# DESIGN, IMPLEMENTATION, AND ANALYSIS OF ADAPTIVE M-ARY FREQUENCY SHIFT KEYING ON GSM VOICE CHANNEL

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**Abstract**

**A mobile voice channel is a high priority service in cellular communication systems, has a wide coverage, and is almost always available. With these advantages, mobile voice channels can be used to transmit digital data remotely in rural areas that are not covered with 3G/4G networks. Non-adaptive modulation configuration must work on the lowest AMR rate, so the configuration is not optimal for higher channel rates. To optimize the data transmission rate within an AMR channel, we proposed an adaptive M-ary Frequency Shift Keying (MFSK) modulation method with a zero crossing demodulator. The Adaptive MFSK modulation is designed to adjust its modulation configurations based on a quality of the channel that shown by vocoder rate. In this project, using signal quality indicator provided by GSM modem, the modulator adjust its symbol time length to fit the maximum bit error rate (BER). Demodulator detects the symbol without need the symbol length information and counts the bit error rate. The adaptive MFSK modulation proposed in this research has higher data rate than fixed lower rate modulation in the similar BER range. The adaptive modulation has lower BER than fixed higher rate modulation in the similar data rate range.**

**Keywords: adaptive modulation, MFSK, voice channel, zero crossing demodulator, adaptive multi rate.**

## 1. Introduction

The proposed communication system in this thesis is based on the need for a more reliable communication system to transmit data from weather stations to the monitoring station. In a previous research conducted by Oka Mahendra [1–4], we have made an intelligent data logger system. The data logger reads the data from the sensors which can be configured based on the type of sensor and sensor value [1]. Communication system using Short Message Service (SMS) was added in the data logger [2]. By using SMS, the data transmitted from the sensor from a remote station (data logger) to the monitoring station (master). SMS data transmission system used in these systems is reliable, but it is relatively expensive. For a cheaper solution, we developed a communication system for data logger with General packet radio service (GPRS) [2]. GPRS systems meet the constraints in the network coverage and reliability. For data communication system in weather stations, failure rate on the GPRS system is 5.7 % [3] and 5.18 % [4]. To improve the reliability, the chosen alternative solution is to modulate the data on the mobile voice channel, because the use of the mobile voice channel is considered quite reliable and has wide coverage in each region.

In this research, the data will be modulated on the mobile voice channel. Testing will be performed primarily on the Global System for Mobile Communications (GSM) voice channel. We plan to use this channel for the weather stations of P2I (Research Center for Informatics) LIPI (Indonesian Institute of Sciences). Some of them will be placed in Cimahi, Bangka, Belitung, and Jakarta.

Communication system through GSM voice channel has been proposed by several previous researchers. Rashidi [5] proposed and tested a method of digital data transmission over GSM voice channel. Chmayssani[6] used Quadrature amplitude modulation (QAM) and Frequency shift keying (FSK) modulation technique. This method is specifically used to address speech coder algorithm and Voice Activity Detector (VAD). The simulation results in a throughput of up to 3 kbps and bit error rate less than $3x10^{-3}$. . To make modulation-demodulation system more flexible, the new method proposed by Dhananjay [7], which is called Hermes. Hermes was developed to transmit digital data through an unknown voice channel characteristics. Binary frequency shift keying (BFSK) modulation was used. Ali [8] conducted research to find most optimal MFSK configuration on the GSM voice channel. In a research conducted by Ladoe [9], data are encoded into the symbols, and the symbols are voice coded as they were speech, modulated into the GSM signal, sent over the air, GSM demodulated, voice decoded, and converted back to data.

The major challenges in the data communication over a mobile voice channel are the operation of speech coder or vocoder (AMR) and Voice Activity Detector (VAD) which makes the voice signal quality decreases. These challenges already have been addressed by previous researchers [5]-[9] with non-adaptive modulation configuration.

The other problem in sending data over mobile voice channel is how to get optimal effective data rate according the AMR rate. The optimal modulation configuration must be adaptively adjusted according the rate of AMR. If it is not adaptively adjusted, the modulation configuration will be chosen from the one that works at the lowest rate of AMR, whereas the other modulation configuration may obtain higher data rate at higher AMR rate. With the fixed modulation configuration, the effective data rate is not optimum.

The adaptive MFSK modulation proposed in this research has higher data rate than fixed lower rate modulation in the similar BER range. The research objective can be mentioned as follows: (1) designing of an adaptive m-ary frequency shift keying (MFSK) for data communication between a remote weather station and master station, (2) implementation of the modulator and demodulator of the adaptive MFSK, and (3) analysis of the experiment and the possibility of using the adaptive MSFK modulator and demodulator for the data communication.

## 2. GSM Adaptive Multi Rate codec

There are hundreds of millions of new phones every year constructed. So it is necessary that a standard should be working on them, whenever a new phone is built, and it should be compatible with old technology. Adaptive Multi Rate (AMR) [15] is operated at various bit rates and can be built into every GSM and WCDMA phone. This scheme works on virtually any wireless phone.

The GSM AMR Adaptive Multi-Rate (AMR) vocoder is an Algebric Code-exited linear prediction (ACELP) vocoders. And for adaptive multirate, the bit rates of the codec are 4.75, 5.15, 5.90, 6.70, 7.40, 7.95, 10.2, or 12.2 kbps. Here the focus is on concerning ETSI standard: basic theoretical background for voice production, voice coding and different types of vocoders.

## 3. Design and Implementation

### 3.1 Adaptive Modulation Design

The research design is shown in Figure 1. The design of adaptive modulation systems is used to overcome channel quality rate variations automatically. Modulation and demodulation functions will be designed and implemented with hardware and software embedded in the microcontrollers.

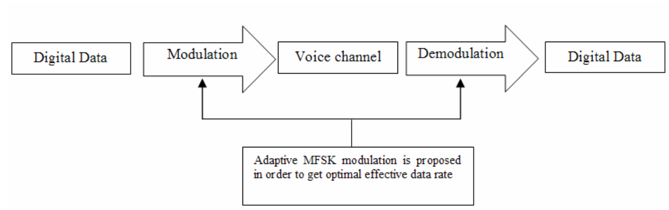


**Figure 1** Research design

### 3.1.1 Feedback Approach

Figure 2 shows the adaptive scheme proposed in this research. The transmitter receives feedback from the receiver in the form of BER estimation for each modulation configuration. In this research, the BER estimations will be carried out continuously by the pilot message method.

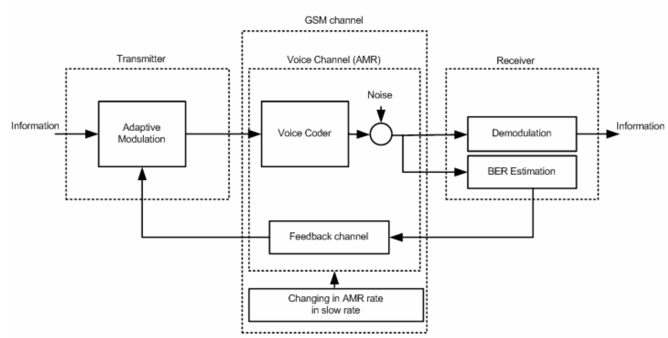


**Figure 2** Proposed adaptive modulation with feedback channel

### 3.1.2 Signal Strength Indicator Approach

Using feedback channel requires a complex systems design. The system also requires two channels for transmitting information in one direction only. Another alternative proposed in this project is to use an adaptive modulation method without feedback as shown in Figure 3. The transmitter uses signal strength indicator from the modem to get an estimation of channel condition. The signal strength and quality of signals received by Base Stations (BS) and Mobile Stations (MS) can be influenced by effects resulting from the movement of the mobile, the overlay of numerous delayed signals caused by reflections, and the other interferences [12]. This phenomenon is called fading and is classified in profiles such as Constant Phase, Pure Doppler, Rice, Rayleigh and Moving Propagation fading.

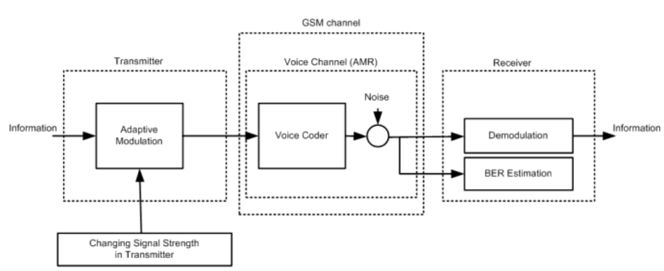


**Figure 3** Proposed adaptive modulation without feedback channel

### 3.2 Modulator Implementation

A modulator was built using a microcontroller for generating sinusoidal codes, a digital to analog converter to generate sinusoidal waves, and an audio amplifier. Figure 4 shows the circuit schematic of the modulator.

The purpose of the modulator is generating an audio signal where its frequency can be controlled by a microcontroller. The audio signal is generated by a sinusoidal wave created by the digital to analog converter (DAC). The DAC is composed of a series of R-2R ladders. The DAC input is given by the microcontroller to generate a sine wave with a desired frequency. The microcontroller uses a look-up table to generate the sampling values of the sinusoidal signal. The sinusoidal signal is amplified by an audio amplifier, which on the prototype uses the LM386 op amp. In the prototype, we used an ATMega8535 microcontroller.

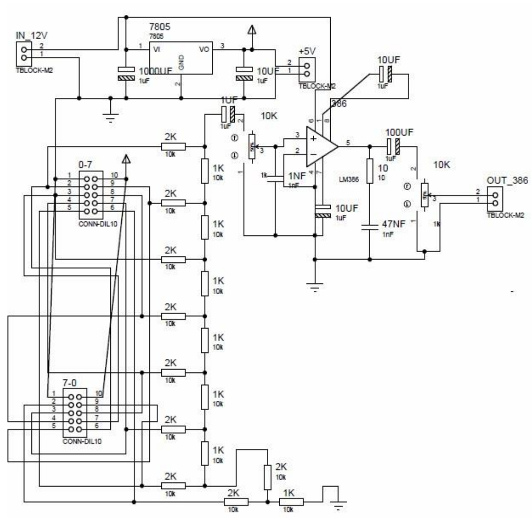


**Figure 4** Schematic of the modulator

### 3.3 Demodulator Implementation

Demodulator uses the principle of the zero-crossing detector. A zero-crossing detector is made using a comparator. In the prototype, we use the LM393 circuit as shown in Figure 5. The subsequent output of the comparator is read by the microcontroller to obtain the signal period. In the prototypes, we used an ATMega8535 microcontroller.

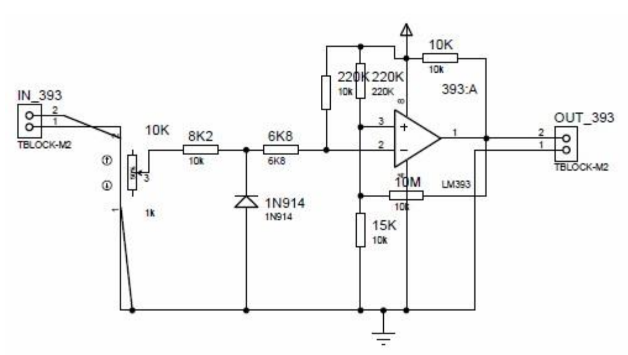


**Figure 5** Schematic of the demodulator

## 4. Data and Analysis

### 4.1 Single tone GSM Voice Experiments

The single tone audio was transmitted using GSM voice channel. The modem that used in the experiments is Fastrack Xtend with Indosat IM3 mobile operator. The frequencies that sent was chosen by the most effective modulator code shown in appendix 1, they are 200 Hz, 395 Hz, 600 Hz, 795 Hz, 1000 Hz, 1196 Hz, 1391 Hz, 1596 Hz, 1792 Hz, 1997 Hz, 2192 Hz, 2387 Hz, 2592 Hz, 2788 Hz, 2993 Hz, 3188 Hz, and 3384 Hz. We make 1000 times of demodulator reading for each frequency. The test result is shown in Figure 6.

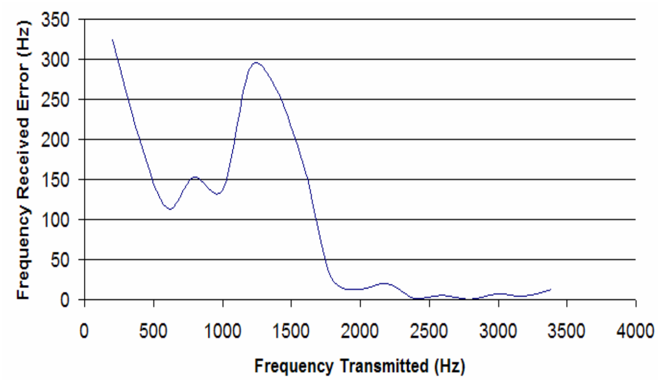


**Figure 6** Demodulation error at different frequencies through GSM voice channel after averaging 1000 data and filtering <3500 Hz only

### 4.2 The proposed modulation system performance

Experiments using the adaptive modulation system proposed in this research was conducted. The first experiment M from 2, 4, and 8. The second experiment uses fixed 4-FSK with varying symbol time.

#### 4.2.1 Adaptive M-ary modulation with fixed symbol time

The frequencies selected for M-ary FSK carrier is based on the previous experiment using single tone that gives low error rate. The carier frequencies are: (1) BFSK used frequencies: 1997 Hz and 3188 Hz, (2) 4-FSK used frequencies: 1997 Hz, 2387 Hz, 2788 Hz, and 3188 Hz, and (3) 8-FSK used frequencies: 1997 Hz, 2192 Hz, 2387 Hz, 2592 Hz, 2788 Hz, 2993 Hz, 3188 Hz, and 3384 Hz.

Figure 7 shows for all m-ary FSK scheme BER increases when bitrate was increased. For the same symbol rate, the lower modulation scheme gives lower BER with lower bit rate. Based on this experiment, symbol time 6.3 baud was selected for the adaptive modulation scheme. The adaptive modulation scheme was based on Relative Signal Strength Indicator (RSSI).

### 4.2.2 Adaptive 4-FSK with varying symbol time

Four frequencies were selected as carrier frequencies: 1997 Hz, 2387 Hz, 2788 Hz, and 3188 Hz. Demodulator decides the symbol by the nearest symbol value that is shown in this line of this program:

```
if (frequency>1797 && frequency<=2192) symbol = 3;  //1997 Hz
if (frequency>2192 && frequency<=2587) symbol = 5;  //2387 Hz
if (frequency>2587 && frequency<=2953) symbol = 1;  //2788 Hz
if (frequency>2953 && frequency<=3400) symbol = 4;  //2788 Hz
```

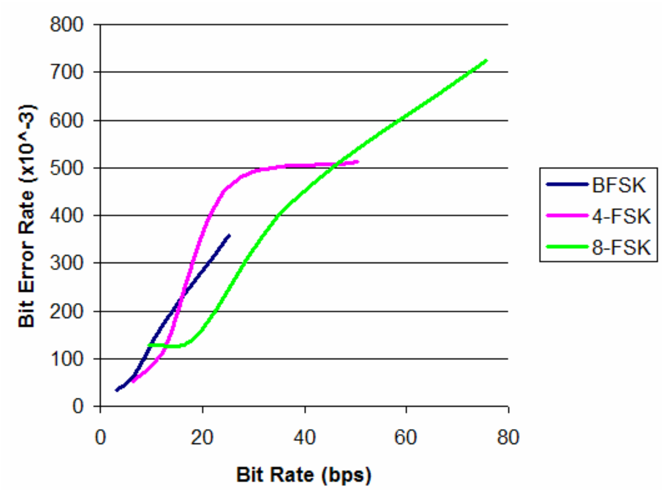


**Figure 7** M-ary FSK performance for various M-ary and symbol rate at average RSSI value = 28

For experiments of performance of the modulation scheme, the system used 1000 bit data for testing. The modulator send the data at fixed or adaptive symbol time, then demodulator count the bit error rate. The performance of the system is shown in table 1.

**Table 1** Performance of the proposed modulation scheme in 1000 bits sent at average RSSI value = 28

| No. | Code of symbol rate (used by software) | Symbol rate per second (baud) | Bit rate (2 symbols per bit) | BER with feedback channel | BER without feedback channel |
|---|---|---|---|---|---|
| 1. | 8 | 25.2 | 12.1 | $502x10^{-3}$ | $253x10^{-3}$ |
| 2. | 16 | 12.6 | 6.3 | $423x10^{-3}$ | $125\ x10^{-3}$ |
| 3. | 32 | 6.3 | 3.1 | $305x10^{-3}$ | $<10^{-3}$ |
| 4. | 64 | 3.15 | 1.65 | $241x10^{-3}$ | $<10^{-3}$ |

Code of symbol rate is a constant that used by software to determine the symbol length. We add an exponential trendlines for the data from table 1. The exponential equation is:

$$\text{Symbol rate} = 201.6 * (\text{code of symbol})^{-1} \quad (1)$$

Experiment for finding the suitable constant value (C) were conducted. The aim of this experiments is to find the suitable constant value (C) that gives error < $10^{-2}$. The experiment result is shown in the table 2. The smaller constant value inflicts the higher BER and the higher data rate.

**Table 2** BER performance with various constant value for 1000 bit sent with average RSSI value = 28

| No. | Constant Value | BER | Average code of symbol | Symbol rate | Bit rate |
|---|---|---|---|---|---|
| 1. | 800 | $<10^{-3}$ | 28.6 | 7.05 | 3.52 |
| 2. | 600 | $<10^{-3}$ | 21.4 | 9.42 | 4.71 |
| 3. | 500 | $15<10^{-3}$ | 20 | 10.08 | 5.04 |
| 4. | 400 | $20<10^{-3}$ | 14 | 14.4 | 7.2 |

Based on the experiments result that shown in the table 4-4, we decided to use constant value for the adaptive modulation $C$ = 400. So the proposed adaptive modulation model:

$$T \quad \frac{400}{RSSIvalue} \tag{2}$$

with T is the code of symbol time.

With adaptive constant value C=400, the proposed adaptive modulation system achieved BER < 2 x$10^{-2}$ at data rate 7.2 bps.

## 5. Conclusion & Suggestion

### 5.1 Conclusion

The low bit rate of the proposed system occurred because of high error in period measurement by zero crossing detector. The low bit rate affect the decision of using this modulation system in the wireless weather station, with consideration of voice call price charged by the cellular operator. If the price is acceptable, the proposed modulation scheme can be used.

The adaptive modulation scheme with feedback channel affect higher bit error rate (BER) that is not to be expected. This is because of the echo found in the GSM modem when transmitting voice like waveform. The adaptive modulation scheme without feedback channel, but with RSSI value provided by modem can increase the higher data rate with acceptable BER compared with lower fixed data rate. The adaptive scheme without feedback also has lower BER compared with higher fixed data rate.

### 5.2 Suggestion

For better detection methods in the demodulator, the other demodulator technique can be used, for example, frequency filter and Fast Fourier Transform (FFT). With better demodulation techniques, the performance of the modulation system will be expected to be increased.

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