

Design, Simulation and Evaluation of a potential real life Communication System

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Abstract

It is essential for a network professional to have a proper knowledge, both theoretical and practical, of designing, testing, and critically analysing real-world networks, as well as knowledge of emerging and advanced network technologies. Towards this purpose, knowledge of using modelling and simulation software is essential. This report presents an attempt towards demonstrating an adequate amount of knowledge in these areas, of which is divided into two parts. The first part presents a research and evaluation of three modulation schemes: Amplitude Shift keying (ASK), Phase Shift Keying (PSK), and Quadrature Amplitude Modulation (QAM). Following this, the second part presents a design and evaluation of a wireless monitoring network with the scope of tackling a hypothetical public security issue. Finally, the report concludes with a brief overview of the previous evaluations.

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1 Introduction

As described in the abstract, the report is divided into two parts. Each part consists of the following:

Part one – describes the function of modulation in a communication system, as well as presenting research with regards to the following digital modulation techniques:

- Amplitude Shift Keying (ASK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)

The research comprises of a description of each modulation technique, followed by each modulation technique's advantages and disadvantages, as well as a comparison of all three modulation techniques.

Following this, implementation examples of each modulation technique is provided.

Finally, Simulink custom-built models of the ASK, PSK, and QAM systems are presented with the scope of evaluating each modulation technique's performance under different noise levels on the communication channel. With this aim in view, the BER (Bit Error Rate) and SNR (Signal-to-Noise Ratio) are the parameters chosen for evaluating performance.

Part two – presents the design and implementation of a wireless network with the scope of minimizing, detecting and/or preventing crimes, such as theft in rural and urban areas, as well as possession of concealed weapons such as knives and guns.

Multiple factors are taken into consideration with regards to the evaluation of the wireless network's performance, such as:

- wireless communication availability in rural areas,
- extent of reachability to all police stations within the area,
- ability to detect concealed weapons and trigger warnings/alerts to nearby police stations

On the other hand, more technical metrics will be extracted towards the scope of the evaluation and comparison of each of the above mentioned modulation techniques' performance, such as:

- delay
- throughput
- packet loss
- BER (Bit Error Rate) against SNR (Signal-to-Noise Ratio)

Finally, with the above objectives covered, one of the three modulation schemes is recommended as the most fit with regards to the proposed wireless network, covering aspects such as robustness, complexity, and bandwidth efficiency.

The report concludes with a discussion of the subsequent findings, as well as recommendations towards improving future work in the areas of digital modulation techniques and wireless network implementation and design.

2 Function of modulation in a communication system

The process of digital modulation [2, p. 181] is comprised of the transformation of a sequence of digital bits into a waveform. On the other hand, de-modulation corresponds to the process of transforming the received waveform back into its corresponding sequence of digital bits.

Within the context of a typical digital communication system [1, p. 2], the modulator and de-modulator precedes the power amplifier and low noise amplifier, and respectively succeeds the channel encoder and decoder. The figure below presents the modulator/de-modulator's placement within a common digital communication system:

A digital communication system could be more or less complex. However, it is important to note that among other components, the modulator and de-modulator are essential to all digital communication systems, as well as an antenna for wireless systems. [1, p. 2]

3 Communication systems and computer networks

At the base of computer networks, whose purpose is to help computers communicate with each-other, lies information theory.

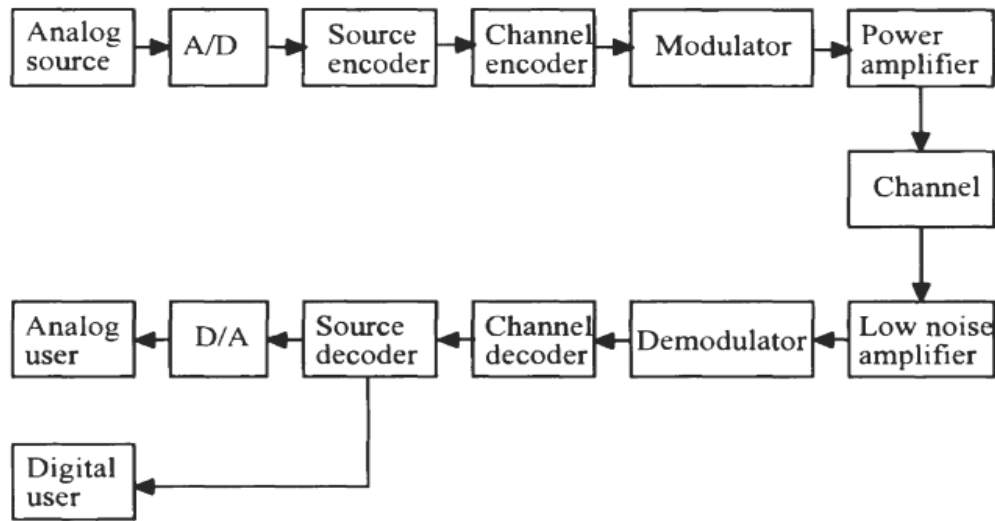


Figure 1: Block diagram of a typical digital communication system [1, p. 2]

Information theory [2, pp. 1-2] states that sources of communication (for example image, video, and audio) should be able to be represented under a binary form.

Furthermore, communication systems should be designed so as to first convert the original source into a binary form (source encoder) and then further convert the binary sequence into the a form suitable to the particular transmission channel (channel encoder). On the other side of the transmission the opposite operations take place, with the help of a source decoder and channel decoder.

As can be seen from the diagram below, the source is first converted into binary with the help of a source encoder. Next, a channel encoder converts the binary sequence into a form suitable for transmission across a particular channel. Once the content is placed, and subsequently, reaches the receiver through the communication channel, the receiving end decodes the channel-encoded binary sequence, then a source decoder is used for recreating the source content back to its original form (image, video, audio).

As a communication system gets more complex, numerous other mechanisms [6, p. 4] have to be implemented, such as:

Multiplexer – Combine signals from difference sources on a single channel

Error detection and correction – Detect errors of received data

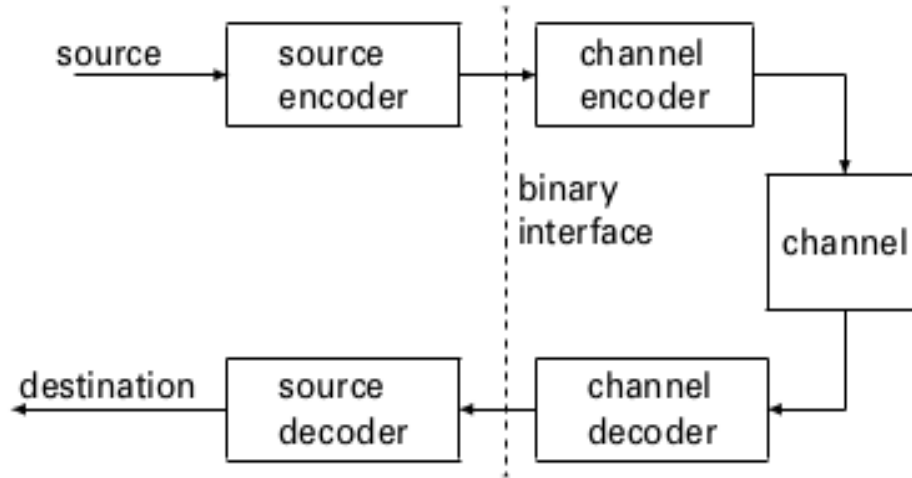


Figure 2: Diagram illustrating the basic architecture of digital communication [2, p. 2]

Source coding – For processing an input signal so that it fits onto a lower-bandwidth channel

Switching – For large networks

Signalling – For helping the network make the necessary operations towards connecting the sender and receiver

As such, the following chapters detail the three previously mentioned techniques of digital modulation. Their purpose, in the context of information theory, is to encode the sequence of binary digits into a form (waveform) suitable for the communication channel (radio-wave transmission), after which it is placed on the communication channel.

4 Amplitude Shift Keying (ASK)

Amplitude Shift keying [3, pp. 370-373], or ASK, is a form of digital modulation in which the amplitude of the carrier varies in accordance with the source binary input. This basic form of modulation is also commonly known as on-off keying, or OOK. In its most basic form, the carrier is switched on and off every couple of seconds T to represent either a value of 1 or 0.

An ASK waveform can be summarized by the following formula, where $s(t)$ is the newly-modulated signal:

$$s(t) = \frac{A}{2} [1 + m(t)] \cos \omega_c t$$

Where A is the amplitude of the carrier, $m(t)$ is the modulating signal (in the case of OOK, 1 and -1) and ω_c is the frequency of the carrier.

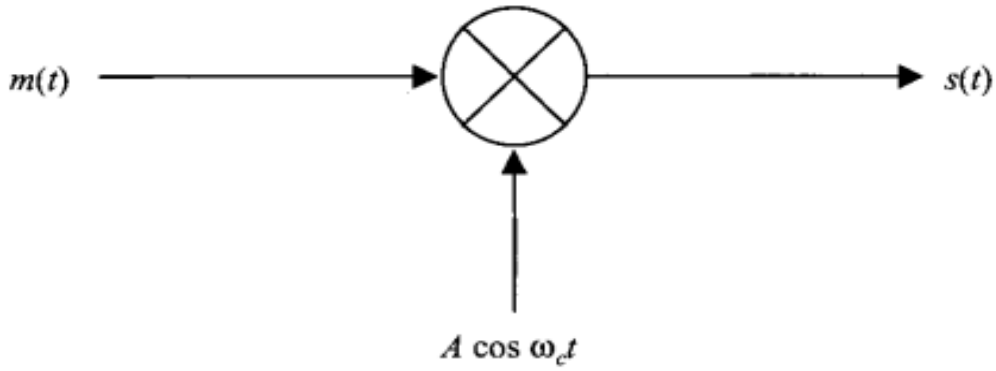


Figure 3: Amplitude modulation [3, p. 370]

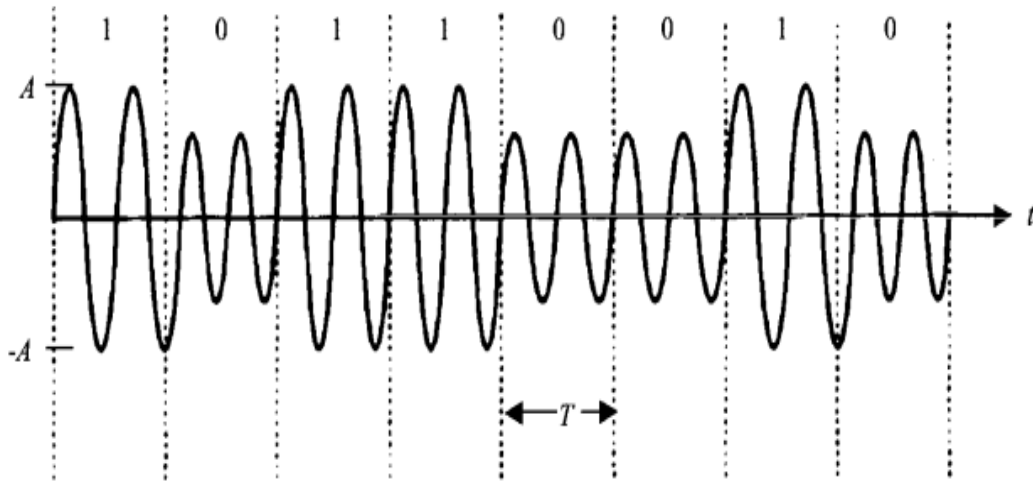


Figure 4: ASK signal [3, p. 370]

De-modulation, on the other hand, is of two categories [3, pp. 372-373]:

Coherent – For coherent detection, a matched filter detection is essential. Each filter presents an impulse response matched to the corresponding modulated signal.

Assuming equal energy on both signals, for OOK a single matched filter is required to detect the presence or non-presence of signal energy.

$$y_1(t) = \frac{A^2T}{2}$$

$$y_0(t) = 0$$

Non-coherent – A non-coherent de-modulator consists of a narrowband filter, an envelope detector, and a decision device.

5 Phase Shift Keying (PSK)

Phase Shift Keying [3, pp. 377-379], or PSK, is another form of digital modulation. This form of modulation consists of changing the phase of the carrier by 180 ° depending on the corresponding source signal. If the source signal is comprised of 1s and 0s, the modulation scheme is called Binary Phase Shift Keying, or BPSK.

The BPSK signal waveform can be summarized as follows:

$$s(t) = \pm A \cos \omega_c t = A \cos (\omega_c t + \phi_j)$$

$$\phi_j = 0 \text{ or } \pi$$

Where ϕ_j is the phase of the carrier.

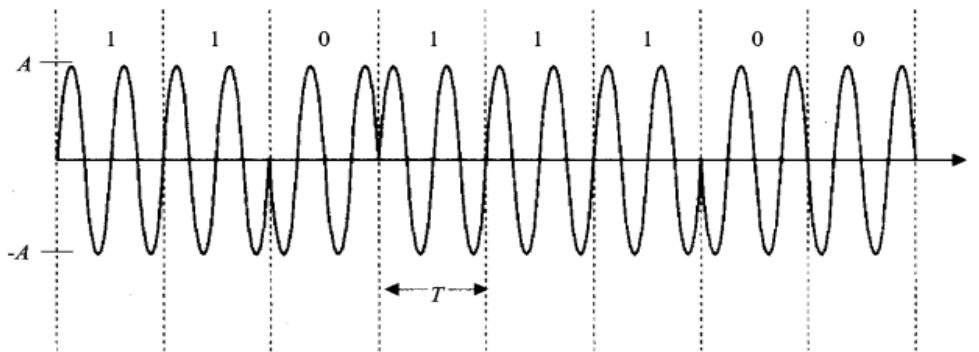


Figure 5: Phase modulation [3, p. 377]

Another form of PSK is Quadrature Phase Shift Keying [4, pp. 43-45], or QPSK. In this case, the number of possible phase shifts is 4 instead of 2. As a result, it can be described as follows:

$$s_i(t) = \sqrt{\frac{2E}{T}} \cos \left(\omega_c t + \frac{\pi i}{2} + \frac{\pi}{4} \right)$$

Where:

E – is the energy of the transmitted signal [4, p. 37]

i – is $(1, \dots, 4)$, depending on the source input value [4, p. 43]

T – is seconds of time

The phase shift, or the transmitted signal, is defined by each 2 bits of the inputted data stream.

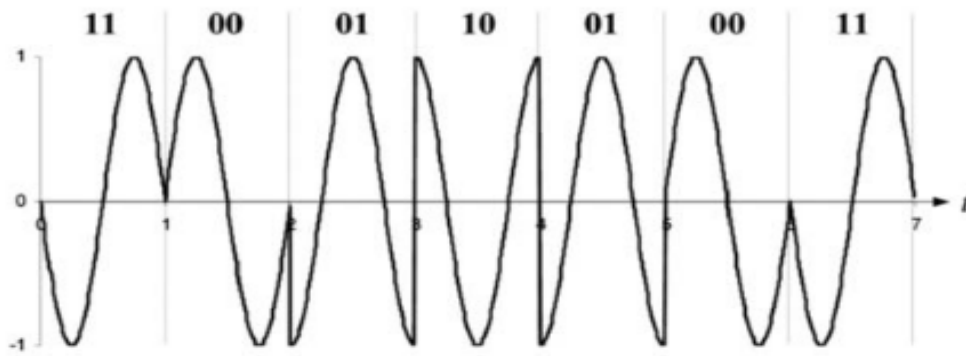


Figure 6: Quadrature Phase Shift Keying [4, p. 45]

6 Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation [7, pp. 44-45], or QAM, is a digital modulation technique which involves the combination of two amplitude-modulated (AM) signals onto a single channel. Additionally, the concept of quadrature modulation is based on the notion of representing the phase angle and magnitude of a signal (or the signal's state) by way of Cartesian x and y coordinates.

Two carriers are present, each containing the same frequency. However, each carrier differs in its' phase. Before transmission, both carriers are combined at the source. Once the combined carriers reach the destination, the

carriers are separated and the data extracted from each. Finally, the extracted data is combined into the original modulating information.

QAM can be described thus [5, p.185]:

$$s(t) = I(t) \cos(\omega_c t) + Q(t) \sin(\omega_c t), \quad -1 \leq I(t), Q(t) \leq 1$$

Where $I(t)$ is the in-phase and $Q(t)$ is the quadrature, after having been transformed from a polar to a Cartesian/quadrature representation:

$$I(t) = A(t) \cos(\phi(t))$$

$$Q(t) = A(t) \sin(\phi(t))$$

Where $\phi(t)$ is the phase shift.

There exist many variations of QAM modulation, such as 16-, 32-, 64-, and 256-QAM. The number represents possible states, where each state represents a specific combination of amplitude and phase. A method of illustrating possible QAM states is through “constellation” diagrams:

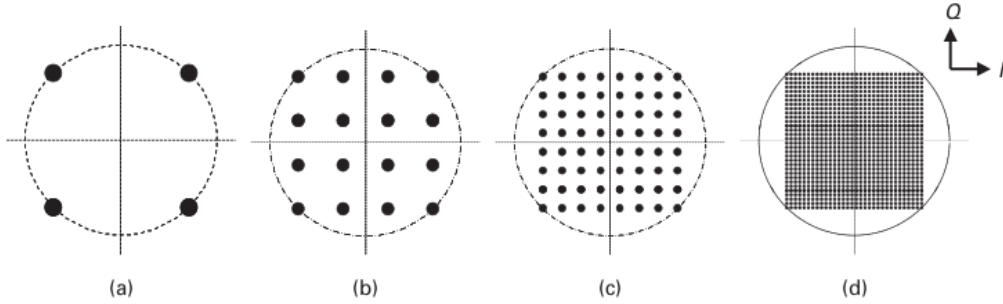


Figure 7: Square QAM constellations. [5, p. 186] 4-QAM (QPSK), 16-QAM, 64-QAM, and 1024-QAM. Q is quadrature and I in-phase. [5, p. 8]

7 Comparison of ASK, PSK, and QAM

ASK – PSK can be seen as a form of ASK (amplitude modulation). However, in the case of PSK, the signal can be filled either by inversion or a 180 degree phase shift of the carrier. [8, p. 158] Furthermore, the concepts of ASK (as well as PSK) combined form the QAM signalling scheme. As such, ASK has a much lower number of possible states in comparison to QAM. [9, p. 31]

PSK – PSK uses DSBSC amplitude modulation, meaning that it requires the same bandwidth as ASK. [10] On the other hand however, there is an

additional 3 dB of transmitter power. [11, p. 475] It has been observed that the bandwidth requirement of QAM is two times lower in comparison to a M-ary PSK signalling scheme. As such, M-ary QAM is a much more efficient signalling scheme than M-ary PSK. [12, p. 25]

QAM – QAM can be summarized as a combination of ASK and PSK. In this sense, a QAM radio wave's characteristics are both its' amplitude and phase shift. Its differing characteristics [13, p. 206] however are the following:

- A four times larger encoding scheme than ASK and BPSK (16-QAM)
- A four times larger minimum bandwidth ($f_b/2$)
- A four times larger bandwidth efficiency (4 in comparison to ASK and BPSK's 1)

8 Examples of implementation

ASK – One can argue that among the first implementations of the ASK concept is found [5, Ch. 4] in the Morse telegraph, through which communication can be performed by the presence or absence of current on a communication wire.

On the other hand, the popularity of ASK rises and falls depending on the current need for minimalistic coding schemes. For example, the need for very simple and low cost DWC applications such as RKE (Remote Keyless Entry) is a suitable candidate for the ASK modulation scheme. [5, Ch. 4]

PSK – An application of PSK is the transmission of digital signals, such as digital television. [14, p. 55] Furthermore, applications of 16-PSK can be found in several WLAN applications. [15, p. 142] Next, PSK is used for very high data rates in satellite channels. [16, p. 21.7] Finally, an $\frac{3\pi}{8}$ -shifted 8-PSK is used for high-speed data transmission in GSM networks. [17, p. 763]

QAM – 16-QAM can be found [13, p. 206] in systems such as:

- fixed terrestrial microwave digital radio
- digital video broadcast cable
- modems

For example, 256-QAM is used for digital CATV applications in the United States. [18, p. 7]

In other words, QAM can be used over a various number of communication channels such as radio, wireline, or fiber. [19, p. 154]

9 Design of a simulation model

With the scope of analysing the performance of the three modulation schemes (ASK, PSK, QAM), a simulation method is employed which makes use of MATLAB's Simulink. The software and hardware specifications of the machine used for the running of the simulation/s is as follows:

Hardware – Lenovo ThinkPad T470 laptop

Software – MATLAB R2019a (9.6.0.1072779) 64-bit

OS – Windows 7 Ultimate 64-bit

CPU – Intel Core i3-7100U CPU @ 2.40GHz, 2 Cores, 4 Logical Processors

Memory – 4GB DDR3 RAM

The objectives, with regards to each modulation scheme are as follows:

1. Design a simulation model, consisting of an input source, modulator, de-modulator, communication channel with (Gaussian) noise, and receiver
2. Run a series of tests with various levels of noise onto the communication channel, using SNR (Signal-to-Noise Ratio) as the metric for measuring the level of noise
3. Extract and analyse the results, which will consist of BER's (Bit-Error Rate)

As such, the following chapter details the implementation of each simulation model.

10 Implementation

ASK – The ASK model consists of the following blocks with regards to modulation:

Bernoulli Binary Generator – Outputs either a 0 or a 1

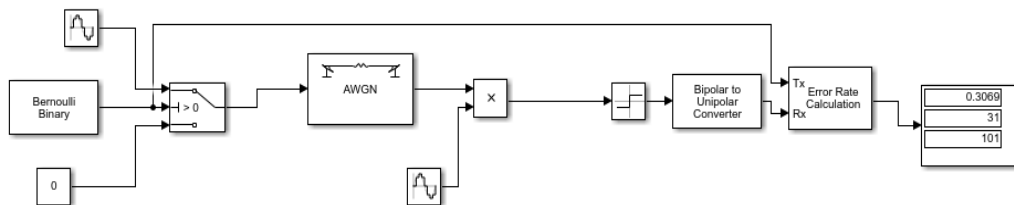


Figure 8: ASK Simulink model

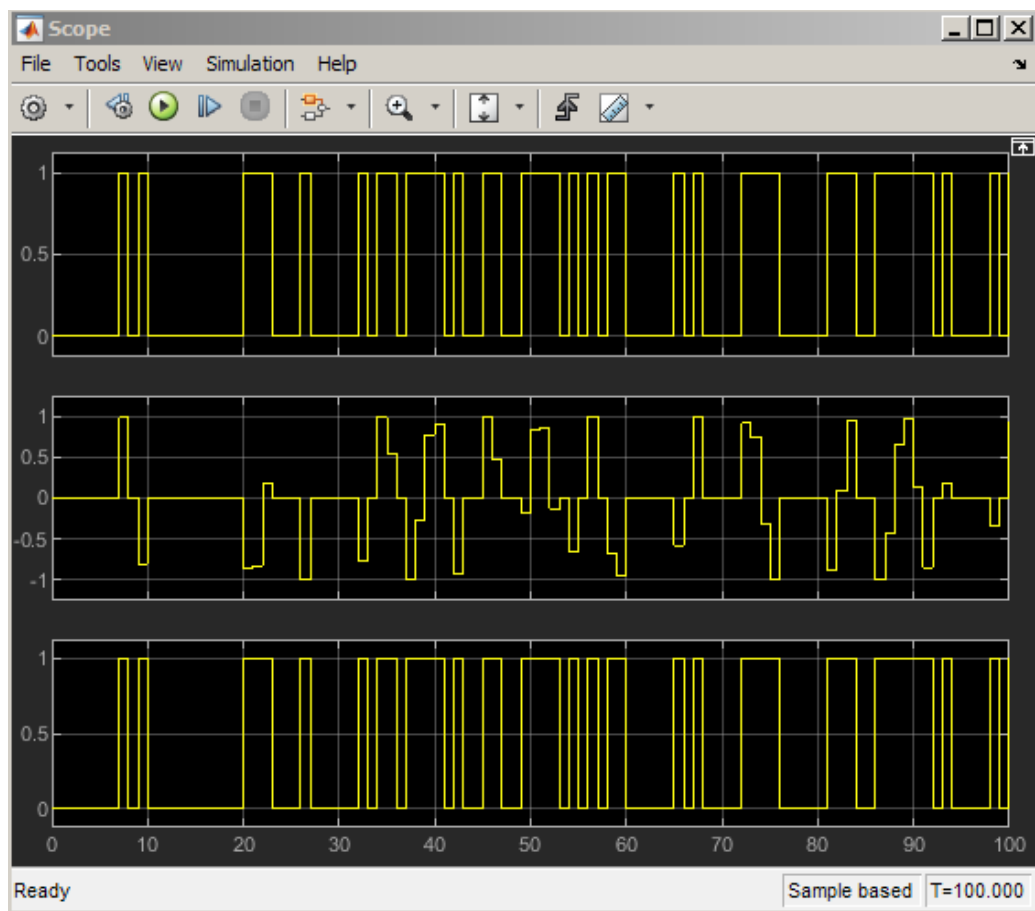


Figure 9: Source input before, during, and after transmission (ASK)

Sine wave – Amplitude and sample time 1, frequency 20 rad/sec

Constant – 0

Switch – Takes output of binary generator as input. Outputs a sine-wave if input is 1, nothing if 0.

As for de-modulation:

Product – Multiplies input (received modulated signal) with original sine-wave

Sign – Takes input, outputs 1 for positive input, -1 for negative input, and 0 for no input

Bipolar to Unipolar Converter – Converts bi-polar input to uni-polar output

PSK – The PSK model consists of the following blocks, listed in left-to-right order:

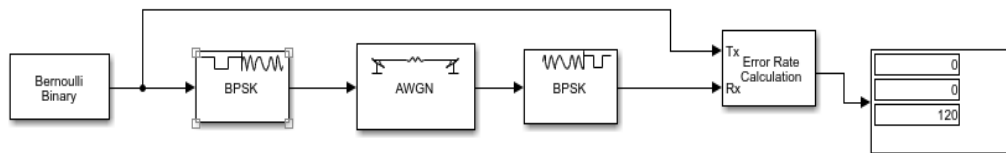


Figure 10: BPSK Simulink model

Bernoulli Binary Generator – Same as above

BPSK modulator – Modulates the signal input according to the BPSK modulation scheme

AWGN – Adds white Gaussian noise to the input signal, with an initial seed of 67. Its mode is SNR (Signal-to-noise Ratio), with an input signal power of 1 ohm (watts)

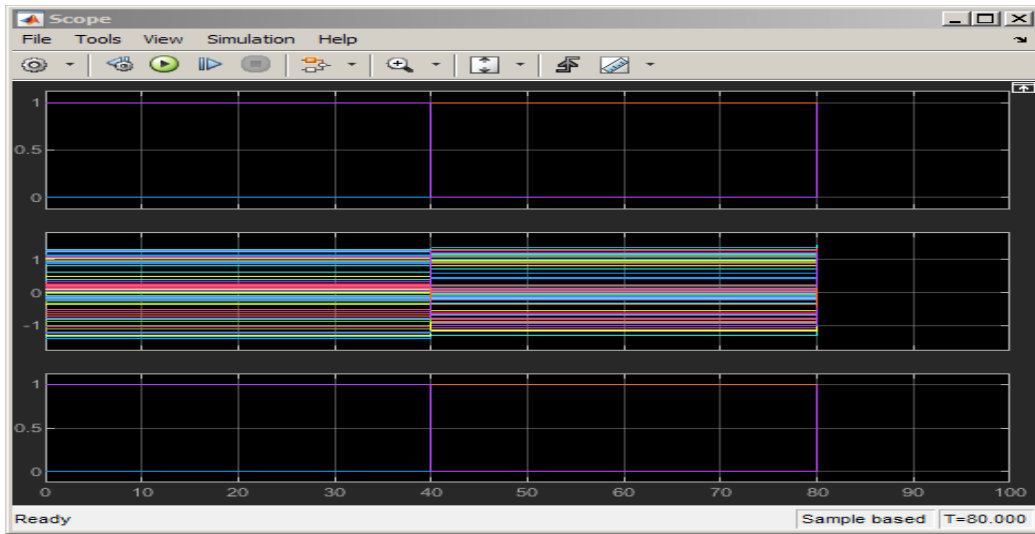


Figure 11: Source input before, during, and after transmission (BPSK)

BPSK de-modulator – De-modulates the signal input according to the BPSK modulation scheme

Error Rate Calculation – Compares the input signal from both the transmitting and receiving end, calculating the BER (Bit Error Rate) as a percentage of error bits out of total bits/symbols transmitted.

Display – Displays the BER

QAM – The QAM model is highly similar to the previously detailed PSK model, with the exception of the following:

- A random number generator with a set size of 16.
- Two constellation diagram blocks are added, taking as input the source signal before and after noise interference with the scope of viewing the effects of noise over the transmitted signal
- Rectangular 16-QAM modulation and de-modulation blocks

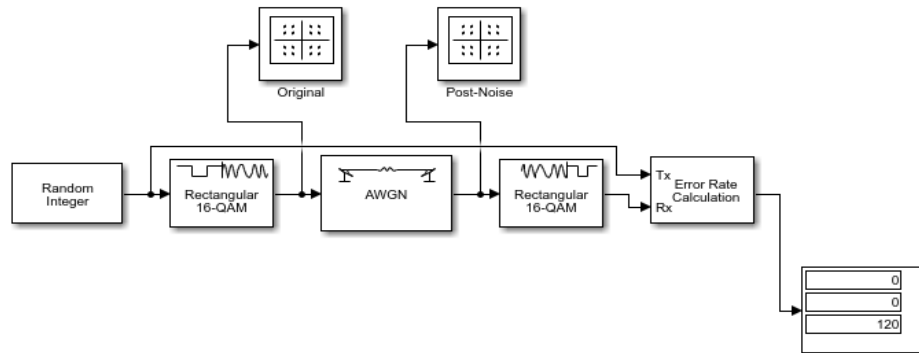


Figure 12: 16-QAM Simulink model

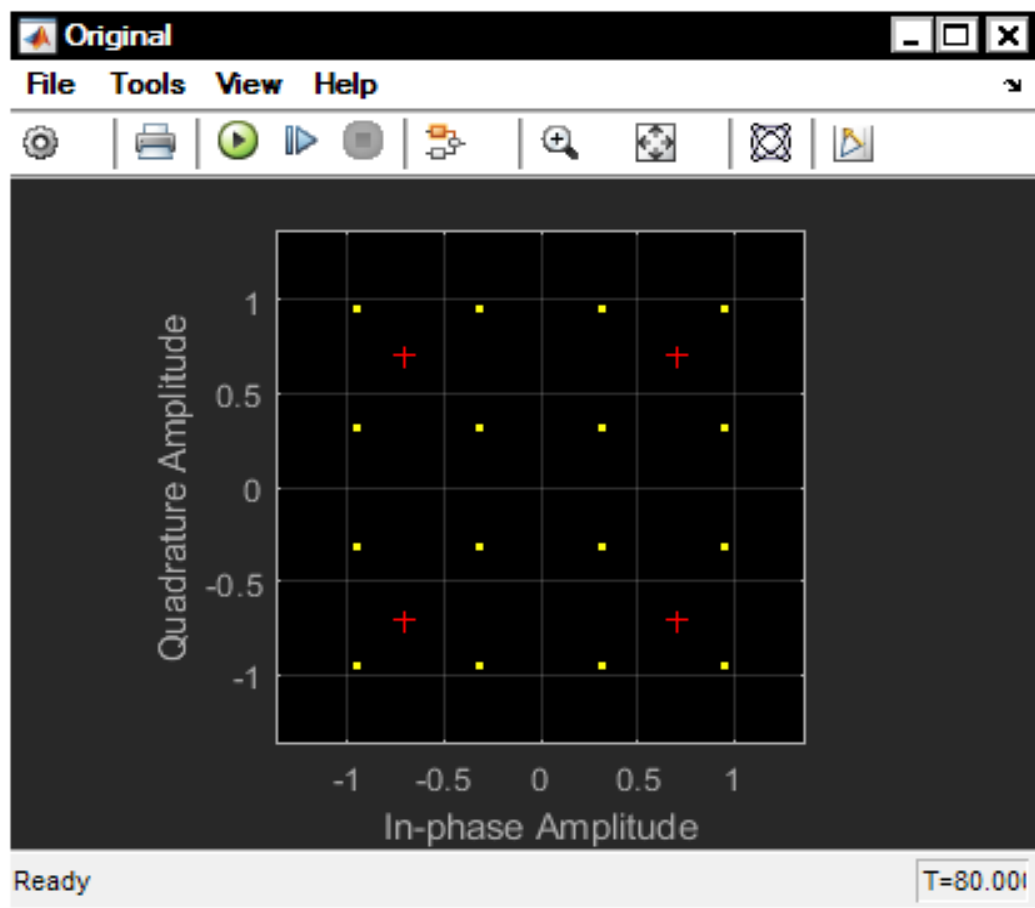


Figure 13: QAM constellation diagram after modulation

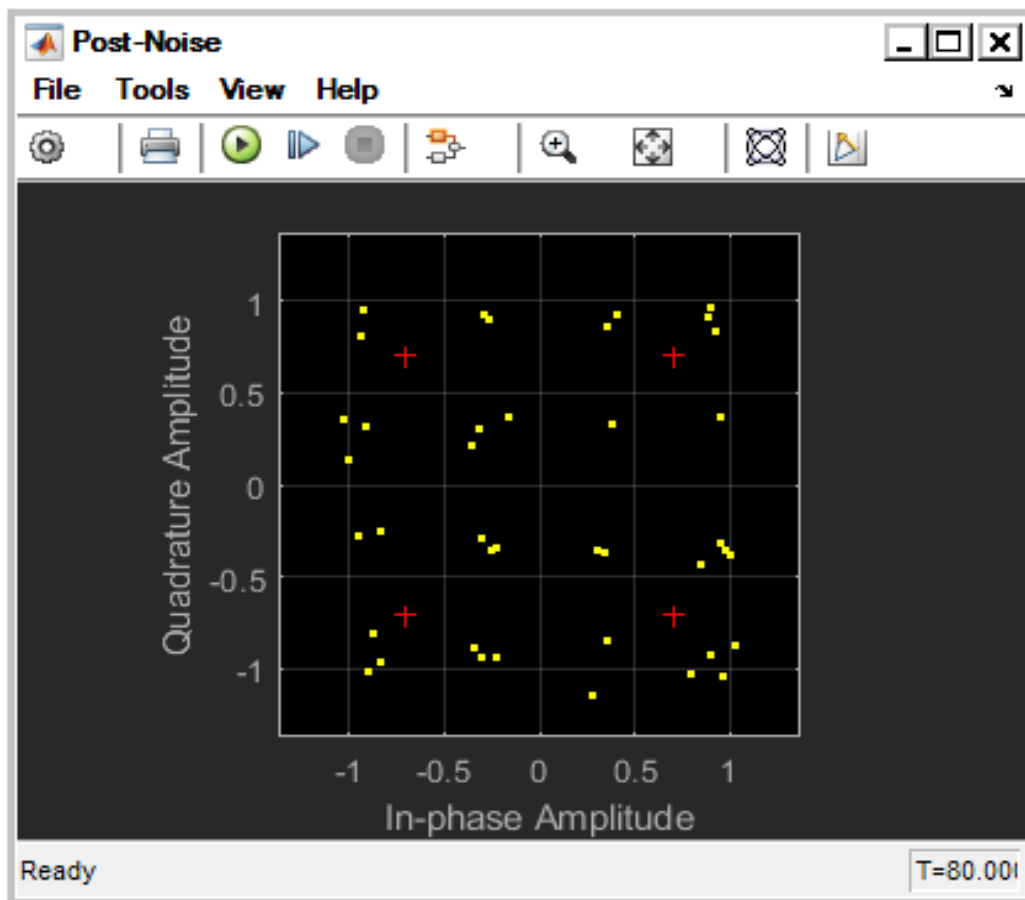


Figure 14: QAM constellation diagram after passing through a noisy channel

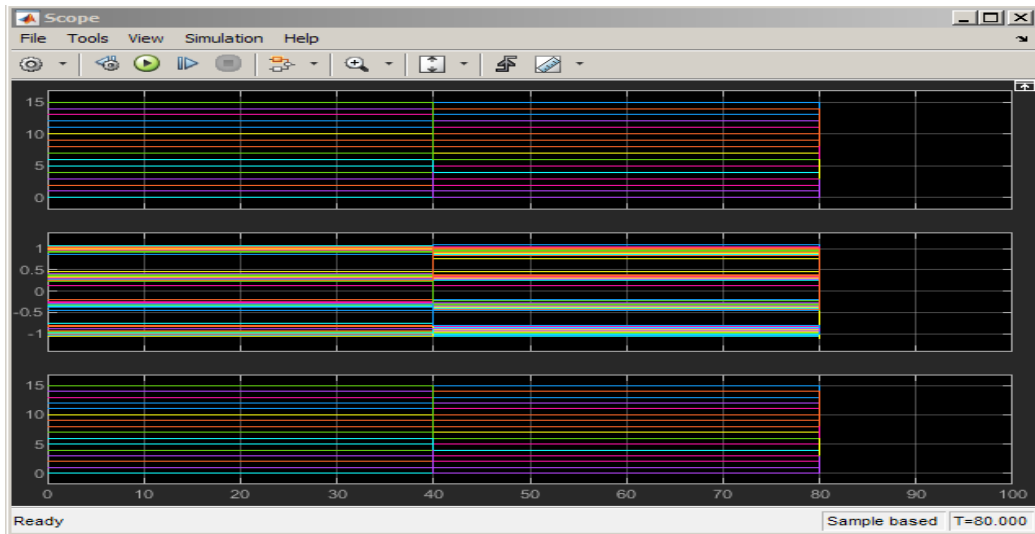


Figure 15: Data before, during, and after modulation (QAM)

Other factors – The following values have been set across all three simulation models:

Source input samples per frame – 40

AWGN Seed – 67

Number of symbols sent – 120

Simulation stop time – 100

As such, the following chapter analyses and evaluates the simulation's results.

11 Analysis and evaluation of the simulation

The results are as follows. The values represent the number of error bits out of 120 transmitted symbols:

SNR	ASK	BPSK	16-QAM
20	34%	0%	0%
10	32%	0%	23%
0	40%	7%	70%
-10	42%	28%	89%
-20	39%	40%	87%

Upon analysis of the results, the following observations can be made:

- ASK has a significant level of BER at all SNR levels
- At SNR levels of 10 and above, BPSK and 16-QAM have a significantly lower BER in comparison to ASK.
- BPSK is the most efficient modulation scheme at the SNR level of 0 dB
- 16-QAM arguably presents the highest BER at SNR levels 0 dB and below

As such, the following evaluations can be inferred:

- 16-QAM is a modulation scheme most suited for areas of transmission in which there are very few or no chances of noise appearing on the transmission channel
- BPSK retains a decent level of efficiency up to a point (-20 dB SNR). As such it can be argued that it is an efficient modulation scheme within the context of communication channels with some level of noise present
- ASK has a near 50% level of BER, thereby making it an inefficient modulation scheme under noisy circumstances.

It must be noted, however, that this case may be due to the fact that at the receiving end there is no digital filter present, thereby increasing the likelihood of BER. It is highly likely that an efficient digital filter would make the ASK modulation scheme significantly more efficient with regards to noisy communication channels.

The next chapters deal with the design and evaluation of a monitoring system with the scope of dealing with theft/larceny issues in rural and urban areas.

12 Monitoring system: introduction

The writer of this report has been tasked with the designing of a solution with the scope of preventing larceny, theft, or public danger issues within a rural and urban environment. With this in mind, two networks have been proposed:

Rural – A network of drones which transmit video content and issue warnings to a nearby police station with the help of a relay composed of an antenna

Urban – A wireless mesh-type network of sensors and cameras which transmit video to nearby police station/s and/or issue warnings in the case of weapon detection

The following chapters deal with the design, implementation, and evaluation of the network/s.

13 Design of network

Rural – The rural network is comprised of:

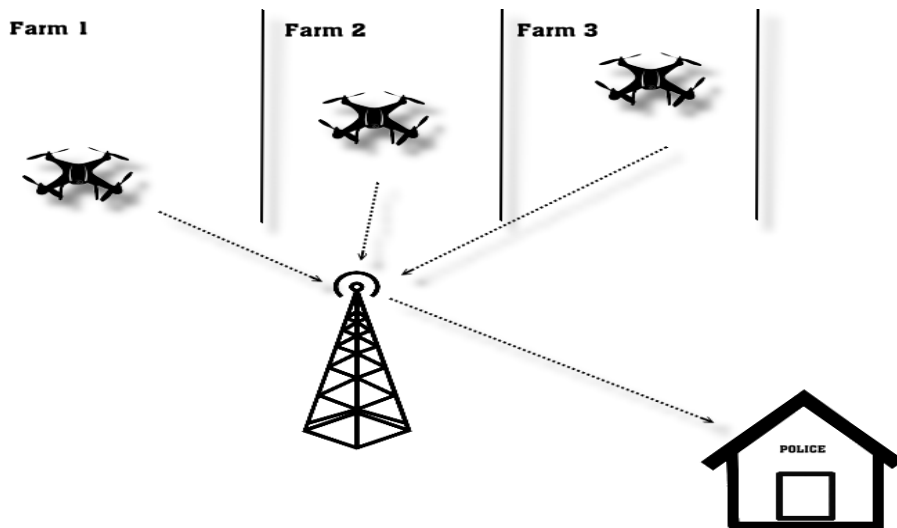


Figure 16: Diagram of a farm surveillance network

Drones – With regards to surveillance, drones are a proper choice. They are useful in the monitoring of agricultural and rural areas, not only with regards to possible theft but also in case of natural disasters such as gully erosion and forest fires. [20, p. 65] As such, a drone is employed for each farm with the scope of surveillance.

Relay Antenna – The antenna functions as a relay between the monitoring drones and the police station/s. Drones will constantly transmit video content to the police station through the relay.

Police station – The police station/s act as a storage for the monitoring content, as well as an end-point for alarms triggered by the drones upon detecting possible crimes and/or other issues with the farm/s.

Urban – The urban network is comprised of:

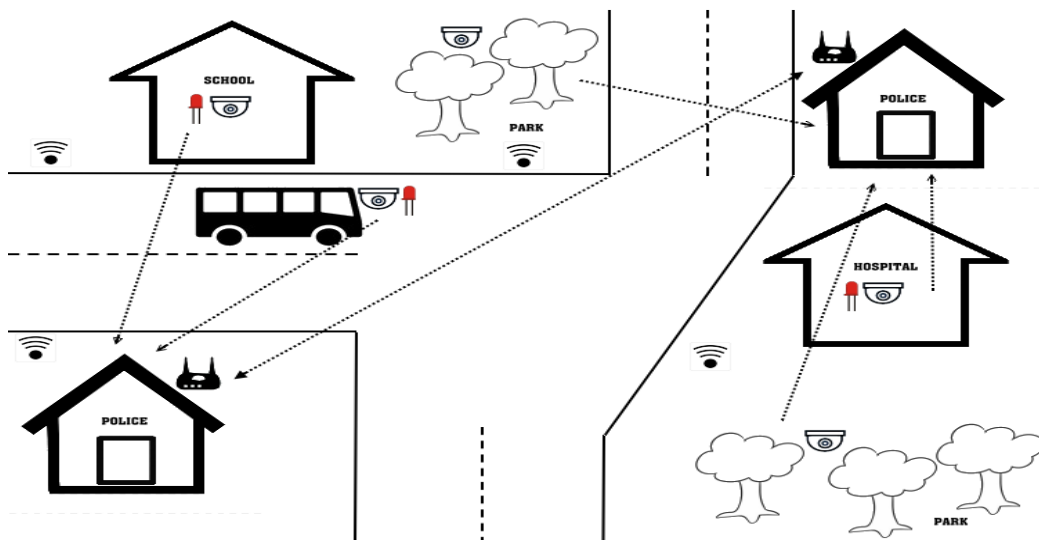


Figure 17: Diagram of a “Smart City” type surveillance network

Surveillance cameras and sensors – CCTV cameras send video traffic to nearby police stations for monitoring. On the other hand, the sensors’ scope is to detect hidden weapons such as knives and guns and alert the facility/ies in danger as well as the police station of detected weapons.

Mesh APs – The APs act as intermediary routers for video/warning traffic from devices to police stations, similarly to a wireless mesh network design.

Wireless Router – The wireless routers employed at each police station function as the receiving ends for video/warning traffic in the wireless mesh network.

14 Conclusion

It has been detailed how digital modulation and de-modulation plays an important role in communication between computers and other devices.

Next, three of these types of modulation, ASK, PSK, and QAM, have been analysed. All of these have their own strengths and weaknesses with regards to their efficiency under different levels of noise on the communication channel.

Finally, an attempt has been made towards designing a surveillance network for both rural and urban areas, making principal use of drones, CCTVs and wireless APs.

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