable and authorized to operate from specific domain persons like the police. Hence there is less development of speech quality services in this domain.

Speech quality is measured in subjective and objective forms. Subjective methods use opinions from a group of speech listening expert people to rank speech quality in the MOS (Mean Opinion Scale) scale from 0 to 5. So speech quality cannot be unique. However, it is accepted widely as it is easy and human-friendly. Speech quality determination using the objective method is based on speech, parametric or a combination of two methods (hybrid). Speech-based objective methods are classified as intrusive and non-intrusive.

ITU-T recommendations G.107 [31] describes a parametric model known as the E model, which was developed to focus on fixed telephone narrowband networks. Initially, networks were developed only for wideband. Later with the increased demand for services narrow, band services were also introduced. This opens the field for Voice codecs. From time to time, basic E model G.107 is modified to include more and more advanced services.

Despite these changes, the E model algorithm does not consider wireless networks. In this context, there was the demand to develop a tool, like the E model, for simple wireless networks operating in either wideband or narrowband. This tool will be very useful for wireless network planners, designers, and equipment manufacturers.

1.1. Literature Review

There are many other contributions to developing E Model. They are mostly for Voice over IP applications or microwave applications.[11]–[22]. This paper deals with digital communication, focusing mainly on the codec and its imperfections. In a professional analog network, neither digital nor microwave network is used. This paper concentrates on analogue communication network speech quality, which is rarely addressed in the literature.

This paper's main contribution is to propose a general mathematical equation that will give speech quality based on specified input parameters. This method will be based on input parameters which can be practically measured using test instruments. These input parameters are Received Signal Strength, Signal Noise Ratio, Signal Interference Ratio, Deviation and Frequency drift.

These input parameters contain many sub-parameters. For example, Received Signal Strength is a single input parameter. To test its effect on MOS value, RF Signal is given from the RF signal generator to the Radio receiver, and the receiver audio quality is tested for MOS value. This shows a correlation between Received signal strength and MOS value. This is for testing purposes. Received signal strength itself depends on many other factors, like link budget parameters. Thus it is possible to design proper RF signal strength using link parameters.

Likewise, all other main input parameters are tested against speech quality in MOS. Each parameter has associated sub-parameters. They are tabulated in Table 2 in section 3. Hence knowing the relation between the main parameter and speech quality helps us to fix the main parameter value for the required MOS. Accordingly, sub-parameters associated with it can be designed to get the main parameter's designed value.

Thus this E model is very useful for designing and network planning purposes.

The remainder of this paper is structured as below. Section 2 provides an overview of the Existing E model. The wireless models considered for this paper are included in Section 3. The Methodology and Instrumentation details used for calculating the proposed E model are discussed in Section 4. In Section 5, experiments and observations are tabulated. Various statistical methods are carried out, and the results are mentioned in Section 6. Section 7 is the Conclusion of this paper.

2. Overview of the Existing E model

The existing E model mentioned under ITU T recommendations G.107 considers five main factors (Basic signal to noise ratio, Delay factor. Processing imperfections circuit limitations and transmission non-related factors) responsible for speech degradation. Each main factor is composed of related sub-factors, as shown in Figure 1. The total degradation factor (R) is mathematically related to Speech quality expressed in MOS. The total flow is shown diagrammatically in Figure 1.

3. Overview of the Wireless Model used in this Paper

It consists of the following components.

3.1. Basic Radio Unit

Portable or Mobile Transreceiver (TRX). Portable TRX consists of a programmable transmitter and receiver. Its transmitter power is limited to 1-5 watts. It has a receiver sensitivity of -119 dbm at 12 db SNR. The Mobile TRX consists of a programmable transmitter and receiver. Its transmitter power is limited to 25 watts. It has a receiver of sensitivity -119 dbm at 12 db SNR. For both portable and Mobile TRX, the default operation is the receiver. The transmitter can be activated by pressing Press to Talk (PTT) switch.

3.2. Repeater Unit

It consists of two TRX units. One TRX is used as the receiver, and the other TRX is used as the transmitter. When user-1 presses PTT on his portable/mobile and speaks, voice transmission occurs at frequency A. Please refer to Figure 2. This RF signal is transmitted through the air and received at the Cell Repeater receiver.

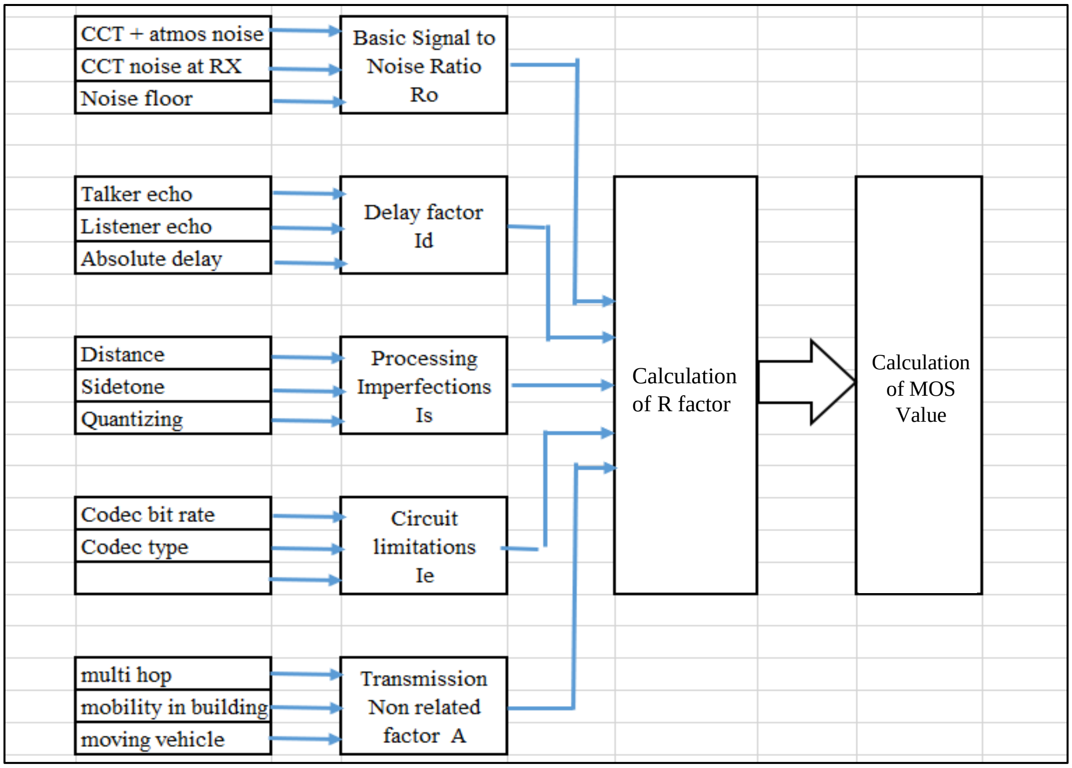

Fig. 1 Theme of e model mentioned in G.107

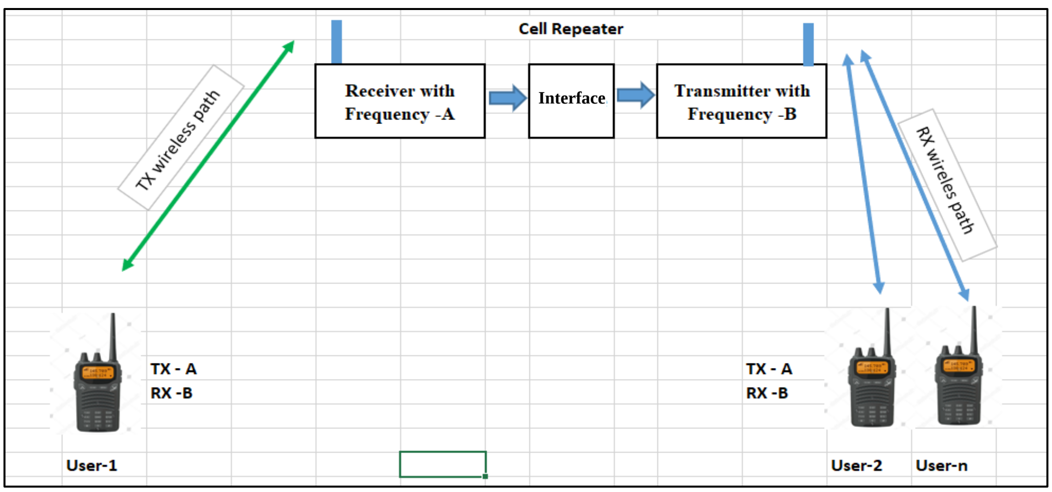

Fig. 2 Single cell architecture of wireless network

The signal received by the receiver is demodulated, and audio with the transmitter turned ON signal is fed to the transmitter. The transmitter is turned on, and the RF signal is transmitted at frequency B. This signal is received by the receiver of all other users (except user-1, as its transmitter is ON). Wireless networks can be organized with Single Repeater Architecture or Multi Repeater Architecture.

3.2.1. Single Repeater Architecture

A Single Repeater Architecture consists of a single Repeater unit. Users may use portable or mobile radios depending on whether they are moving or static. The frequency planning for the cell is shown in Figure 1. It consists of one frequency pair per cell. The portable radio at user-1 transmits its voice through a modulation process and sends it to Cell Repeater. The cell Repeater receives this frequency, its audio is recovered, and the audio and control signal is sent to the transmitter through the interface unit. Then that audio is modulated using Cell Transmitter and sent through a high-gain antenna in the air. The signal received at the user end (user 2 to user n as shown in Figure 1) and audio of user 1 is heard at a distinct end.

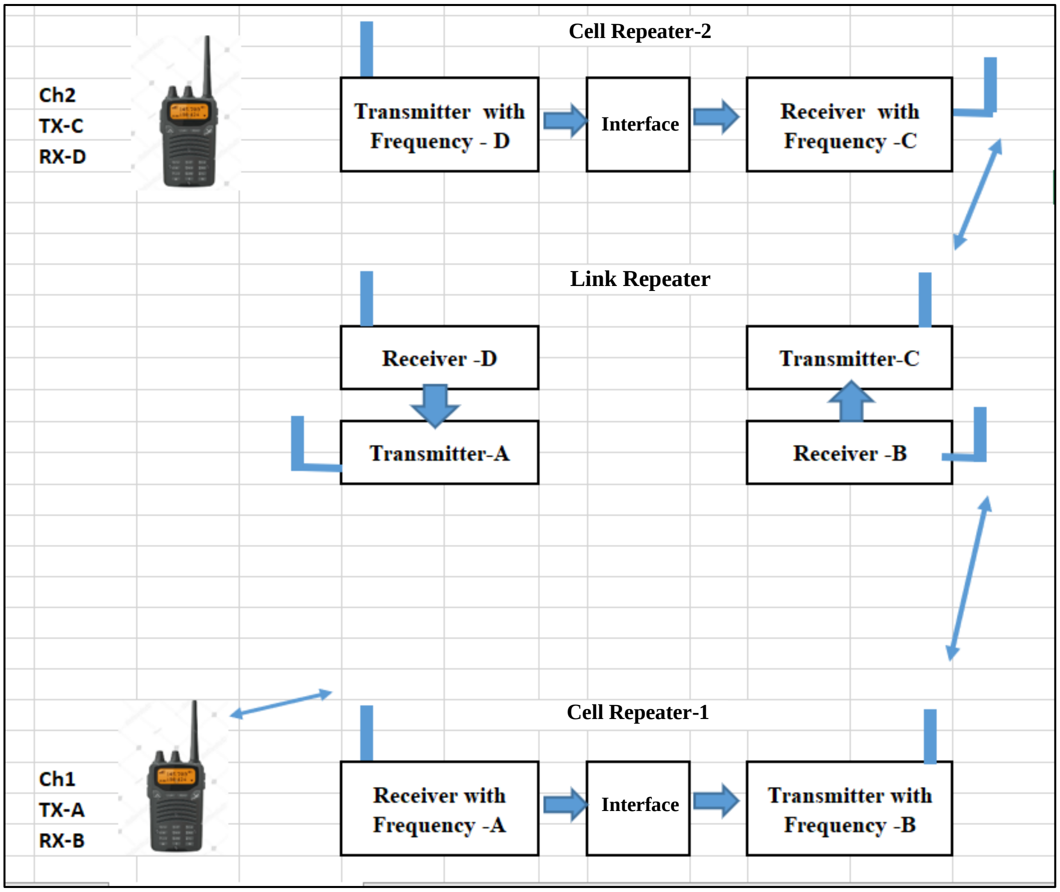

Fig. 3 Multi cell architecture of wireless network

Table 1. Test instruments and testing

Sr.	Name of Testing	Test instruments		Other supplementary instruments
		For input	For output	
1.	Correlation between RF Signal strength and MOS value.	RF Signal Generator with external modulation input.	RF Signal is applied to Radio Receiver, and output audio is tested for MOS value.	Frequency counter and Deviation meter.
2.	Correlation between Signal noise ratio and MOS value.	RF Signal generator + Noise generator + Receiver multi coupler	RF Signal with noise is applied to Radio Receiver, and output audio is tested for MOS value.	Frequency counter and Deviation meter.
3.	Correlation between Signal to Interference ratio and MOS value.	RF Signal generator + RF signal generator as interference representation + multi-receiver coupler	RF Signal with interference is applied to Radio Receiver, and output audio is tested for MOS value.	Frequency counter and Deviation meter.
4.	Correlation between deviation to and MOS value.	RF Signal Generator with variable external modulation input. Moreover, the deviation meter is connected to the input.	RF Signal is applied to Radio Receiver, and output audio is tested for MOS value.	Frequency counter
5.	Correlation between Frequency drift and MOS value.	RF Signal generator.	RF Signal is applied to Radio Receiver, and output audio is tested for MOS value.	Frequency counter and Deviation meter.

Table 2. Main testing parameters and their dependencies

Sr.	Main Parameter	Dependency factors
1.	Received signal strength	1. Transmitter Power 2. Transmitter coaxial cable loss 3. Transmitter antenna height, gain and orientation towards repeater or user depending on network architecture. 4. Signal loss along the path of propagation. 5. Receiver antenna height, gain and orientation. 6. Receiver coaxial cable loss 7. Receiver sensitivity.
2.	Signal Noise Ratio at the receiver input	1. Environment noise 2. Circuit noise
3.	Signal-to-interference ratio	1. Receiver antenna orientation and directivity with transmitter antenna orientation and directivity at the Repeater station. 2. Location of other electrical and electromagnetic interference sources' directivity and their power.
4.	Deviation	1. Speaker Sex, age and fluency in spoken language. 2. Microphone type, gain, polar pattern.
5.	Transmitter frequency drift	1. Stability of Reference oscillator crystal

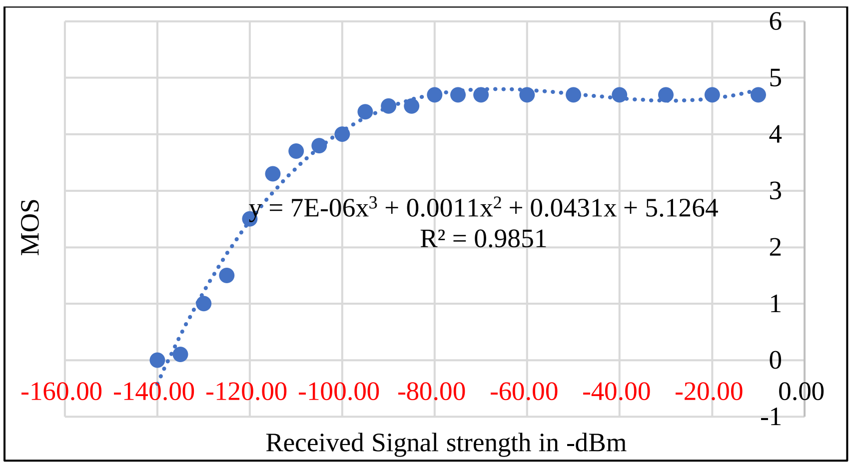

Fig. 4 Correlation between received RF signal strength and MOS

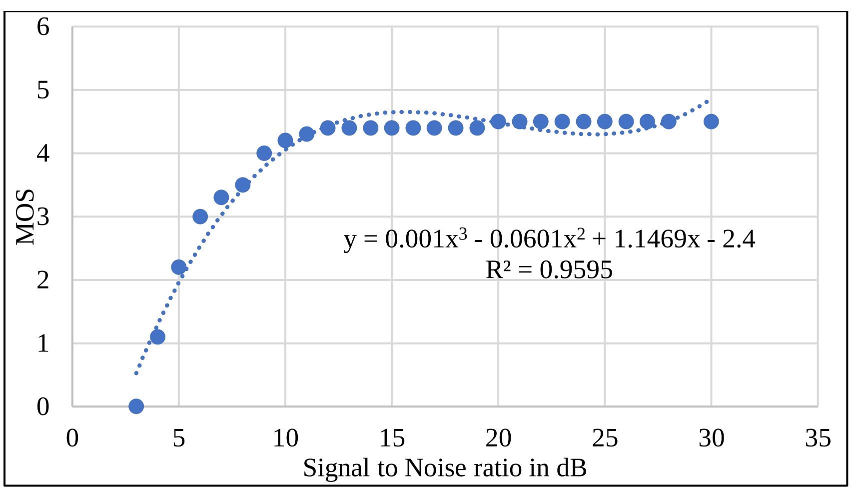

Fig. 5 Correlation between signal to noise ratio and MOS

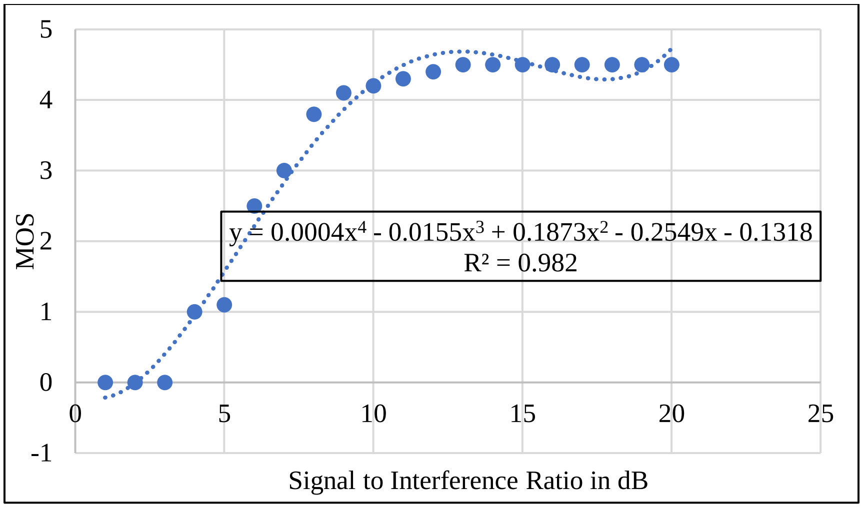

Fig. 6 Correlation between signal to interference ratio and MOS

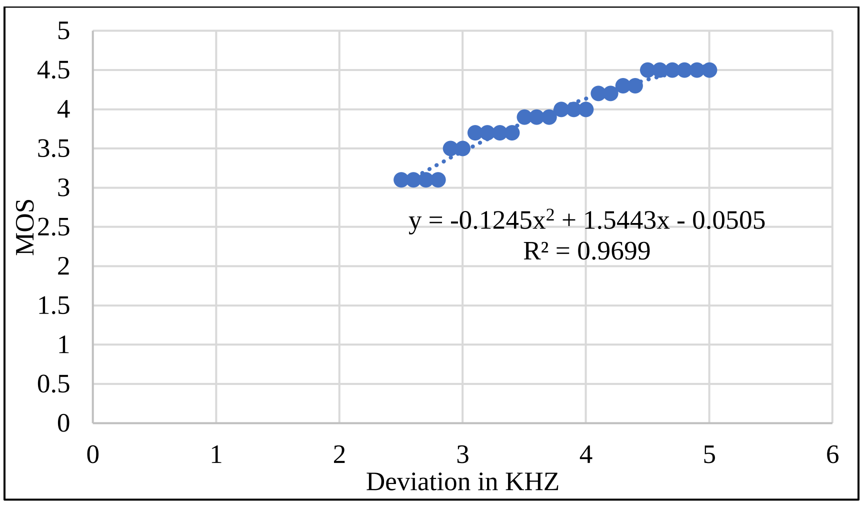

Fig. 7 Correlation between deviation and MOS

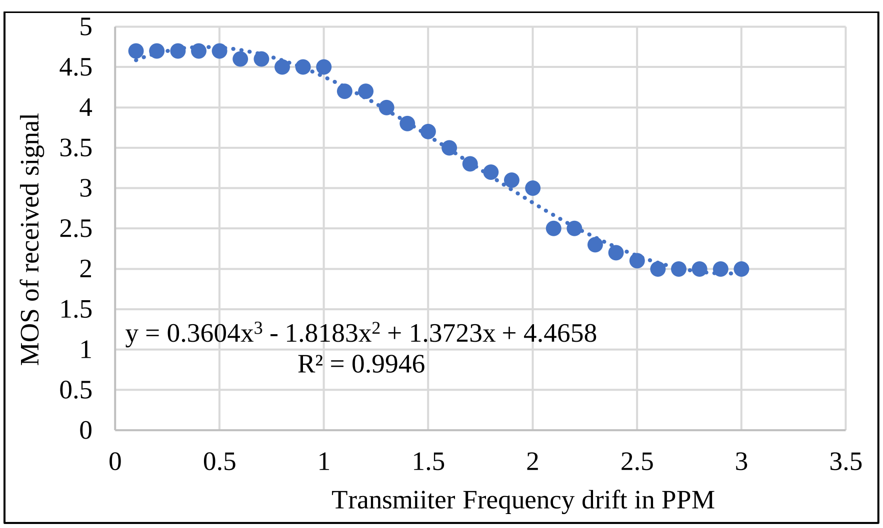

Fig. 8 Correlation between transmitter frequency drift and MOS

Table 3. Results of multiple regressions

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-1.582665384	2.610901276	-0.60618	0.54928121	-6.9308542	3.76552344
Signal strength	-0.014723411	0.022199668	-0.66323	0.51260915	-0.06019737	0.03075055
SNR	-0.056144005	0.022818247	-2.46049	0.02030578	-0.10288507	-0.00940294
Interference	0.037325022	0.039671704	0.940847	0.35482982	-0.04393878	0.11858882
Deviation	1.211511135	0.172646305	7.017301	1.2433E-07	0.85786121	1.56516106
Drift	-0.322170877	0.327952562	-0.98237	0.33433022	-0.99395125	0.34960949

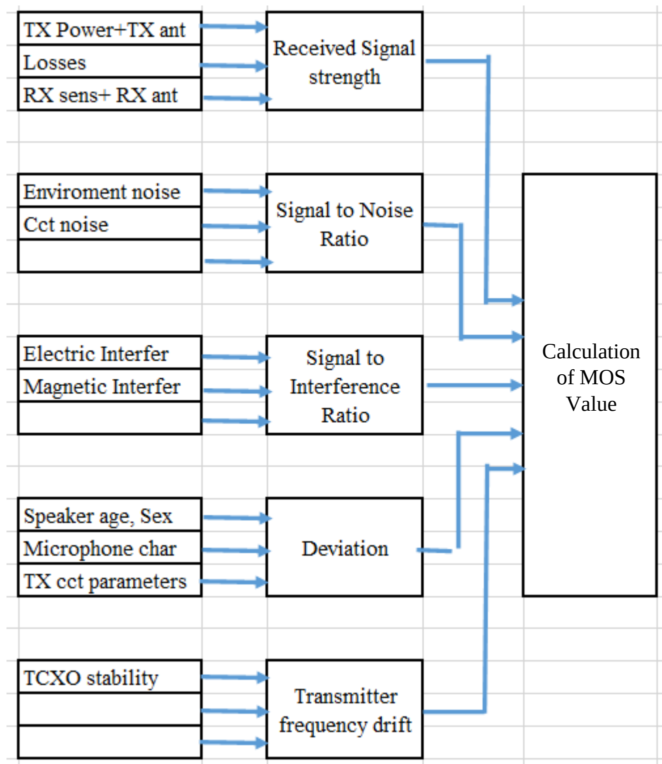

Fig. 9 Our e-model scheme

The signal received at a distinct end receiver is termed received signal strength. This signal strength depends on the link budget [26]. It is given by the mathematical formula given below.

$$\text{Received signal strength} = Ptx+Gtx+Grx-Pl-10\log_{10}(kT)-10\log_{10}(B)-NF$$

Where, Transmitter Power (Ptx), Gain of Transmitting antenna (Gtx), Cable loss at transmitter and receiver cable, path loss, and Receiver antenna gain (Grx) are major contributors to receiving RF signal strength.

3.2.2. Multi Repeater Architecture

In practical wireless communication, a single-site communication range is normally insufficient to complete communication needs. So one more cell repeater, 2, is connected to cell repeater 1 through Link Repeater.

One such multi-cell architecture is shown in Figure 3. For each cell, single frequency pair is required. Hence n number of cells requires n frequency pairs (n*2 actual frequencies), n cell repeaters and n/2 link repeaters. Such multi-cell architecture is required in wireless communication. At each stage of the cell repeater, signal to noise ratio is improved. The deviation level can be adjusted. However, interference at each repeater becomes an additive term degrading signal quality.

While using multi-linking repeaters, some annoying noise causes degradation of speech quality. It can be removed using the technique described in [27]. These analogue networks do not use speech coders, so their effect is neglected. The effect of environment and coder is described in [29].

4. Methodology and Instrumentation used

The testing is carried out with the following preparation mentioned under subsection 4.1, test instruments and Procedures are mentioned under subsection 4.2, and dependencies are mentioned under subsection 4.3.

4.1. Testing Preparation

The following are preplanned.

4.1.1. Speaker Selection

In all these experiments, we have considered skilled wireless operators (male and female) aged 25 to 50. All conversation is carried out in the Marathi language, which is the native language of all speakers. The audio level of all speakers was different, and their pronunciation was different, even though they were talking in the same Marathi language.

4.1.2. MOS Score Selection

The value of MOS is decided by averaging the opinion of experienced listeners. These listeners regularly work on wireless networks for more than 10 years with the same job.

4.2. Test instruments and Procedure

It is carried out as per Table 1.

4.3. Dependencies

For each of the testing mentioned in section 4.2, dependencies or sub-parameters of the Main parameters are as mentioned under Table 2.

5. Experiments and Observations

For each of the experiments carried out under section 4, the following are the results. The results are tabulated, and regression analysis is carried out for each test.

5.1. Correlation between RF Signal Strength at the Receiver End and MOS Value of Speech Quality

To carry out this experiment, RF signal strength is varied and applied to the receiver under test. The receiver output is tested for tone input and speech input in the Marathi language. Correlation between received RF signal strength and MOS are shown in Figure 4.

5.2. Correlation between Signal to Noise Ratio at the Receiver End and MOS Value of Speech Quality

Correlation between Signal to noise ratio and MOS are shown in Figure 5.

5.3. Correlation between Signal Interference Ratio and MOS Value of Speech Received

Correlation between Signal to Interference ratio and MOS are shown in Figure 6.

5.4. Correlation between Deviation and MOS Value of Speech Received

Correlation between deviation and MOS are shown in Figure 7.

5.5. Correlation between Transmitter Frequency Drift and Received Signal MOS Value

With these experiments, we found that Received signal strength, Signal noise ratio, signal-to-interference ratio, deviation value and transmitter frequency drift are five major factors which decide the MOS value of the received signal. The correlation between each of these parameters and the MOS value is shown mathematically on the graph. When carrying out the regression test, each experiment showed an R-squared value of more than 0.98. It indicates that the curve and its mathematical representation accurately represent the relation between two related quantities. Practically looking into the reality of the results shows that most of the radio and allied devices used in such networks are available with these types of specifications. Hence minute variations in the results are expected. Correlation between Transmitter frequency drift and MOS are shown in Figure 8. Results of Multiple regressions are shown in Table 3.

6. Results

If multiple regressions are carried out for all these five factors against the MOS value, then found that is given by,

MOS value at receiver output = -1.58267-0.01472*(Signal strength in dbm)-0.05614*(Signal to Noise ratio in db)+0.03732*(Signal to interference ratio in db)+1.21151*(Deviation in KHZ)-0.32217*(Transmitter frequency drift in ppm)

The E model developed by us is completely devoted to the wireless network of the characteristics of mentioned LMRS system mentioned in the Introduction section. Figure 9 shows the basic theme of the E model developed for us. The results are well verified under any practical wireless network.

7. Conclusion

It is clear from the results of experiments and the use of statistical methods that the E model developed by us produces results that are very close to real practical results. The individual parameters of these models also have a very good value of R square and RMSE value.

Hence these results are trustable. We have compared the results of our E model with practical cases in different network configurations with different radio devices from different manufacturers, results are 95 percent accurate. We have tested these results for VHF and UHF analogue radio networks, which are the most useful and popular networks among the concerned organizations. Further investigation of each sub factor's role in the E model is possible. Our main findings are that the developed E model can be successfully used to mathematically find the Speech quality of VHF and UHF analogue radio networks. Hence it will be very useful for radio network designers and planners. Once speech quality is calculated based on the E model, further it can be modified by modifying related parameters.

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