THE REPUBLIC OF TURKEY
BAHCESEHIR UNIVERSITY

RELIABLE IMAGE TRANSMISSION IN WIRELESS SENSOR NETWORKS FOR SMART GRID APPLICATIONS

Master's Thesis

MOSTAFA SHAMIL JASSIM

ISTANBUL, 2020

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SCIENCES COMPUTER ENGINEERING

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ABSTRACT

RELIABLE IMAGE TRANSMISSION IN WIRELESS SENSOR NETWORKS FOR SMART GRID APPLICATIONS

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Computer Engineering Master's Program

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With the rapid development of Smart Grids over wireless sensor networks, the reliable image and video transmission has become more imperative and faces many challenges in wireless harsh environment. Transmission of the image data may experience distortions that decrease the quality of the image due to noise, interference and path loss. In the recent years many studies have been conducted in order to improve the quality of services offered by the wireless sensor networks, with the technologies evolving rapidly, we were able to transmit multimedia including video and audio and images via Wireless Sensor Networks this service can be implemented in various areas and places especially in places where Natural Catastrophes occur constantly or remote places where it is hard for human to be 24/7 present, with that being said wireless sensor network nodes use different algorithms in order to collect and send the data to the sink (end node) and since the nodes uses wireless connection and is highly prone to noise due to the location of these nodes , we may receive a highly distorted multimedia or lose entire packets of data , in our algorithms we have used the relatively new and innovative way of using correction algorithms such as Reed Solomon algorithm but in an adaptive method where we can achieve a much lesser error rate as well as fast processing times Which in many ways can help with more reliable data transmission, more efficiency and Integrity of data transmission through the network (from the source to the consumer), WSNs have a Number of sensors, each sensor node

Have multiple components as: a radio transmitter (TELOS), internal antenna, a micro-controller, and battery sources. The Applications of WSN are the sensing, data processing, gathering, and data forwarding. WSNs are suitable for monitoring applications for their ability to operate in harsh environments and can be used in military defense, disaster relief, environment monitoring, biological and commercial applications, and other fields have broad application prospects.

The aim of WSN's is to create a robust connection with minimum error rate high speeds connections and that can be difficult to achieve since the environment in which the WSN's are installed may suffer from high amounts of interference such as noise, fading, path loss , shadowing, reflection and diffraction that may affect the quality of transmission , using a proper (Error Correction) technique is a necessity to achieve the best possible results and minimize the Bit Error Rate (BER) in the smart grid applications such as Generation-Side , Utility-Side and Demand-Side. Many Error Correcting techniques has been implemented such as Forward Error Correction (FEC) in which is digital signal processing technique used to enhance data reliability.

FEC provides the receiver with the ability to correct errors without a reverse channel to request the retransmission of data. In these techniques many algorithms has been used which they are different from each other, the efficiency of each of these techniques differs from one another based on the channel itself. In this paper will discuss the transmission of an Image through a Wireless Sensor Network and applying error correction techniques such as Reed Solomon (RS) with the efficient adaptive error control algorithm is proposed and integrated with LQ-CMST routing protocol and multi-channel scheduling algorithm.

In this thesis, we show the effect of two error correction algorithms (Static and Adaptive RS) in order to increase the perceptual quality of the transmitted images. Here, as Static Reed-Solomon (RS) coding utilizes additional bits to the information transmitted to correct errors at the receiver side. Unlike Static RS, Adaptive RS is a derived version of the Reed-Solomon that sets the error correction codes of the algorithm based on the distance between the nodes adaptively. Performance results obtained from numerous simulations indicate that the Adaptive RS exhibits much better performance results in terms of PSNR, BER, and Throughput than Static RS. It is good candidate for providing application layer perceptual quality requirements for Smart Grid applications.

Keywords: Smart Grid, Wireless Sensor Networks, Multi-Channel Communication, Image Transmission, Adaptive Error Control

ÖZET

AKILLI ŞEBEKE UYGULAMALARI IÇIN KABLOSUZ SENSÖR AĞLARINDA GÜVENILIR GÖRÜNTÜ AKTARIMI

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Akıllı Şebekelerin kablosuz sensör ağları üzerindeki hızlı gelişimi ile güvenilir görüntü ve video aktarımı daha zorunlu hale geldi ve kablosuz zorlu ortamlarda birçok zorlukla karşı karşıya kaldı. Görüntü verilerinin iletimi gürültü, parazit ve yol kaybı nedeniyle görüntü kalitesini düşüren bozulmalarla karşılaşabilir. Son yıllarda kablosuz sensör ağları tarafından sunulan hizmetlerin kalitesini artırmak için birçok çalışma yapılmış, hızla gelişen teknolojilerle Kablosuz Sensör Ağları üzerinden video ve ses ve görüntü içeren multimedya iletebildik. çeşitli alanlarda ve yerlerde özellikle Doğal Felaketlerin sürekli meydana geldiği yerlerde veya insanların 7/24 mevcut olmasının zor olduğu yerlerde, kablosuz algılayıcı ağ düğümlerinin veri toplamak ve göndermek için farklı algoritmalar kullandıkları söylenir. lavabo (uç düğüm) ve düğümler kablosuz bağlantı kullandığından ve bu düğümlerin konumu nedeniyle gürültüye çok eğilimli olduğundan, çok bozuk bir multimedya alabilir veya tüm veri paketlerini kaybedebiliriz, algoritmalarımızda nispeten yeni kullandık ve Reed Solomon algoritması gibi düzeltme algoritmalarını kullanmanın yenilikçi bir yolu, ancak daha düşük bir hata oranı elde edebileceğimiz uyarlanabilir bir yöntemle hızlı işlem sürelerinin yanı sıra WSN'lerin daha güvenilir veri aktarımı, daha fazla verimlilik ve ağ üzerinden veri aktarımının bütünlüğüne (kaynaktan tüketiciye) yardımcı olabilecek WSN'lerin her biri bir sensör düğümü sayısı

Bir radyo vericisi (TELOS), dahili anten, bir mikro denetleyici ve pil kaynakları gibi birden fazla bileşene sahip olun. WSN Uygulamaları algılama, veri işleme, toplama ve veri iletmedir. WSN'ler, zorlu ortamlarda çalışma yetenekleri nedeniyle uygulamaları izlemek için uygundur ve askeri savunma, afet yardımı, çevre izleme, biyolojik ve ticari uygulamalarda kullanılabilir ve diğer alanlarda geniş uygulama beklentileri vardır. WSN'lerin amacı, minimum hata oranı yüksek hızlı bağlantılarla sağlam bir bağlantı oluşturmaktır ve WSN'lerin kurulduğu ortamın gürültü, solma, yol kaybı, gölgeleme gibi yüksek miktarda parazit olabileceğinden başarılması zor olabilir. Generation-Side, Utility gibi akıllı şebeke uygulamalarında mümkün olan en iyi sonuçları elde etmek ve Bit Hata Oranını (BER) en aza indirmek için, iletim kalitesini etkileyebilecek yansıma ve kırınım, iletimin kalitesini etkileyebilir. -Yan ve Talep Tarafı. Veri güvenilirliğini artırmak için kullanılan dijital sinyal işleme tekniği olan İleri Hata Düzeltme (FEC) gibi birçok Hata Düzeltme tekniği uygulanmıştır. FEC, alıcıya verilerin yeniden iletilmesini istemek için ters kanal olmadan hataları düzeltme yeteneği sağlar. Bu tekniklerde birbirlerinden farklı birçok algoritma kullanılmıştır, bu tekniklerin her birinin verimliliği kanalın kendisine göre birbirinden farklıdır. Bu makalede, bir Görüntünün Kablosuz Sensör Ağı üzerinden iletilmesi tartışılacak ve etkili uyarlamalı hata kontrol algoritması ile ReedSolomon (RS) gibi hata düzeltme tekniklerinin uygulanması önerilecek ve LQ-CMST yönlendirme protokolü ve çok kanallı programlama algoritması ile entegre edilecektir.

Bu tezde, iletilen görüntülerin algısal kalitesini artırmak için iki hata düzeltme algoritmasının (Statik ve Uyarlanabilir RS) etkisini gösteririz. Burada, Statik Reed-Solomon (RS) kodlaması, alıcı tarafındaki hataları düzeltmek için iletilen bilgilere ek bitler kullanır. Statik RS'den farklı olarak, Adaptive RS, Reed-Solomon'ın, düğümler arasındaki mesafeye uyarlanabilir olarak algoritmanın hata düzeltme kodlarını ayarlayan türetilmiş bir sürümüdür. Çok sayıda simülasyondan elde edilen performans sonuçları, Uyarlanabilir RS'nin PSNR, BER ve Verim açısından Statik RS'den çok daha iyi performans sonuçları gösterdiğini göstermektedir. Akıllı Şebeke uygulamaları için uygulama katmanı algısal kalite gereksinimleri sağlamak için iyi bir adaydır.

Anahtar Kelimeler: Akıllı Şebeke, Kablosuz Sensör Ağları, Çok Kanallı Iletişim,
Görüntü Aktarımı, Uyarlanabilir Hata Kontrolü

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ABBREVIATIONS

ACKs : Acknowledgments
AEC : Adaptive Error Control
ARQ : Automatic Repeat Request
BCH : Bose-Chaudhuri-Hochquenghem
BER : Bit Error Rate
BERs : Bir Error Rates
CMST : Capacitated Minimum Hop Spanning Tree
CMSTs : Capacitated Minimum Hop Spanning Trees
DPSK : Differential Phase Shift Keying
ECC : Error Correction Code
ECCs : Error Correction Codes
FEC : Forward Error Correction
FSK : Frequency Shift Keying
LOS : Line-of-Sight
LQ-CMST : Link-Quality-Aware Capacitated Minimum Hop Spanning Tree
MAC : Medium Access Control
MHST : Minimum Hop Spanning Tree
MHSTs : Minimum Hop Spanning Trees
MPR : Main Power Control Room
MSE : Mean Squared Error
PER : Packet Error Rate
PRR : Packet Reception Rate
PSNR : Peak Signal to Noise Ration
RS : Reed Solomon
QoS : Quality of Service
SNR : Signal to Noise Ratio
UTV : Underground Transformer Vault
WSN : Wireless Sensor Network
WSNs : Wireless Sensor Networks

SYMBOLS

Minimum bit error rate : BERMIN

Maximum bit error rate : BER_{MAX}

Code word length : n

Distance : d

Frame length : f_L

Noise floor : P_η

Output power : P_t

Path loss exponent : η

Preamble length : PL

Terrain dimension of X : D_X

Terrain dimension of Y : D_Y

1. INTRODUCTION

1.1 IMAGE TRANSMISSION VIA WIRELESS SENSOR NETWORK

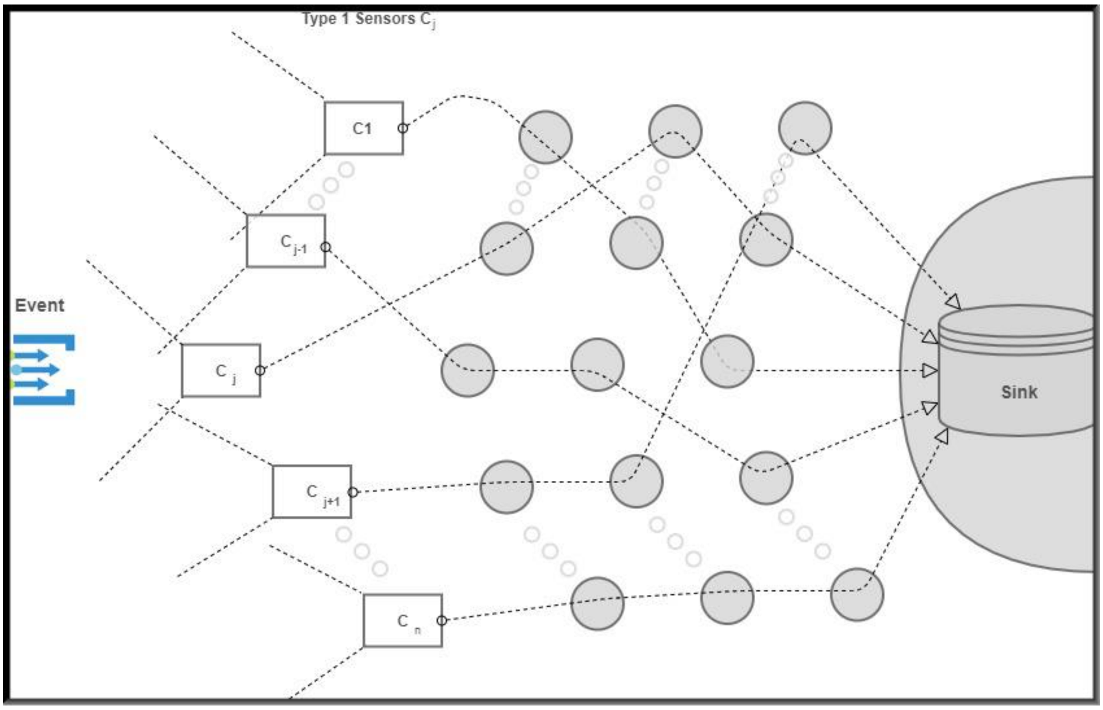
With the rapid development in recent technologies we were able to integrate advanced and new capabilities in WSN, the WSN nodes that have multimedia capabilities can transmit and receive both video and audio from the environment that is placed in. These capabilities unlock a vast spectrum of services that if implemented successfully can provide a great benefit in multiple areas such as in places where natural catastrophes occur or can be used in surveillance on the borders therefore, the transmitting / receiving data through a WSN efficiently is crucial (Boluk, P., et al., 2011).

These networks have been employed for multiple purposes that offers reliability and cost efficiency for the management of the power grid environment. Many capabilities can be implemented in these systems from surveillance to managing the operating conditions in real time and also monitor the grid's performance (Bicen, et al., 2012), (Gungor, et al., 2011), (Gungor, et al., 2010), with the usage of these systems, many advances comes from the low-priced/economical nature of the WSN's compared to the Electrical conventional monitoring systems, some of these benefits includes , enhanced tolerance of faults, localized events extraction and higher accuracy (Yigit, et al., 2014). The usage of WSN's offer lower power consumption and inexpensive wireless communications for a variety of the applications in a smart grid, this includes dynamic thermal rating, line fault and power theft detection, distribution automation, outage detection, underground cable system monitoring, real time pricing and the wireless automatic metering. Additionally there are certain requirements that these general applications demand such as throughput, delay, and efficiency of energy, therefore, the architecture of the WSN-based smart grid applications has to meet these requirements.

In smart grid applications, which are deployed in a harsh smart grid environments in the wireless sensor network, reliable communication capability is essential depending on the applications.

One of the WSN's several difficult tasks is to transfer the images collected through wireless channels while meeting QoS application requirements. The nature of wireless channels that is highly error-prone and with low bandwidth make it difficult to transmit large quantities of image data. In addition, the higher sampling rates in the wireless sensor networks and the application can require accurate temporal relationships between samples to be transmitted, so that it can be interpreted correctly , WSN applications typically obtain the whole image from multiple sensors to obtain results that are meaningful. when transferring an entire image through the WSN it can be exposed to a wide variety of interference such as noise, fading, diffraction and other types of interference that can affect the signal therefore the content of an image negatively. In this thesis we compare the performance of many transmission variants considering the possible combinations of potential techniques such as Reed–Solomon (RS) coding with both Static and Adaptive RS that implemented by a previous team (Yiğit, M., et al., 2019), We changed the parameters along with the input for our simulation purposes we used the DPSK modulation for the evaluation of these schemes and transmitted and a grayscale image with the size of 196×420, we consider a general WSN scenario as shown in Figure (1.1).

Figure 1.1: WSN Scenario



1.2 SMART GRID

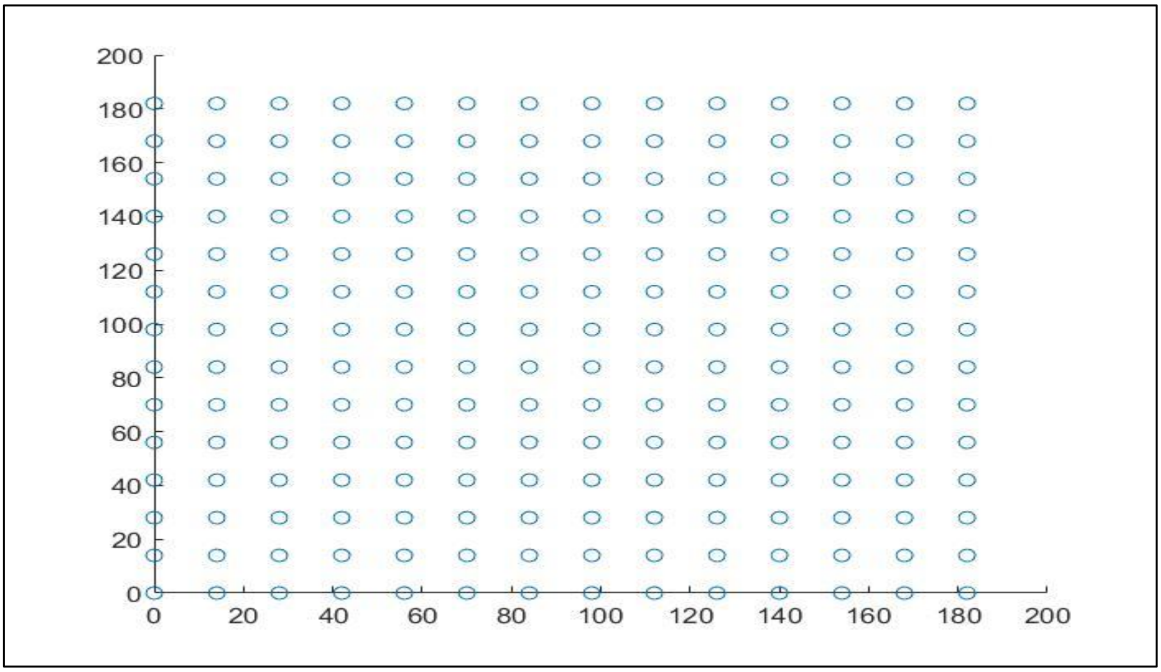
The design of the smart grid is to ensure a better communication by adding components with certain technologies into electrical power grids to make them “smarter”. Given the growing energy demand and increasing age of power grid, one of the challenges that face the electrical utilities is ensure that the customers receive reliable power at competitive prices. many of the failures that occur in a power grid, blackouts and voltage drops because of the large and complex systems of the power network (Yigit, et al., 2014) and they all can be prevented if we can create better and more stable systems and adding new technologies and faster communication devices In order to make the power grid into a smart grid, we analyzed the performance of both static RS and AEC, DPSK modulation scheme, in a 500kV LoS (line-of-sight) substation smart grid environment in (Yigit, et al., 2018). We have found the Adaptive RS with the DPSK modulation demonstrates the best performance for image transmission, for that reason choosing a suitable error correction technique is imperative in order to lower the delay and reduce the BER using the examples presented in Table 1.1 for smart grid applications (Gungor, et al., 2013). There are multiple domains in smart grid applications such as consumer side, generation side, and (Transmission and Distribution) side. On the basis of their domains we have the ability to use different error control techniques such as forward error correction (FEC) can be implemented to help ensure that transmission is both secure and reliable over a channel ((Yiğit M., et al., 2019). Prior to transmission all the data to be transmitted is encoded using different encoding algorithms, when the receiver node obtains the data transmitted it decodes the data encoded by the transmitter and acquire the data originally sent. Based on the communication channel the efficacy of these error control techniques varies. Even under the same channel conditions, the efficiency of those techniques differs.

Table 1.1: The Smart Grid- Based Applications (Yiğit, M., et al., 2019)

Smart Grid Application	Domain
The management of the energy in residential areas	Consumer side
The Management of the load in the Demand-side	Consumer side
Building automation	Consumer side
Smart energy metering	Consumer side
Rating system for the conductor temperature	T&D side
Power outage detection	T&D side
The monitoring of underground cable system	T&D side
Distributed generation	Generation side
Real-time generation monitoring	Generation side
The wind and solar turbines remote monitoring	Generation side

The previous team used a random topology to distribute the nodes we have used the Grid topology, Figure (1.2) shows the Grid topology with the 196 nodes distributed with a fixed distance between them of grid with a distance of 14m between each node and with the first node (0, 0) being the sink node which every node transmits part of the image to it.

Figure 1.2: 196 Nodes Distributed Over a Grid Topology (MATLAB)



1.3 INTEGRATING THE WSN IN THE SMART GRID

With the latest advancements in the systems that are embedded within the hardware and the evolution of With the development of the WSNs it facilitated the implementation of both dependable and economic power grid management systems, which offer many capabilities such as real-time monitoring and the performance of the power grid (Bicen, et al., 2012), (Gungor, et al., 2011), (Gungor, et al., 2010)

The design of a Wireless Sensor Network can be affected by many elements for a certain Smart Grid inside an environment designed for this Smart Grid such as low link-quality; network topology; interference; contention; and hardware constraints.

The Link Quality of the wireless links differs highly with the time and location because of signal fading, many types of smart grid environments such as 500kV, Underground Transformer Vault and Main Power Room (Gungor, et al., 2010).On top of these factors, the Radio Frequency (RF) which can be caused by the interference that can happen because of parallel transmissions, and in the wireless medium contention can occur so it can limit the capacity of the WSN’s precisely in the smart grid environments(Yigit, et al., 2014).

1.4 PROBLEM STATEMENT

The image transmission over a wireless sensor network can be impacted by the effects of noise, signal degradation, interference and (BER) via different smart grids such as Main Power Room, 500kv and Underground Transformer Control, in this thesis we are using the WSN to transmit an image from source node to receiver node while meeting the QoS requirements which can demand high quality results and low error rate so it’s crucial to meet those requirements, some of these performance results can be perceptual quality of the images transmitted as seen by the receiver and also delay is a significant factor for meeting the QoS requirements, during the image transmission over WSN’s , the link quality of WSN state varies considerably over time and can be affected by man factors , based on different characteristics of the WSN such as distance between the nodes, scattering and environmental factors such as wind and humidity etc. The wireless communication's dynamic nature causes packet loss and negative effects on image perceptive quality and delay and higher error rate (Pınar B., 2011). In order to avoid the possible data loss and to obtain the optimal results with high quality images and low errors, error detection and correction techniques must be implemented for the image transmission. In this thesis we are implementing the forward error correction (FEC) (Mao, S., et al., 2011). FEC adds redundant bits to the data to create a code-word and so the receiver can detect and correct the errors by using these redundant bits. In FEC technique, no feedback sends from receiver to transmitter and therefore, half-duplex communication is sufficient for FEC technique. Therefore, FEC scheme is an effective mechanism since it does not to require retransmission to correct the data (Yiğit, M., et al., 2019).

1.5 CONTRIBUTIONS

This thesis focuses on the image transmission via wireless sensor network in a harsh smart grid environment, the main factor considered that the quality of the images transmitted perceived and lower bit error rate with higher throughput that can satisfy the QoS requirements for the applications in the smart grid.

The contributions of the thesis are listed as follows:

a. Contribution 1: Image Transmission via a Wireless Sensor Network Using an Adaptive Error Control Technique

In this thesis, an image transmission framework using a previously proposed AEC that is being used for obtaining the highest perceptual quality and also for energy saving purposes for the QoS applications in WSN, we are simulating the real time effects that can affect a transmission in an open world environment from noise, fading, path loss, shadowing, reflection and diffraction, we are transmitting a Grayscale image we start from the Sender side by converting an RGB image to Grayscale and since our network only transmits in binary (Bits) we are converting the image to Grayscale then to binary and then reconstruct the image back to Grayscale and measure the BER, PSNR,MSE between both original and reconstructed image in order to assure high quality of transmission with better results as we make numerous number simulations to test our network and get multiple results for analysis purposes and to try to improve the results of our network's performance.

We are using the (AEC) algorithm that were proposed by (Yiğit M., 2019) and LQ-CMST (Yigit, et al., 2016) algorithm And along with that we are using the multi-channel scheduling that we implemented for the purpose of data transmission in wireless sensor networks, therefore the effect of these algorithms combined on the performance of static RS and Adaptive RS for image transmission are also analyzed for WSNs in smart grid environments. We have also conducted multiple evaluations for the RS code for the performance of these codes and we used DPSK modulation scheme in 500kV substation in a smart grid environment. The Criteria for these evaluations are the PSNR, BER, Delay and throughput for these simulations in our simulation for sending and image through a WSN we have got the best result using the DPSK has the most efficient result with low BER and low Delay and high throughput Performance in our smart grid application with a high PSNR and low MSE.

b. Contribution 2: Image Transmission via Multiple Propagation Environments

The link quality of the wireless links in different smart grid propagation environments such as the Main Power Room (MPR), 500kV outdoor substation (Subs), and Underground Transformer Vaults (UTV) can be affected differently based on multiple variables such as the type of the propagation environment, noise and path loss. To establish a reliable and efficient image transmission among different propagation environments we investigate the effect of multi-channel transmission and choosing the best Modulation techniques and the affect it has on our performance measuring criteria which is BER, delay and throughput and also perceptual measurement criteria which is PSNR for the image transmission in a smart grid environment.

1.6 ORGANIZATION OF THE THESIS

This thesis starts by explaining the advances in image transmission via wireless sensor network and the forward error control techniques the rest of the thesis is organized as follows:

Chapter 3: in this chapter, we introduce algorithms and methods that used for transmitting an image using both static and adaptive Reed Solomon with DPSK in a 500kV LoS substation smart grid environment

Chapter 4: in this chapter, the performance evaluation of the used algorithms are given. Additionally, performance results were compared in terms of Delay, Throughput, BER, PSNR and MSE from the image transmitted via wireless sensor network.

2. BACKGROUND

One of the properties of a wireless sensor channel that it is extremely unreliable (Irgan K., et al., 2010), (Mao, S., et al., 2005), (Zuniga, M., et al., 2007) can lead to packet losses during the transmission which can affect the quality if the media that is being broadcasted. Therefore, changing the transmission mechanics and the error handling techniques to deal with packet losses are essential for delivering high quality multimedia transmitted via WSN.

As we have described in Chapter 1, this thesis main objective is to ensure a reliable image data transmission and delivery in a Wireless Sensor Network (WSN), using the algorithms of error detection and correction and selecting the suitable routing protocols for QoS with the attention to perceptual quality. This work adapts the previous project implemented by previous team (Yiğit M., et al., 2019) on data transmission and changes the data to an image data to be transmitted, and implementing multiple techniques for error correction and various routing protocols to ensure the QoS for the purpose of image transmission in WSN. In order to ensure a robust image transmission via a WSN the characteristics of an image should be included into the communication protocols. QoS based MAC protocols combined with service differentiation and directional antenna, and error correction methods. many techniques are used for the purpose of evaluating the transmitted image quality and the communication of the image, one of the common methods for measuring the quality of the Image is Peak Signal to Noise ratio or (PSNR) and also Mean Squared Error (MSE) are widely used (Boluk, P., et al., 2011).

2.1 RELATED WORK ON IMAGE TRANSMISSION VIA WSN

A number of studies have been conducted on the Adaptive forward error correction in WSNs (Pham, et al., 2017), (Yu, K, et al., 2012)). In (Pham, et al., 2017) the proposition of an adaptive forward error control method based at the MAC layer is introduced in wireless sensor networks. The efficiency of energy, PER, energy consumption and the image quality, that we mentioned before is (PSNR) value of the images transmitted using different algorithms and modulation schemes. All of the previously mentioned are metrics used for performance evaluation purposes, The Adaptive RS is built upon two tables a

BER look-up table and a distance between nodes look-up table, the most suitable FEC codes are obtained and stored based on the different distances between the nodes and the BERs because due to the channel conditions the BER always changes, The algorithm gives a quick and reliable solution by choosing the best FEC value in the look-up table (Yiğit, M., et al., 2019).

The project from the previous team aims to offer a certain solutions that are associated with the data transmission challenges in WSN's, with the development of the WSN's many issues arise especially in a harsh smart grid environment that can vary from the low rate of data transmitted in monitoring applications to an applications that require higher QoS such as low delay and higher throughput, these applications require the transmission of large amount of data and need the efficacy and timely delivery of the data. There are many difficulties that faces the transmission such as radio frequency interference, multi-path, fading, node contentions, and noise to transmit data in various smart grid environments. Respectively, a number of solutions were proposed to handle these difficulties such as implementing multiple channels together with routing trees, link-quality-aware routing as well as the priority and channel-aware multi-channel scheduling strategies, QoS-aware medium access control techniques, and error correction techniques such as both the Adaptive Reed Solomon and the normal/static Reed Solomon to transfer the data via a WSN that is in smart grid environment and measure the BER, Delay and throughput using multiple modulation and FEC algorithms (Yiğit, M., et al., 2019).

As for the image transmission via the WSN many studied have been made to improve the perceptual quality of the images transmitted several ways, in (Boluk, P., et al., 2011) in order to be able to meet The QoS for the application layer specifications in WSN, the quality of the image perception and the incorporation of the characteristics of image into the protocols that are used for transmission is studied. The findings suggest that it is appropriate for WSN to use the EC approach as an error mitigating strategy at the cost of the source node overhead in order to be able to balance the perceptual quality of the image and the communication's overhead tradeoff, it has been proven that by mapping the application's multimedia requirements accurately into the parameters of the network layer communication. This mapping operation also contributes to exploring smart ways in which communication protocols can be adapted to the wireless sensor network environment. Therefore, the algorithms and systems proposed are useful in providing

WSN image applications high image quality and the different requirements of the QoS for the image-based applications. In order to combat the channel errors, the bit stream needs error protection during transmission. Typically, forward error coding (FEe) and automatic retransmission request (ARQ) are used as error control strategies. Intuitively, one would expect that as the packet loss probability goes up, which may happen because of increasing bit error rate or because of larger packet size, a FEe code will do increasingly better while an ARQ scheme will do worse from the battery power consumption perspective (Min Wu, et al., 2003).

In (Huaming Wu, et al., 2006) an image transportation scheme has been introduced which, despite channel impairs and node failures, can provide a picture of decent perceptual quality. In particular, an "in-network" diversity scheme that benefits from the variety of paths to improve performance. The algorithms works when sending a packet in a network a number of relaying nodes selected to provide redundancy to eliminate the random nodes failure effect on data, it means that multiple copies of the encoded image coefficients that being sent from different nodes are combined together to help reduce the errors that occur in the wireless channel, additionally, forward error correction coding is also applied to the transmitted packets. The metrics that were used for the performance evaluation are the energy consumption and the image quality of the image transmission scheme, the results showed that there is a significant improvement in terms of metrics used and especially with high number of node failures and higher number of hopes for the packet transmitted between sender and receiver.

3. ALGORITHMS AND MODELS

3.1 REED SOLOMON

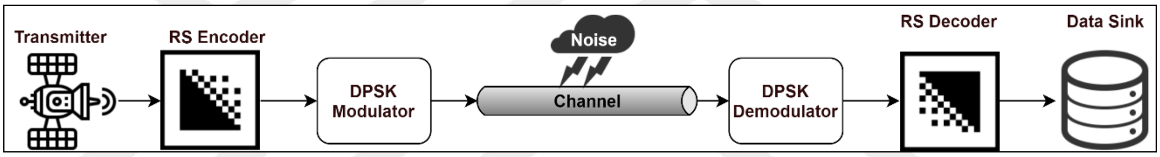
One of the common forward error techniques is Reed Solomon it was first defined by Reed and Solomon in (I.S. Reed, et al., 1960), it can be used in different fields from almost all type of digital communications to wireless communications and space communication, and it can also be used in digital media, the algorithm encodes the data into blocks and the decoding part of it takes more time , many improvements have been made to make the algorithm more efficient by Berlekamp and other in the 1960's (E. R. Berlekamp 1968), (R. T. Chien 1964), (G. D. Forney (1965) and (J. L. Massey, et al., 1969). but at that period of time it was impossible to end large amount of data in a high bandwidth until a few years later it was possible to send the high-bandwidth data using the Reed Solomon codes. the RS is different than the previous hamming as it encodes the bits as a group unlike the hamming which it creates a long string of bits, these groups of bits are called symbols , these symbols are without an error given that the bits of the whole symbol are without an error, the following example briefly explains how does reed Solomon works:

Original Bits	Received Bits	Corrupted
10100101	10110101	Yes
10110101	10110101	No

3.1.1 Static Reed Solomon

The codes of Reed Solomon can be used for the purpose error detection and correction to ensure a reliable communication on the channels that are prone to interference. These Error correction codes are also known as forward error correction codes because it prevents the back-channel or retransmission of data. So, Reed-Solomon codes are preferred for error checking (P. Dayal and R. K. Patial, 2014). FEC coding processes the redundant data in wireless settings to correct wireless communications errors due to channel noise, path loss , and signal attenuation at the cost of bandwidth, power consumption or otherwise, (Boluk, P., et al., 2011). RS coding provides the following capability: to be able to send k digit of any type of message in our case it's an image, the Reed Solomon algorithm will send n = k + 2s digits, and to ensure that the image can be reconstructed at the receiver side if there is less than s number of corrupted digits , a common RS code is widely used which is RS(255,223) where n = 255 ,k = 223 and s =16 , it means that the algorithm can correct up to 16 corrupted digits at the receiver side out of the entire codeword size which 255 digit packet we can see a simple representation of how RS works in Figure (3.1). In general, the number of bits in a digit and the parameters n and s are tuned to optimize for your application which we used for the adaptive Error Control explained next.

Figure 3.1: Architecture of RS



3.1.2 Adaptive Reed Solomon

The Adaptive RS is a different version of the typical Static RS which you have to assign the number of extra bits to be added before starting the simulation which can be reliable in certain fields where a low bit error and higher throughput is required as for the AEC it uses the different codes of RS such as RS(63,35), RS(57,35), RS(51,35), RS(45,35) and RS(39,35) and assign them to the nodes adaptively based on the distance from its parent A look-up table has been used in order to assign the RS codes this table included all of the best RS codes that are applicable for each distance range between the nodes (Pham, et al., 2017). The construction of the look-up table has been made by conducting a number of simulations, in the second step , a criterion has been set for switching that were defined based on the number of ACK's of P previously transmitted packets (Yu, K., et al., 2012) all of these packets were received inside a defined window. a pre- defined threshold has been used as a criteria that can be compared to the measured Packet Error Rate (PER) so the appropriate RS code switching can be determined whether it's weaker or stronger RS code is assigned . In order to be able to solve these BER levels, the code was picked from a second search table that stores the level of RS codes in BER and the related RS codes. This table was designed with a heuristic method (Yiğit, M., et al., 2019).

AEC's objective is to maintain the applications reliability while maintaining the balance of the trade-offs between reliabiltiy and the network's overhead. Adaptive RS output for transmission of images via WSN was analyzed and the results were compared with the static Reed Solmon. The results of multiple simulations shows that the AEC can increase the PSNR considerably with th results obtained are higher than the static/classic reed solomon algorithm.

How the AEC works:

In this part, we explain how the AEC algorithm implements the use of different RS codes along with DPSK modulation that were used in previous simulation for data transmissions and used different parameters (Yiğit, M., et al., 2019). We have chosen to use the RS codes with DPSK modulation for our image transmission since they give the best outcomes based on the results of the simulation, the Adaptive RS has three steps:

A. RS Node Codes initialization;

B. Constructing the look-up table using a heuristic model;

C. Switching between the RS codes based on the threshold.

3.1.2.1 RS Node Codes initialization

The algorithm that we are using has been previously tested and simulated, to get a clear view of the AEC what it does, the AEC assigns RS codes such as RS(63,35), RS(57,35), RS(51,35), RS(45,35) and RS(39,35). the assigning of the previously mentioned RS code was based on the distance between the nodes and its parent node, accordingly, we have used the previously created look-up table (Yiğit, M., et al., 2019), as we can see from Table 3.1 it shows which RS should be assigned to a node at which distance, we can see in Algorithm 3.1 the pseudocode which was used for the creation of the look-up table, this algorithm starts by calculating the distance between each node in the topology and its parent node, the distances had to be normalized since the nodes were distributed in a 200*200m^2 area in addition all the distances between the nodes and its parents would be changed if different topologies used , so the distances had to be normalized, the algorithms assigns higher RS code as the normalized distance increases it means that the higher RS codes have higher redundant bits which can correct more errors especially when the distance increases between the node and its parent, these normalized distance values grouped into a five elements group that depends on the RS value , finally the assignment of the RS for each node based on the distance that has been normalized. For example, RS (63, 35) was selected for a node that has a normalized distance of (0.55 and 1m) than its parent.

Table 3.1: Assigning the RS codes based on the normalized distance between the nodes and its parent (Yiğit, M., et al., 2019)

RS codes based on the distance	Distance threshold between nodes and parent
RS(63,35)	$0.55 < d \leq 1$ m
RS(57,35)	$0.44 < d \leq 0.55$ m
RS(51,35)	$0.34 < d \leq 0.44$ m
RS(45,35)	$0.22 < d \leq 0.34$ m
RS(39,35)	$0 < d \leq 0.22$ m

3.1.2.2 Look-up table Construction by implementing a heuristic model

the creation of the look-up table has been created heuristically that was created by choosing a greedy scheme to resolve the issue of which RS code can provide the best results at which level of BER. There were a numerous number of simulations using each RS code the ranges of the BER has been calculated and we can see it in Table 3.2. Based on the computed BER it has identified the effective RS code to see which RS code will successfully send the packet. This process has resulted in finding which range of BER can be corrected if we selected this RS code. For example. , this $10^{-4} \leq BER < 10^{-2}$ range has been obtained the corresponding range of bit error rate when we used RS(39,35) with eight channels; and it has been selected that RS(57,35) could solve this BER range as shown in Table 3.2. Further, RS (63, 35) could also solve this BER range, but the RS (57, 35) was used to help reducing overhead by transmitting less redundant bits (Yiğit, M., et al., 2019).

Algorithm 3.1: the RS codes assignment according to distance (Yiğit, M., et al., 2019)

```
Input: pA (parentArray); nL (nodeList); grpSize (groupSize)
Output: assignedInitialFECValues
for n ← 1 to nL do
    myParent ← pA(node);
    distanceArray(node, myParent) ← calculateEuclideanDistance(node, myParent);
end for
    ─ Normalized Distance ─
minDistance ← min(distanceArray);
maxDistance ← max(distanceArray);
biggestDiffDistance ← maxDistance – minDistance;
for nodeIndex ← 1 to size(distanceArray) do
    currentNodeDistance ← distanceArray(nodeIndex);
    normalizedDistance ← (currentNodeDistance - minDistance) / biggestDiffDistance;
    normalizedDistanceArray (nodeIndex)   ← normalizedDistance;
end for
    ─ Sort Normalized Distance ─
sortedNormalizedDistanceArray ← sort(normalizedDistanceArray);
    ─ Group Normalized Distance ─
startIndex ← 0;
sliceSize ← (sortedNormalizedDistanceArray / grpSize);
remainSize ← mod(sortedNormalizedDistanceArray, grpSize);
endIndex ← 0;
for groupIndex ← 1 to grpSize do
    if remainSize ≠ 0 then
        endIndex ← startIndex +1;
        distanceGroups(groupIndex) ← sortedNormalizedDistanceArray(startIndex + endIndex);
        remainSize ← remainSize – 1;
    else
        endIndex ← startIndex +sliceSize;
        distanceGroups(groupIndex) ← sortedNormalizedDistanceArray(startIndex, endIndex);
    end if
    startIndex ← endIndex;
end for
    ─ Assign Initial FEC Values ─
```

Table 3.2: BER levels of RS codes and the appropriate RS codes that can solve these BER levels (Yiğit, M., et al., 2019)

No. of Channels	RS codes	BER$_{min}$ and BER$_{max}$	The Optimal Reed Solomon Code
1	RS(63,35)	$0 \leq BER \leq 1$	RS(63,35)
8		$0 \leq BER \leq 1$	RS(63,35)
16		$0 \leq BER \leq 1$	RS(63,35)
1	RS(57,35)	$0 \leq BER \leq 1$	RS(63,35)
8		$0 \leq BER \leq 1$	RS(63,35)
16		$0 \leq BER \leq 1$	RS(63,35)
1	RS(51,35)	$10^{-11} \leq BER < 10^{-9}$	RS(57,35)
		$10^{-9} \leq BER \leq 1$	RS(63,35)
8		$10^{-12} \leq BER < 10^{-9}$	RS(57,35)
		$10^{-9} \leq BER \leq 1$	RS(63,35)
16		$10^{-14} \leq BER \leq 1$	RS(57,35)
1	RS(45,35)	$10^{-7} \leq BER < 10^{-5}$	RS(51,35)
		$10^{-5} \leq BER \leq 1$	RS(57,35)
8		$10^{-8} \leq BER < 10^{-6}$	RS(51,35)
		$10^{-6} \leq BER \leq 1$	RS(57,35)
16		$10^{-9} \leq BER \leq 1$	RS(63,35)
1	RS(39,35)	$10^{-3} \leq BER \leq 1$	RS(63,35)
8		$10^{-4} \leq BER < 10^{-2}$	RS(57,35)
		$10^{-2} \leq BER \leq 1$	RS(63,35)
16		$10^{-6} \leq BER < 10^{-4}$	RS(51,35)
		$10^{-4} \leq BER \leq 1$	RS(57,35)

3.1.2.3 Switching between the RS codes based on the threshold

In static reed Solomon we have to set RS code before every transmission which is inefficient since the conditions of the channels can change and differ from one transmission to another, therefore the definition of a switching mechanism that has been inspired from (Yu, K, et al., 2012). As we mentioned before that this method works based on the ACKs of the number S of the previously transmitted packets that has been received within a window of transmission the computation of the PER has been done and can be seen in equation 3.1 which can be calculated with the ratio of ACK’s from packets to the packets transmitted previously S. The Packet Error Rate inside this transmission window was calculated as shown in Equation 3.1 by taking the ACK packet ratio to the S packets previously transmitted (Yiğit,M., et al., 2019).

$$PER_{window} = 1 - \frac{ACK_S}{S} \quad \textbf{(3.1)}$$

In order to fully understand the channels conditions, the S shouldn’t be either too large or too small, for S values that are high the usage of the whole history of the transmitted packets can increase the BER since the outdated history can cause infinite number of the current channel estimation, as for the small S values it causes the RS code to change frequently, we used the S= 15 which has been used in previous study for the 500kV smart grid environment. As we can see from algorithm 3.2 the pseudocode for the AEC algorithm first the RS codes initialization and the assigned these values to the appropriate RS codes, after that the calculation of the $PER_{window}$is conducted and checking whether the if the PER_{window} equals or bigger than the pre-defined threshold value, an iterative checking on the look-up table in Table 3.2 and each row has been inspected until the RS code has been chosen based on the current channel, after that every RS code candidate inspected and managed the value of the BER . if the BER that we are currently calculating is between the values of the BER_{MIN} and the BER_{MAX} of the RS code that we are selecting for this BER range, then this code will be assigned to this particular node, if the range of BER didn’t contain the current BER that is in the look-up table then the RS value of the node will not be changed, alternativley if there was no error that occurred in the S transmissions, and also if the current RS code was not the first RS code in the look-up table which is RS(39,35) so this code is switch to a less influential RS code that contains less parity bits. Otherwise, if the PER_{window} is below than the set threshold, same RS code is used for the next tranmission.

Algorithm 3.2: The assignment of RS codes based on threshold and heuristic lookup table (Yiğit, M., et al., 2019)

```
Input: th (threshold); pW (perWindow); rs (currentRScode); aRS (allRScodes); h (heuristicLookupTable); ch (channel); ber (currentBERvalue)
Output: nRS (nextRScode)
if pW ≥ th then
  for i ← 1 to size of h do
    heuristicItem ← h(i);
    if heuristicItem.channelID == ch AND heuristicItem.RScode == currentRScode then
      for i ← 1 to size of aRS(i) do
        possible nRS ← aRS(i);
        if $BER_{min}$ value of possible nRS < ber AND ber ≤ $BER_{max}$ value of possible nRS then
          nRS ← possible nRS;
        end if
      end for
    end if
  end for
  if nRS is not assigned then
    nRS ← rs;
  end if
else
  if pW == 0 then
    if rs is the first of aRS then
      nRS ← rs;
    else
      nRS ← rs – 1;
    end if
  else
    nRS ← rs;
  end if
end if
```

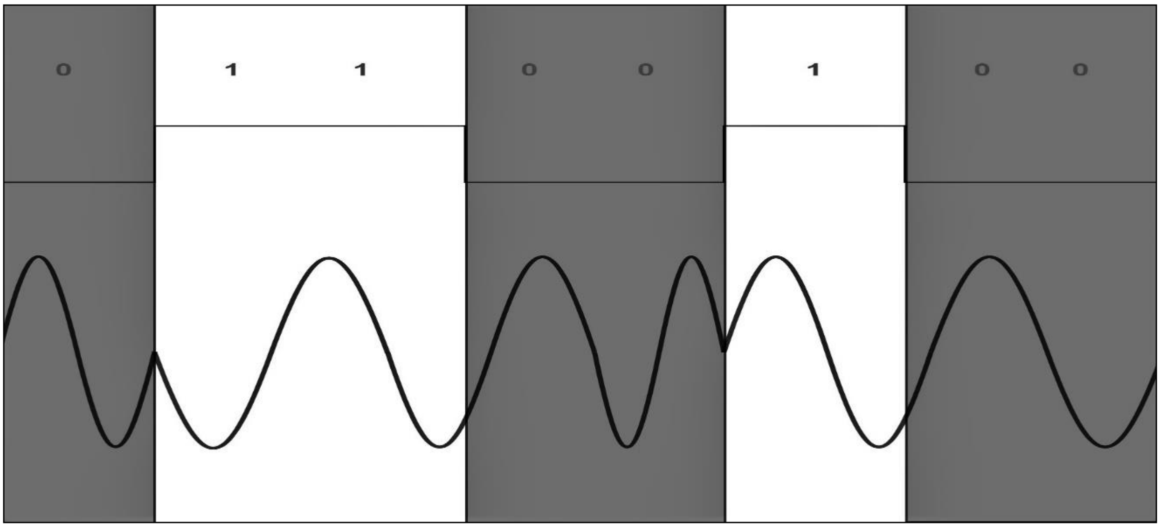
3.2 MODULATION

Modulation is the process of converting data that we are transmitting wirelessly into radio waves by adding information to an electronic or optical carrier signal. A carrier signal is one with a steady waveform, constant height, or amplitude, and frequency Information can be added to the carrier by varying its amplitude, frequency, phase, polarization (for optical signals) and even quantum-level phenomena like spin. Advanced data modulation formats have become quite important within the optical communications community, and of particular interest is differential-phase-shift-keying (DPSK) (Lin Zhang, et al., 2007).

3.2.1 DPSK

Differential Phase Shift Keying is a variation of phase modulation, the phase of the modulated signal which in our case is a radio frequency is shifted relative to the previous signal element. There are two phases for the signal to follow either high or low state based of the previous element, in other words it delivers the data to the demodulator by changing the phase of the transmitted wave corresponding to either 0 or 1.

Figure 3.2: DPSK Modulation



It is seen from the Figure (3.2) that, when the data in a low state which corresponds (0), the phase of the signal will not change however if the data is in high state which corresponds to (1) then the signal's phase is reversed.

3.2.2 Log-normal Shadowing Model

the log-shadowing model can used to simulate actual conditions of a channel in a 500kV LoS smart grid environment , the parameters for the 500kV propagation environment are shown in Table 3.3 (Yigit, et al. 2016). We can see from Equation 3.2 that the calculation of the link qualities between nodes has been done by computing the path loss in the log-normal shadowing model.

$$P_L = P_{L_0} + 10\gamma log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \qquad \textbf{(3.2)}$$

where P_L is the path loss that can be measured in dBm (decibel), P_{L_0} is the path loss parameter measured in dBm at the reference d_0, d is reference distance, γ is path loss exponent, and X_σ is Gaussian random variable with standard deviation σ.

Table 3.3: Log-normal shadowing channel parameters of 500kv LoS substation smart grid environment

Path loss (γ) :	2.42
Shadowing deviation (X_σ) :	3.12

3.3 PROPAGATION ENVIRONMENTS

3.3.1 Image Transmission via 500kV, MPR, UTV Environments Comparison

Substation is integral part of a power system and form important links between the generating station, transmission systems, distribution systems and the load points. Many factors influence the selection of the proper type of substation for a given application. This selection depends on such factors as voltage level, load capacity, environmental considerations, site space limitations, and transmission-line right-of-way requirements.

The primary substations such as the 500kV obtain electricity using the EHV lines and then transform the voltage to range from 66kV to 22kV to meet the requirements of the distance and load for the consumers, the substations have various tasks for the distribution and the transmission system that includes:

a. Offering security of the transmission system.
b. Monitoring the energy exchange.
c. Establishing a consistent equilibrium between state and transitional.
d. Maintaining the frequency of the system within target range
e. Controlling of Voltage
f. Providing adequate line capacity.
g. Using the power line carrier to transmit data
h. Analysis of failures and the cause of failures detection
i. Determination of transmission line energy transfer
j. Offering reliable supply
k. Establishing the distribution of economic load

This can be found in (Substation Main Functions and Classification by Edvard Csanyi 2012).

Table 3.4: Propagation Environments with their types and application type

Propagation environment	Type of the environment	Application
500 kV substation	Outdoor	*Primary Grid Substation*
Underground transformer vault (UTV)	Indoor	*Primary Grid Substation*
Main power control room	Indoor	*Primary Grid Substation*

The evaluation of these performances all done according to an actual field tests conducted using the IEE 802.15.4 that were based on a number of wireless sensor nodes that are distributed in a smart grid environment (Yiğit, M., et al., 2019) (Gungor, et al., 2010).

The log-normal shadowing model is being used for simulating real conditions that affect the quality of the links in different propagation environments. The model has been adapted and used for a numerous number of studies and proved that it can provide precise results for simulating smart grid environments with obstructions. The selection of the parameters is done according to multiple field studies by (Gungor, et al., 2010) for different propagation's environments link qualities and characteristics in smart grid. The field tests have been conducted in a multiple electrical system environments such as Underground Transformer Vault, Main Power Room and 500kV Substation. as we mentioned the IEEE 802.15.4 compliant wireless sensor nodes has been used for measuring the variables that affect data transmission negatively from signal attenuation to different channel characteristics, noise and the link quality, from these field tests the parameters for the different propagation environments have been used as shown it Table 3.5.

Table 3.5: Path loss and shadowing deviation in electric power environments

Propagation Environment	Path Loss (η)	Shadowing Deviation (X_σ)	Noise Floor (P_n)
500 kV Substation	2.42	3.12	-93
Underground Transformer Vault	1.45	2.45	-92
Main Power Room	1.64	3.29	-88

Source: (Yiğit, M., et al., 2019)

We can see in the log normal shadowing path loss model, the signal to noise ratio γ (d) at a distance d from the transmitter is shown in Equation 3.3 where P_T is the transmit power in dBm, $P_L(d_0)$ is the path loss at a reference distance d_0, n is the path loss exponent, X_σ is a zero mean Gaussian random variable with standard deviation (σ) (Yiğit, M., et al., 2019).

$$\gamma(d) = P_T - P_L(d_0) - 10_n log_\eta log_{10}\frac{d}{d_0} - X_\sigma - \mathrm{P_n} \qquad \textbf{(3.3)}$$

We have made a numerous number of simulations with the simulation parameters seen in Table 3.4 for the 500kV, UTV and MPR environments respectively the parameters were changed accordingly and the measurement metrics were BER, MSE and PSNR with 196 Nodes for the image to be transmitted totally, we did these simulations to assure that the environments were working perfectly and to make sure that the results were consistent with the previous simulations that we created.

These Simulations have been made to show how the changing the number of nodes and the size of the data transmitted in our case is an image and compare the results between the Static RS and the AEC to fully comprehend the differences between the performance of the stations.

3.4 IMAGE QUALITY EVALUATION

WSN applications that uses images as an input have a certain QoS requirements that the image transmitted must fulfill, one of these metrics is perceptual quality of how the user perceives the transmitted image and Delay is an important factor for the QoS, The multimedia transmission can be affected by multiple ways from resource constrained of the nodes in the WSN's to the highly unreliable wireless links, this all could lead to the deterioration of the QoS for the image transmission, certain methods must be implemented in order to ensure that the application's QoS requirements has to be fulfilled. (Yiğit, M., et al., 2019), in this section we discuss the results and the methods used for evaluation such methods are needed to Track network current status and take proactive measures to ensure an adequate image communication efficiency. In this context, it is important to accurately map the perceptional quality requirements from the application layer to low layer system parameters, the requirements of the application layer is highly dependable on the multimedia transmitted data , multimedia data characteristics is associated with the transmission., so we created a numerous numbers of simulations by sending and image through our WSN and using these metrics to evaluate and obtain the best results to ensure that the AEC was indeed the better choice for image transmission via WSN with the higher PSNR and Lower MSE and lower BER are all considered comparing the images transmitted using the static RS and using multiple channels for evaluation purposes using the same modulation of DPSK and Manchester encoding.

3.4.1 PSNR and MSE

PSNR measurement method is an objective criterion for evaluating images, is one of the most common and extensive image evaluation objective measurement methods (Jianqiang Lu, et al., 2017) it is considered One of the reliable evaluation methods to measure the image quality we use the PSNR between the Original Image and the Reconstructed Image, the color value of each pixel in the image can change during an image transmission, the signal may have a wide dynamic range, that's why the PSNR is usually measured in Decibels, which can be defined as a logarithmic scale, Essentially the Greater the PSNR the better the reconstructed image quality, we can use the mean squared error (MSE) to calculate the PSNR, this can be done by averaging the squared intensity of differences of both original and reconstructed image pixels, along with quantity of PSNR that is related. The use of these methods can be appealing since its fast and easy to implement and can be easily edited mathematically (Boluk, P., et al., 2011) We start by defining the bel and the decibel, we define the bel in a mathematic manner as $LB = log_{10}\left(\frac{P1}{P0}\right)$ where P1 and P0 are both quantiles the can be measured in the same unit of measurement, the decibel is 0.1 of the bel, so the value of the decibel can be defined as LdB is *LdB = 10 log10 (P1/P0)*. And the MSE can be defined as the mean squared error between two given images, in our case it's the original and reconstructed images so they are approximation of one another. the MSE can be defined also as the mean square of the differences for the pixel value in the same pixel in both images we can express the MSE mathematically from the description as we can see the MSE formula in Equation 3.4.

$$MSE = \frac{\sum_{\mathrm{m,n}}[\mathrm{I}_1(\mathrm{i,j}) - \mathrm{I}_2(\mathrm{i,j})]^2}{\mathrm{m} * \mathrm{n}} \qquad 3.4$$

Where I1 and I2 are the matrix representation of both images that we are comparing, both of the summations are implemented for the image dimensions (*i, j*), hence, I (*i,j*) means the value of the pixel (*i,j*) of the image I. in an image I in rder to determine the maximum value of the pixels and this can be don typically $(2^n - 1)$ where n is the number of the bits that represent the pixel for example an image with 8-bit pixel can have the maximum value of $(2^8 - 1 = 255)$. So if the maximum value for the pixel in an image I be MAX so we express the PSNR from the equations above as:

$$L\,\mathrm{d}B = 10\,log_{10}\left(\frac{P_1}{P_2}\right)$$

Now let $(P_1 = R^2)$ and P0 = MSE

We then have:

$$10\,log_{10}\left(\frac{R^2}{MSE}\right) \Rightarrow 10\,log_{10}\left(\frac{R}{MSE^{\frac{1}{2}}}\right)^2 = 20\,log_{10}\left(\frac{R}{MSE}\right)^{\frac{1}{2}}$$

Therefore we can conclude the formula of the PSNR as in Equation 3.5.

$$\mathrm{PSNR} = 20\log_{10}\left(\frac{\mathrm{R}}{\sqrt{\mathrm{MSE}}}\right) \tag{3.5}$$

Where R is the maximum fluctuation in the input image data type. For example, if the input image has a double-precision floating-point data type, then *R* is 1. If it has an 8-bit unsigned integer data type, *R* is 255, etc.

3.5 SCENARIO AND ASSUMPTIONS

We assumed that each node transmits part of an image to sink node using mediator nodes and they are forwarded using multiple hops from sender node to receiver node, this is a best effort deliver model and with multi-channel scheduling is assumed, hence there are no retransmissions even if there is a packet loss

Table 3.6*:* Simulation Parameters and Notations

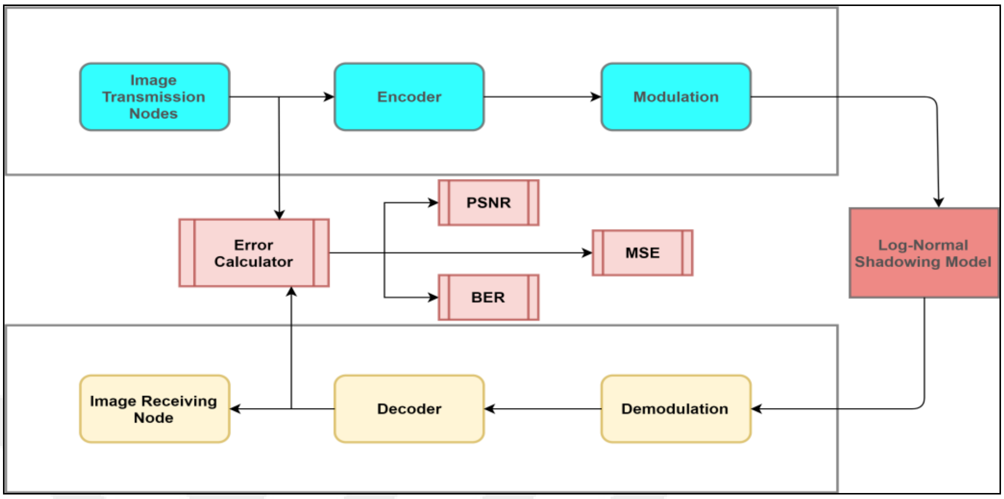
Parameter	Definition	Values & Notations
Q(.)	Standard Gaussian error function	$Q(x) = 0.5 \times erfc\left(\frac{x}{\sqrt{2}}\right)$, $erfc(x) = \frac{2}{\pi}\int_{x}^{\infty} e^{-t^2} d_t$
E_b/N_0	SNR (Signal to noise ratio)	$\frac{E_b}{N_0} = \psi \frac{B_N}{R}$
Modulation schemes	DPSK	$P_b^{FSK} = 0.5 \times \frac{1}{e^{E_b/N_0}}$
P_t	Output power	10 dBm
P_n	Noise floor	-93 dBm
fL	Frame size	400 bits
#nodes	Number of nodes	196
D_x	Terrain dimension: X	200 m
D_y	Terrain dimension: Y	200 m
mse	Mean Squared Error	$MSE = \frac{\sum_{\mathrm{m,n}}[\mathrm{I}_1(\mathrm{i,j}) - \mathrm{I}_2(\mathrm{i,j})]^2}{\mathrm{m} * \mathrm{n}}$
psnr	Peak Signal to Noise Ratio	$\mathrm{PSNR} = 20\log_{10}\left(\frac{R}{\sqrt{\mathrm{MSE}}}\right)$
Topology	Topology of the Distribution of Nodes	Grid topology

Some of the Parameters we used directly to measure the quality of the reconstructed image we also increased the Output power to get better results.

3.5.1 System Model

the following steps constitute our system model: (1) Loading a JPEG Image and converting it to Grayscale and then to Binary; (2) the information sequences converted to a unique codeword by the encoder consisting of n symbol sequence; (3) the codeword will be sent to the modulator; (4) the data then will be transformed to signal waveforms based on the modulator scheme; (5) the signals generated from the modulator will be transmitted via the log-normal shadowing channel based on the propagation environment characteristics ; (6) the path loss or other factors can corrupt the data transmitted during transmission ; (7) the signal data enter the demodulator which demodulates the data by detaching it from the waves of the carrier; (8 then at side of the receiver the decoder decodes the demodulated data into the original sequence transmitted. (9) The image is converted back to grayscale original image and the evaluation of the results based on multiple criteria. The flow process of the system is shown in Figure 3.3.

Figure 3.3: System Model



4. PERFORMANCE EVALUATION AND RESULTS

4.1 PERFORMANCE EVALUATION

There are many challenges that faces the WSNs, for example the satisfaction of QoS requirements is imperative as it is difficult to transfer a large amount of data in our case image data through an error prone environments. The purpose of this study is to satisfy all of the QoS from perceptual quality to lower delay and higher throughput for the image transmission via WSNs in smart grid environment. In this section we have made a visual representation of the transmitted images in both static RS and the AEC as well as a numerical representation and transmitted the images using the 1, 8 and 16 channels with the DPSK modulation and a 500kv substation environment so we can fully evaluate the results and using them to compare both the static RS and AEC performance the results were as follows:

Figure 4.1: PSNR vs number of channels for log-normal shadowing channel (using DPSK), static and adaptive RS codes in 500kv los substation smart grid environment

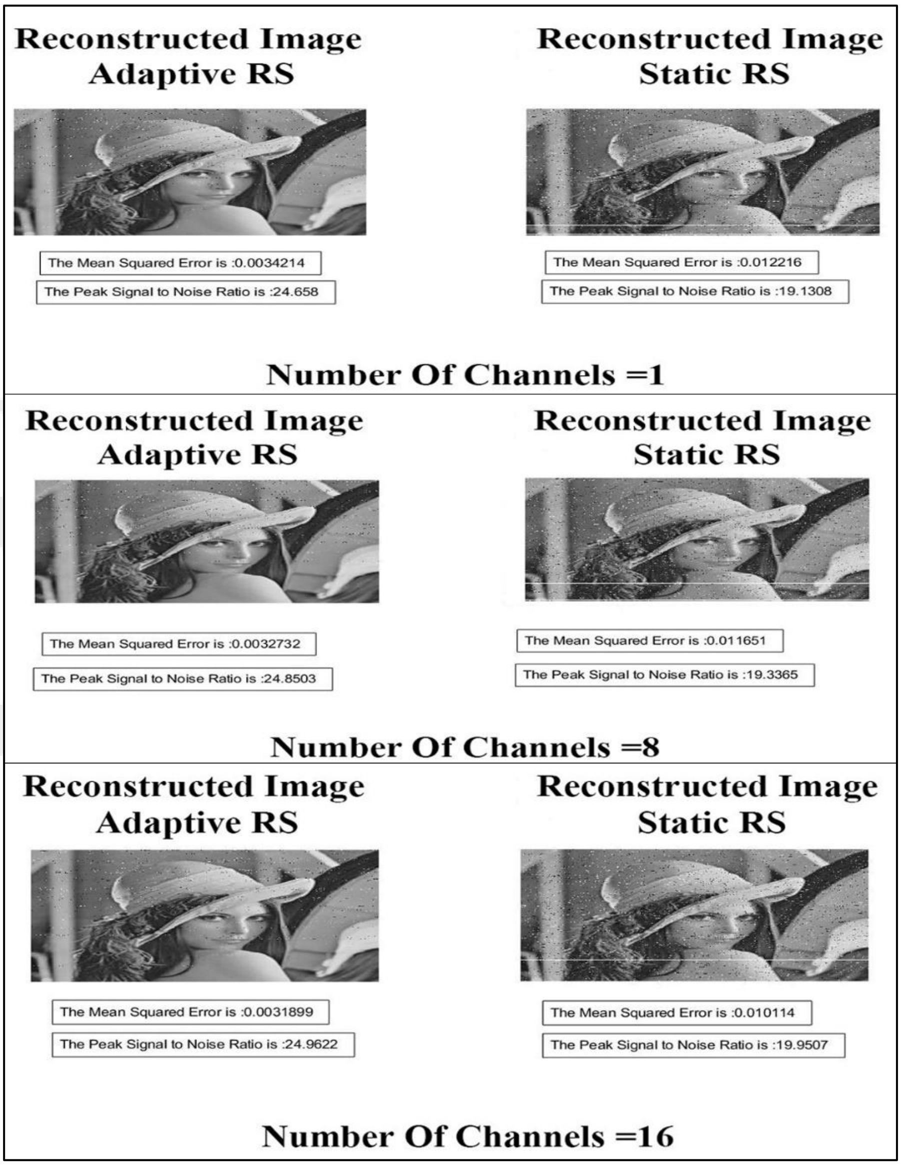


Figure 4.1 shows PSNR results of static RS, and AEC. We can see that as the number of channels increases from 1 to 8 to 16, that the quality of images from the AEC is much higher than the static RS with the DPSK with the PSNR values being the highest at the 16 channels scheme ,these results are mainly for the human visual system which can judge of high the quality of the image apart from the numbers and as for the PSNR numbers the numbers were promising as it was sent wirelessly and using 500kv smart grid substation

environment which has the harshest condition that affects the channels negatively such as noise, interference , multi-path fading so using this FEC provided and excellent substitution for the normal/static RS in terms of image Quality as for the other criteria we will discuss forward.

Figure 4.2: Comparison of BER of the static RS, AEC as the number of channels increases for image transmission

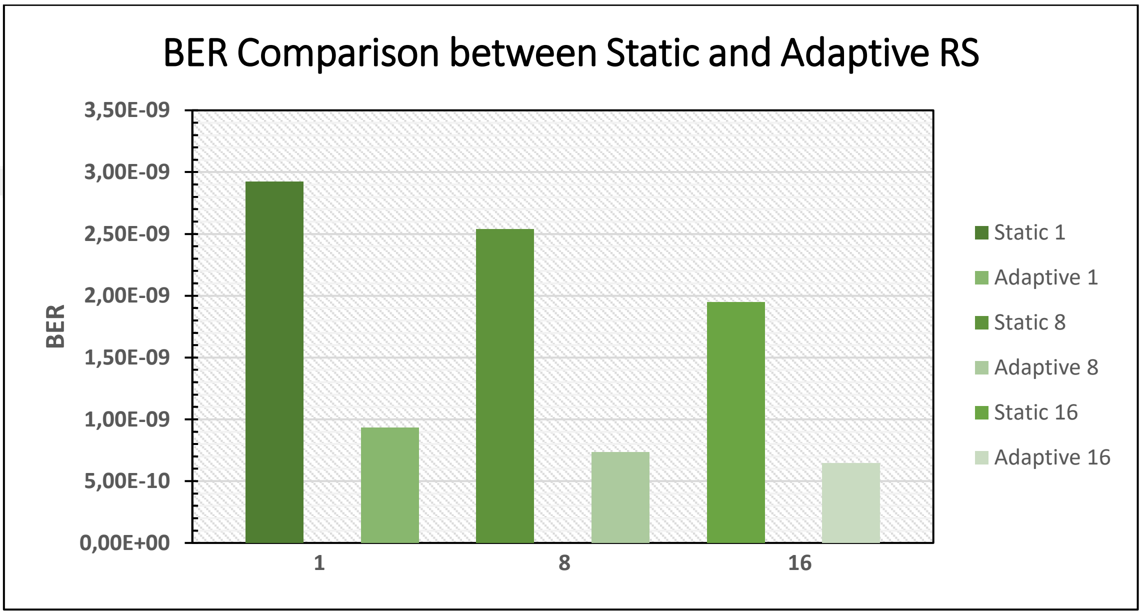


Figure 4.2 compares the BER of RS codes between adaptive and static algorithms with DPSK modulation for image transmission through WSN. It can be observed from the Figure that BER decreased by almost 30% as we increased the number of channels in the AEC, the effect of interference has been reduced by the use of multi-channel communication as well as providing concurrent transmissions over multiple channels. The results, in Figure (4.4), show the BER performance of RS with the adaptive approach combined with the DPSK have a very low BER compared to the static RS algorithm obtained for channels 1, 8, and 16, respectively.

The previous team proved that the lowest results for the BER were obtained with the threshold of 0 for the AEC and the number of channels was 16 because AEC quickly changes the RS code which we proved also in our simulation of image transmission that we got the lowest BER and also highest PSNR as we seen previously.

Figure 4.3: Throughput vs. number of channel for log-normal shadowing channel (DPSK), static and adaptive RS in 500kv los substation smart grid environment

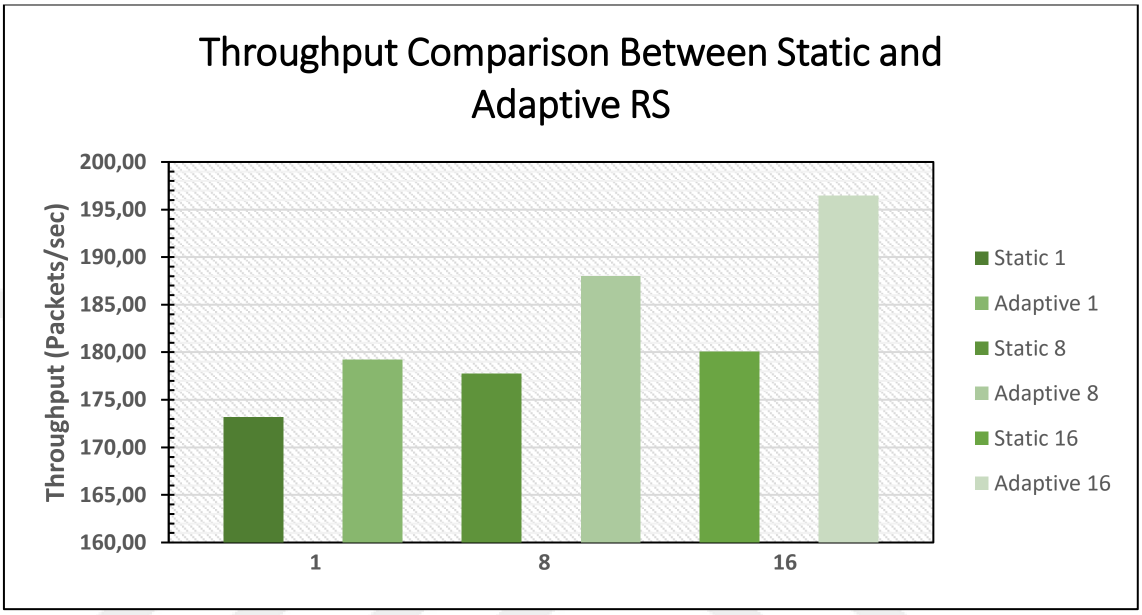
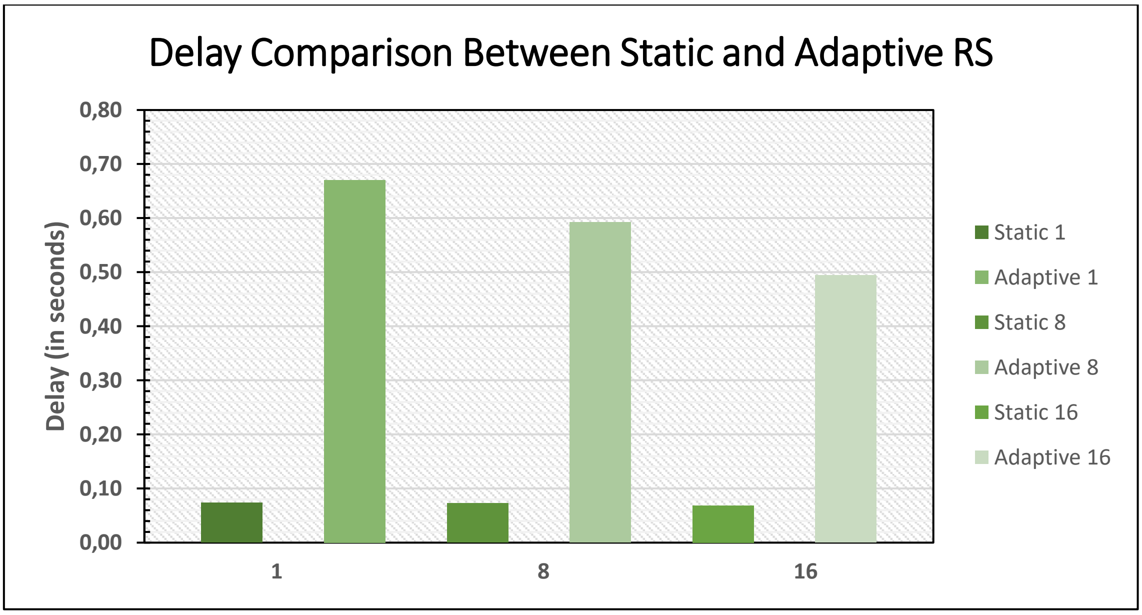
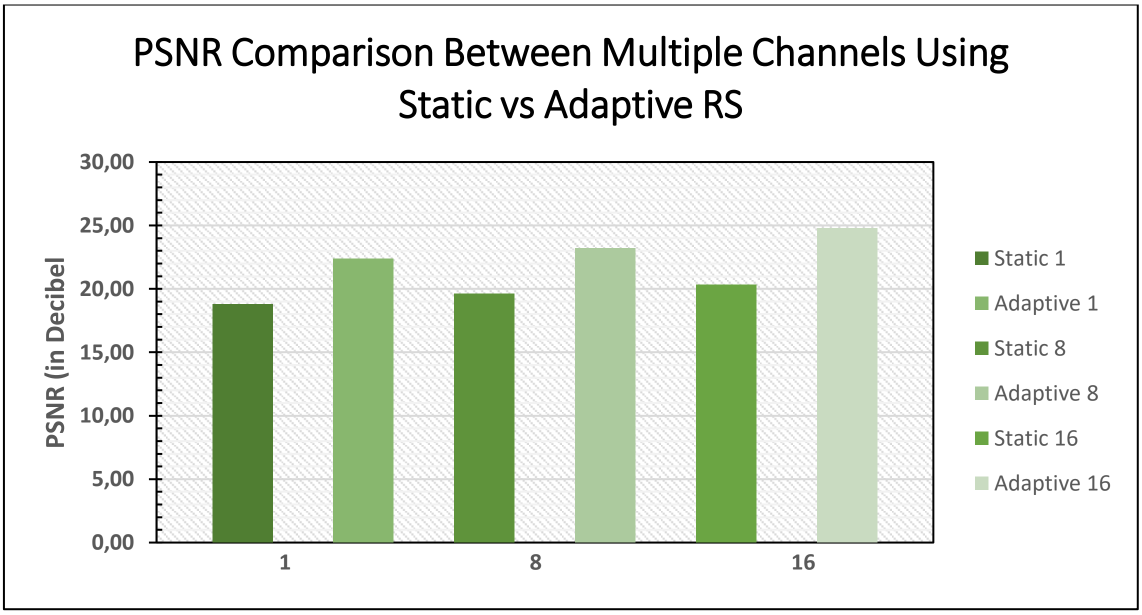


Figure 4.4: Delay vs. number of channels for log-normal shadowing channel (using DPSK), static and adaptive RS codes in 500kv los substation smart grid environment



Figures (4.3, 4.4) compare the throughput and delay of RS codes both Static and AEC using the DPSK modulation technique in a 500kV LoS substation smart grid environment by sending an image through the WSN. These results show that the performance of the throughput increase as much as 10% as the channels number increase for these RS codes, the increased number of channels provide more concurrent transmissions in order to deliver the packets from the sender node to receiver node in a short interval of time. Notably, the throughput results in Figure (4.3) show that the performance RS codes in the AEC are much better than the static, In addition, Figure (4.4) shows that average of the delay of RS codes for the AEC is higher than the Static code but it decreases as much as 26% as the number of channels increases, the delay in the adaptive RS is more because it assigns the RS codes by the addition of the redundant bits to the original data packets for the purpose of detecting and correcting the bit errors that can cause the overheads while the data packets are being transmitted that can increase the transmission delay and also the AEC calculates the distance between nodes and assigns the redundant bits based on the distance, which can cause higher delay for the transmission.

Figure 4.5: Multiple simulations for PSNR comparison between static and adaptive RS codes on multiple channels in a 500kv smart grid environment



We have run multiple simulations to fully compare the methods that we are using for transmitting the images as we can see the comparison between the Static and Adaptive

RS with DPSK modulation using multiple channels from 1 , 8 and 16 respectively in a smart grid environment as we can see in Figure (4.5) the PSNR in the Static RS increases as the Number of channels increases but the highest level which is in the 16 channels still less than the AEC which reaches the highest number in the 16 channels which is close to 25 dB making almost 31% increment , which is really decent when used in an places that require high quality images that our simulations can provide

4.2 OUTPUT POWER

In wireless sensor networks each remote sensor is typically battery-powered and thus has a limited energy budget for operations such as wireless transmissions. Therefore, one of the most prevalent issues in WSNs is how to provide reliable and energy-efficient communication (Tao Ma, et al., 2017). Generally the WSN's are resource constrained hence, the energy consumption is a crucial matter to be considered while analyzing the performance of WSN's and the cost of the WSN's power consumption must be taken into consideration (Boluk, P., et al., 2011). Maximizing the transmission power of each node in a wireless sensor network system can minimize the BER and make the transmission distance to the farthest. But this will lead to unnecessary power consumption and shorten the battery life of a wireless sensor node. Hence to control the transmission power with a certain level of communication being guaranteed is an important topic of transmit power control (Kuo-Hsien Hsia, et al., 2017). in this thesis we have studied the change of output power before transmission and how it affects the quality of the image transmitted and how it affect the MSE and BER of the image data. In our scenario the distance between the sensor nodes is fixed and it is assumed that the probabilities of the packet loss will be considered. multiple parameters has been used for the purpose of fully evaluating how the effect of manipulating these parameters can impact the performance of the transmission schemes are listed in Figures (4.6, 4.7, 4.8) we tested our AEC in multiple output power and measured the BER, Delay, Throughput and how it is affected the image by the increase of the output power:

Figure 4.6: **BER vs the output power using adaptive RS codes on multiple channels in a 500kV smart grid environment**

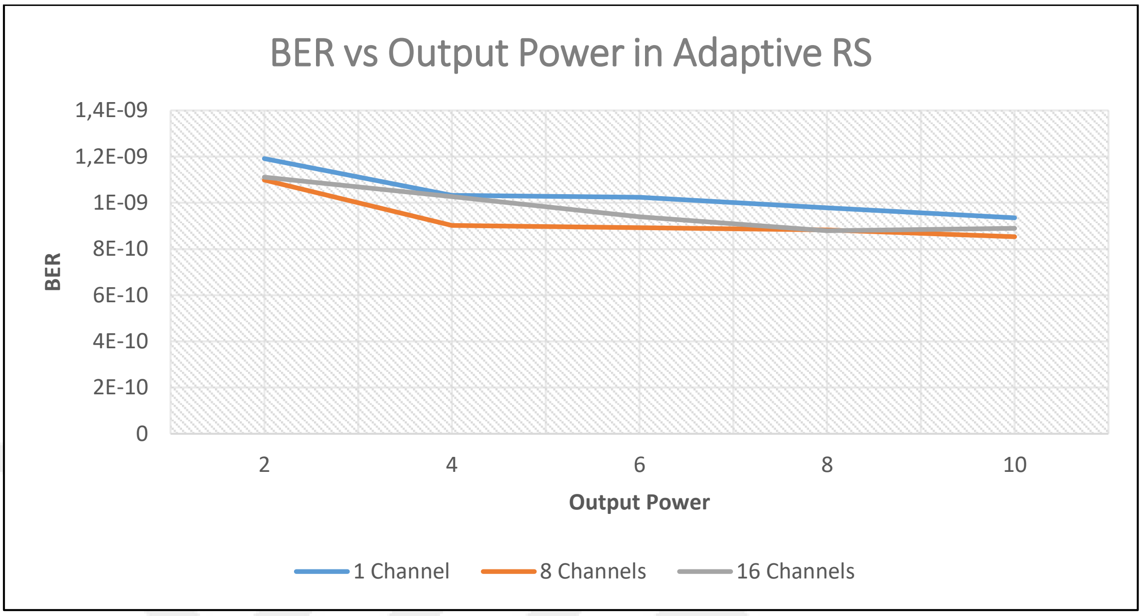


Figure 4.7: Delay vs the output power using adaptive RS codes on multiple channels in a 500kV smart grid environment

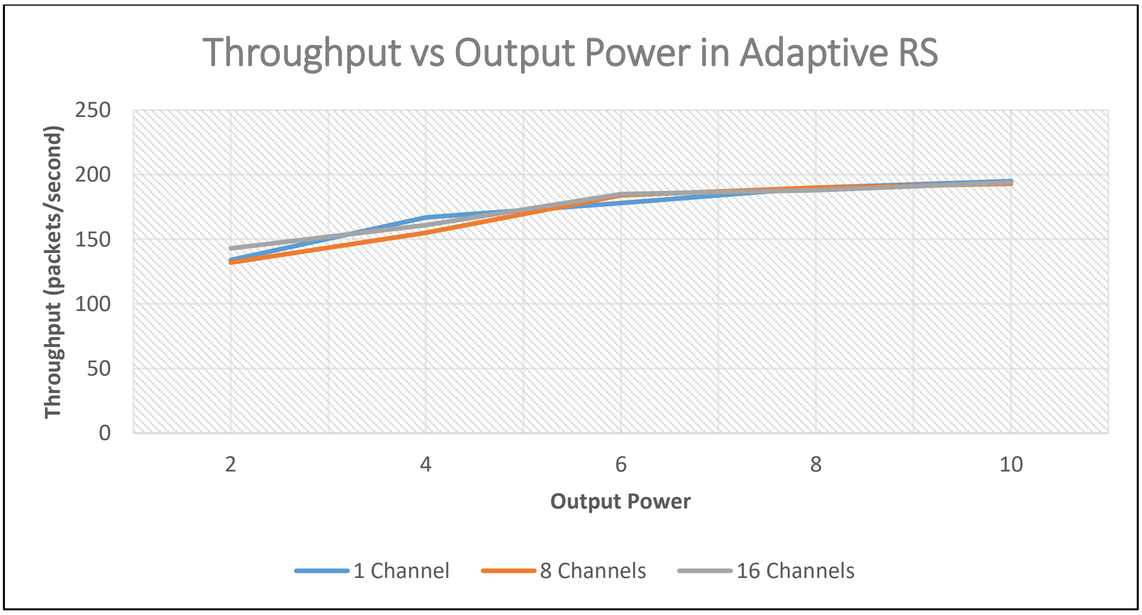
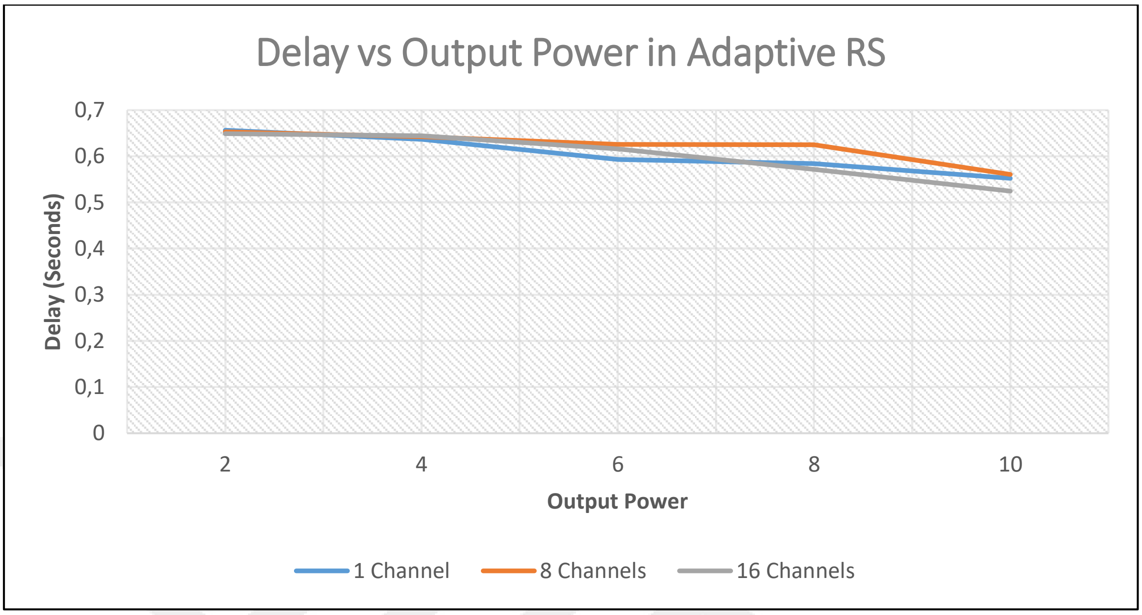


Figure 4.8: Throughput vs the output power using adaptive RS codes on multiple channels in a 500kV smart grid environment



For the Simulation results Analysis, We have concluded that the Adaptive RS has performed good for the applications that requires high throughput and lower BER and Delay. As the algorithm lowers the BER and increases the number of received packet and also we can see that the delay has been decreased when the power is increased for all channels while this can be effective in terms of these criteria but it can lead to higher energy consumption ,

Performance results also show that the channel number does affect the performance of AEC. In Figure (4.6) we created multiple simulations with the increase of the output power for number of channels (1, 8, 16) we can see that the BER has decreased It is also observed that optimal transmit power required in our simulation is 10. In Figures (4.7, 4.8) we can see that the Throughput is increased as the output power increased and the Delay is decreased for the multi-channel transmissions.

4.3 MULTIPLE PROPAGATION ENVIRONMENTS RESULTS

As we mention in Chapter 3 that we have chosen the 500kV substation as our main simulation environment as it has the harshest conditions that can affect the data we are transmitting negatively and we used the parameters assigned to it of the path loss and the shadowing deviation we also created multiple image transmissions over different environments which are the UTV and the MPR for testing the different results and comparison purposes the following results were obtained:

Figure 4.9: BER vs multiple propagation environments using adaptive RS with 196 nodes for image transmission

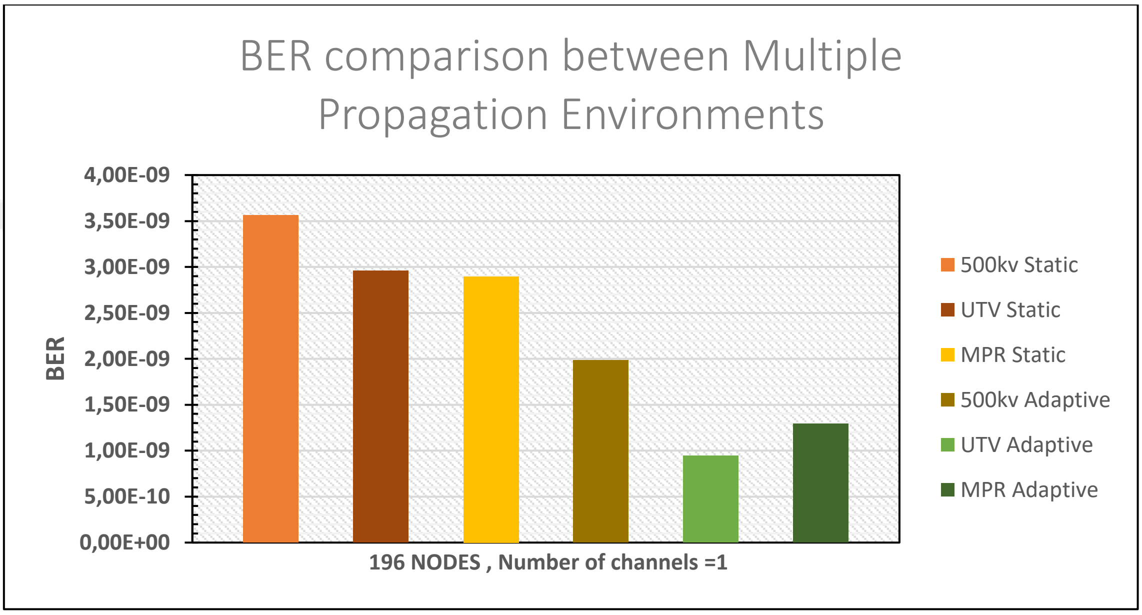


Figure 4.10: MSE vs multiple propagation environments using adaptive RS with 196 nodes for image transmission

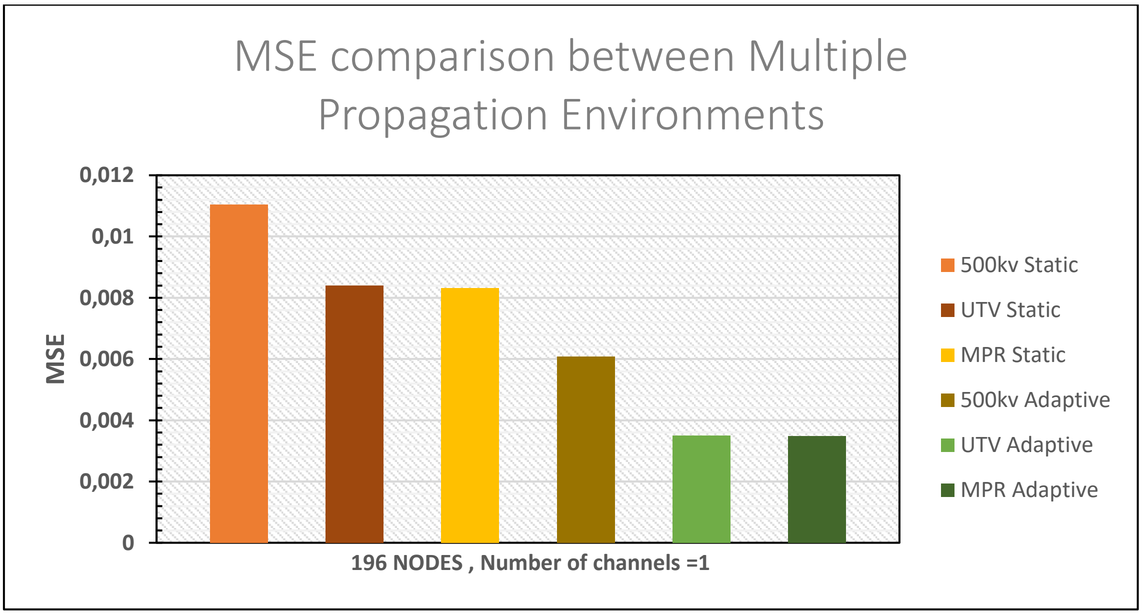
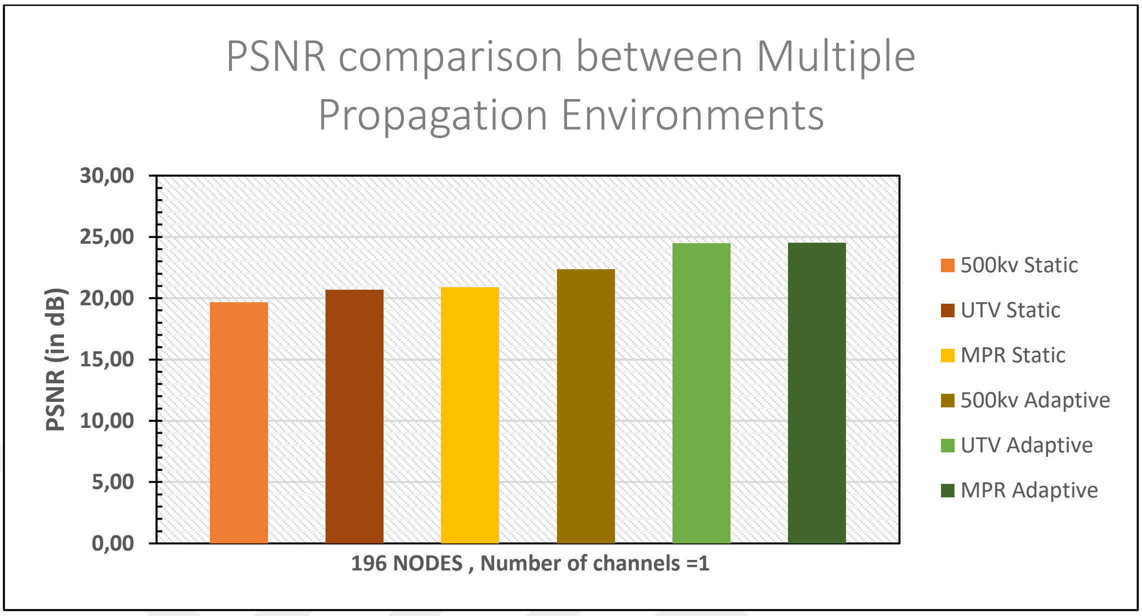


Figure 4.11: PSNR vs multiple propagation environments using adaptive RS with 196 nodes for image transmission



BER, MSE and PSNR in three smart grid environments are presented by considering different parameters extracted from real field tests (Yiğit, M., et al., 2019). The data has been sent in previous simulation has been changed to an image with the size of 196*420 Grayscale with grid topology and DPSK modulation, these simulations are performed to evaluate the impact of the switching between Static and Adaptive RS algorithms explained previously, and changing the number of nodes in different smart grid environments. The comparative performance evaluations have been done to determine quantitatively how much these parameters can affect the performance of the environments. As we can see in Figure (4.9) the BER is significantly less in the 500kV, UTV and MPR using the AEC which is consistent with the results previously made, as for the Figures (4.10, 4.11) the MSE and the PSNR differs noticeably between stations as we can see the MSE in Figure (4.10) decreases from static RS to AEC considerably but the MSE in the 500kV substation environment is higher than the UTV and the MPR which is Correct due to the fact that the 500kV simulates harsher more error prone environment which we can see also in Figure (4.11) that the PSNR is also increasing significantly as we switch from the static RS and the AEC but the 500kV has a lower PSNR than both the

UTV and the MPR which is also because the MPR and the UTV perform in a more forgiving environment with less error prone links due to simultaneous transmissions.

5. CONCLUSION

This thesis aims to offer solutions for the image transmission and provides a performance comparison for reliable image transmission over WSN for Smart grid applications.

There are many hurdles that come along with the continued advancement of the WSN’s from the applications that is being used for monitoring that uses a low-data rate to the more complicated multimedia applications, that requires and highly efficient and reliable timely delivery of the image that is being transmitted.

The smart grid communication system contains harsh and severe environmental conditions such as noise, interference and path loss that can affect the data transmission negatively. Therefore, the quality of the transmitted image may not be acceptable for Smart Grid applications. In order to increase quality of the distorted images, the use of a forward error correction for the image transmission is vital in order to provide the optimal results for our image starting from lower PSNR and MSE with higher throughput etc., we used two forward error correction techniques: Static RS and Adaptive RS.

We have made extensive simulations using the Static RS and the Adaptive Reed Solomon with the DPSK modulation. On the opposite of Static RS, Adaptive RS estimates the channel condition and assigns the correcting codes based on the distance between nodes. In other words, it corrects the error dynamically. The performance comparisons showed that the Adaptive RS provides higher performance in terms of BER, PSNR, and throughput. However, due to its lower complexity, Static RS is faster than Adaptive method for smart grid applications. Our results show that Adaptive RS is useful scheme to deal with the wireless errors. It also provides application layer perceptual quality requirement for Smart Grid applications.The contributions of the thesis are summarized in the following section.

5.1 CONTRIBUTIONS REVISITED

Contribution 1: Image Transmission via a Wireless Sensor Network Using an Adaptive Error Control Technique

An extensive number of simulations have been made using multiple Forward Error Correction (FEC) algorithms to lessen the image distortions that occur during a transmission via a WSN , performance evaluations for comparing the Static and Adaptive

Reed Solomon algorithms have been done according using DPSK modulation schemes in 500kV substation smart grid environment. Performance metrics including peak signal to noise ratio, mean squared error, bit error rate, throughput, and delay are used in simulations. Simulation results reveal that the Adaptive Reed Solomon code with DPSK modulation outperforms the Static Reed Solomon in smart grid communication network because of its high PSNR values, low BER and high throughput performance. However, delay performance of AEC code is worse than the Delay performance of the static RS. This is because AEC adds parity bits based on the distance between the nodes which adds to the communication delays,

Results also show that increasing the number of channels also improves the performance of AEC for our modulation scheme. Furthermore, the perceptual image quality of the images transmitted using the AEC showed high improvement from the static RS which leads to a deeper understanding of the impact of physical layer parameters on PSNR, BER, throughput, and delay performance of smart grid communication. The performance of the adaptive RS improves as we increase the output power the reason is when we increase the output power the PRR increases and would decrease the BER while gaining a higher PSNR,

in this thesis we have obtained two images from the static and adaptive RS, to evaluate the results we have compared the reconstructed images with original image using Peak signal to Noise Ratio (PSNR) and Mean Squared Error (MSE), PSNR and MSE results for transmitted images have been consistent with FEC we are using and proven that the AEC was the better choice for transmission for the crucial requirements by the QoS applications.

Contribution 2: Image Transmission via Multiple Propagation Environments

We explored image transmission a multiple propagation environments and how it can be affected by choosing the correct routing topologies and different simulation parameters for the different propagation environments in wireless communication. The network performance is evaluated by using a receiver-based channel selection method and using different routing trees, including routing trees constructed considering the link qualities, CMSTs, capacitated minimum hop spanning tree considering link qualities and MHSTs.

Specifically, CMST trees were presented to minimize latency with perfect link qualities in (Gungor, et al., 2010), but, their performance was not investigated for WSNs operating in smart grid environments with varying link qualities. Therefore, We have made multiple simulations using different propagation environments such as 500kV smart grid environment and underground transformer vault (UTV) and the main power room (MPR) we changed the parameters according to the real life field tests conducted by the previous team (Yiğit, M., et al., 2019) which helped explore how the changes of environments affect the perceptual quality of the image in terms of the PSNR and the MSE and also the BER , we made the comparisons between the station using both static and adaptive Reed Solomon algorithms with DPSK modulation and 196 nodes , the results were consisted in terms of all the metrics that we used for evaluation the UTV were the best in all of the results which consistent with the description of the station that has less harsh environment and higher link qualities as for the 500kV although it had a lower results than both the stations however these are duo to harsh environment with higher interference and noise that affect the quality of the image negatively.

5.2 SUMMARY

As a final mark of the thesis, error correction techniques, several ways of the image quality awareness and the integration of the image characteristics to the protocols are studied in order to satisfy the application layer QoS requirements in WSN. The performance of RS codes in both the static and adaptive are evaluated with using DPSK modulation scheme and using the AEC protocol for our image transmission purposes in order to maintain reliability requirements of WSN-based smart grid applications. The purposes of this study are to identify the impact of some ECCs on sensor networks in a 500kV LoS substation smart grid environment These results show that with the selection of the correct error correction technique we can provide a high image quality, it is also verified that with the changing of the output power we were able to enhance the image quality and the throughput, on the other hand the image transmission in multiple propagation environments provided deeper understanding of each smart grid environment and how the characteristics of each environment is different and can affect the perceptual quality of the image and other criteria used for the evaluation purposes of the image transmission.

5.3 FUTURE RESEARCH DIRECTIONS

a. Video transmission via wireless sensor network in smart grid application is a promising topic

b. integrating the frame work with other error control methods such as ARQ and Hybrid ARQ so the comprehensive analysis can be conducted of these algorithms and also obtain the results of these methods on PSNR, MSE, throughput and BER for image transmission

c. integration of the frame work with watermarking error correction method it will help decrease the energy consumption at intermediate nodes, hence retransmission could be removed from the MAC layer as well

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