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MATLAB Modelling of Bridge Health Monitoring Using Wireless Sensor Network

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ABSTRACT

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The prominence and importance of Wireless sensor network (WSN) is on the rapid increase. This has led to new ways of assessing the safety and reliability bridges. There have been great strides made in the monitoring of bridges' health but research on how to improve these health monitoring techniques of bridges are still on going. This thesis project focus on using Simulink (MATLAB function) to model a wireless bridge health monitoring system.

The effect of SNR and interference, such as noise, on the system could be investigated using the MATLAB simulink modelling platform. This gives great insight on how to mitigate against these parameters and adequate precaution can be taken.

Key words: WSN, SNR, MATLAB

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ABBREVIATIONS AND TERMS

WSN	Wireless Sensor Network
FHWA	Federal Highway Administration
MATLAB	Matrix Laboratory
NDE	Non Destructive Evaluation
BHM	Bridge Health Monitoring
ACM	Autonomous Crack Monitoring
ACPS	Autonomous Crack Propagation Sensing
FBGs	Fibre Bragg Gratings
AWGN	Additive White Gaussian Noise
SNR	Signal to Noise Ratio

1 INTRODUCTION

In most developing countries, the safety and reliability of civil structures, such as Bridges, Buildings, rail tracks, etc. are essential to the economic and social stability of a country. These structures are generally not giving the right attention it deserves, most especially in third world countries. Once the construction of these infrastructures is completed, there is basically little or no consideration taken to monitor the health of this infrastructure. Even in developed countries, like US, the infrastructures are deteriorating rapidly. For example, nearly 42% of bridges built before 1940's is reported to be structurally deficient and are below the required safety standards [1]. These Bridges have little or no real-time health monitoring techniques installed in them. The need to monitor the health of these structures are very important to the safety of the citizens and the economy of the country as a whole. These infrastructures are consistently subjected to physical stress such as loads, wear and tear, etc. and also environmental effects such as temperature, humidity, etc.

To ascertain the health of these Bridges and ensure the safety of the general public, visual inspections are employed. However, visual inspection is highly dependent on the professional views of the inspector and these may vary from one specialist to another. For example, a survey carried out by U.S. Federal Highway Administration (FHWA) to verify the reliability and accurateness of visual inspections shows a variation in the condition ratings assigned by trained inspectors to a bridge intentionally damaged as part of the study [2]. This shows visual inspection are not usually accurate. Furthermore, visual inspections are both costly and labor intensive. Hence the need for a low cost, real-time monitoring system that can assess quantitatively the quality, integrity and remaining life span of the structure [3].

As a complimentary inspection techniques to visual bridge structure inspection and probably becoming an alternative, Bridge health monitoring techniques was proposed. The task of monitoring the health and safety of bridges requires the continuous access to reliable data concerning the state of the bridge. Some of the parameters that can to be measured to ascertain the health of bridges are temperature gradient, cracks, corrosion, decrease in load capacity, vibrations, humidity, etc.

The motivation behind this thesis is to explore the possibility of implementing a wireless Bridge health monitoring system using the Simulink platform in MATLAB as the main technology. There are already few wireless technologies being employed in Bridge health monitoring but using MATLAB Simulink is a novel approach.

This thesis work is presented in six (6) different chapters.

In chapter 1, introductory information related to the thesis work was discussed.

Chapter 2 gives a review of Bridge health monitoring system and the various types used.

Chapter 3 start with an overview of a wireless sensor network (WSN) and its application. Features and Benefits of WSN were discussed and the different challenges in WSNs are also highlighted. Multiple Access Techniques

In chapter 4, shows a detailed description and function of each block in the modelled WSN for Bridge health monitoring. Matlab Simulink environment is used. The simulation results are also presented

In Chapter 5, Conclusion on the work and gives recommendation into possible future work to improve the modelling.

2 BRIDGE HEALTH MONITORING

The term Bridge health monitoring can be described as the continuous monitoring of Bridge’s health and the near real-time quantitative analysis of acquired data. The measurement and analysis of response of the bridge to environmental factors (wind, Temperature, etc) and forced excitation (Load, vibration, etc.) is a major requirement of a Bridge monitoring system.

The purpose of having health monitoring system installed on Bridges are (1) to detect any structural defect or possible deterioration of the Bridge early; (2) provide a real-time monitoring and evaluation of the Bridge; (3) provide data and information to make scientific decision on the need for bridge inspection, maintenance and repairs; and (4) validate assumptions and parameters with the potential benefit of improving design specification and guidelines for future similar structures [4].

2.1 Bridge Health Monitoring Technology

Bridge health monitoring technology can be broadly classified into three major method, they are traditional inspection methods, wired inspection methods and wireless inspection method.

A brief overview of these methods is described below

2.1.1 Bridge Health Monitoring Using Traditional Inspection Method

This dates back to the construction of bridges itself. It is the first method employed in monitoring and investigating the health and reliability of bridges. This involves the inspection and evaluation of the health of bridges visually. Visual Inspection gives a qualitative assessment of the bridge. When Cracks and/or structural defects are detected in a component of the bridge by visual inspection, a nondestructive evaluation (NDE) is then carried out to ascertain the health of the Bridge. Nondestructive evaluation (NDE) gives a quantitative assessment of the health of the Bridge. Examples of nondestructive Evaluation Technologies are acoustic emissions, ultrasonic, radar, and thermography [11].

Visual inspections most times fail to detect crack and /or structural defect that are not visible. Therefore, most structurally deficient bridges may go un-noticed for a long time and this potentially put the general population at risk due to the health of the bridge [4].

Visual inspection relies on planned schedule. It can be quarterly, bi-annual or yearly depending the engineer in charge of the bridge maintenance. It is also not reliable because of the shortcomings associated with this monitoring techniques.

2.1.2 Bridge Health Monitoring Using Wired Sensor

The apparent problems associated with the traditional inspection methods led to research for a more reliable technique or system to monitor the health of bridges; monitoring system that could monitor the health of these bridges continuously and more reliably than the traditional inspection techniques was proposed. With the introduction sensor in the monitoring of Bridge health system, their popularity and acceptance soared quickly. This was largely due to its relatively low cost as well as its higher reliability as compared to the traditional inspection method. Some of the widely used wired sensors used are accelerometer, strain gauge, inclinometer, etc.

Despite the advantages Wired sensor has over traditional inspection method, it is still considered an expensive system. Hence, wired sensor monitoring system were only installed in Bridges that are exposed to extreme load conditions and long-span bridges in seismic regions. Also, the complexity of installing wired sensors in a long-span bridge constrain these systems to relatively sparse sensing arrays [12]. This lead to more research on developing a better system than the wired sensor system

2.1.3 Bridge Health Monitoring Using Wireless Sensor

Wireless smart sensors offer a solution for long-term, scalable Bridge Monitoring System by providing easier installation and efficient data management at a lower cost than visual inspection method and wired monitoring systems. Also, wireless sensing platform can address real-time, structural vibration, strain, and temperature measurements on highway bridge monitoring [17].

One of the main advantage of wireless sensors are the fact that they are easy to install, remove and re-install. Some of the wireless sensor system used in BHM are;

- Wisden system was developed to address the drawbacks associated with traditional visual inspections or wired sensor system. Wisden is a multi-hop wireless data acquisition system and it consists of tens of wireless nodes, placed at different locations on the bridge structure, to collect and transmit reliably time-synchronized structural vibration data to a base station [13]. To this end, actuators, which apply forced excitation to the structure, are networked with sensors, which detect the effects of these excitations. Mica2 or MicaZ mote are the nodes used in Wisden to sense and measures the bridge vibration.

- Autonomous Crack Monitoring (ACM) is a system that measures and records the changes in crack widths and time-correlates these changes with conditions in and around the bridge. The measured and recorded data are made available on a web page. ACM is an autonomous system and it continuously record and publish changes in the crack width on the web. This data is then used to ascertain the health of the bridge under investigation.
- Autonomous Crack Propagation Sensing (ACPS) is very similar to the ACM. It is a health monitoring technique that measures and records the propagation of existing cracks in structures, not only automatically making available the data via a securely- accessible Web page but also alerting stakeholders via e-mail, telephone, text message, or pager, should cracks extend beyond some pre-determined length. Developed for use on steel bridges, ACPS is designed to supplement federally mandated crack inspection procedures, which suffer from poor repeatability and low frequency of occurrence, with precise, objective, and repeatable information on the condition of cracks.

2.2 Wireless Sensor used in Bridge Health Monitoring

The use of wireless sensors in bridge health monitoring has made great strides in the last few years. More and more wireless sensors are now being deployed in bridge monitoring.

Wireless sensors used in Bridge health monitoring can monitor temperature, pressure, cracks width, humidity, car movement, noise, light, strain, stress, and other properties. The sensing mechanism of these sensor may be seismic, magnetic, thermal, visual, infrared, acoustic, or radar.

These sensors operate in one of three ways, they are (1) line of sight to the target (such as visual sensors), (2) proximity to target (such as seismic sensors), and (3) propagation like a wave (such as acoustic sensors) [8] [9].

2.2.1 Temperature

The exposure of Bridges to environmental weather conditions like sun causes a change in the temperature of all the parts and components of a bridge structure. This temperature change in the bridge components and parts occurs continuously and slowly daily and they affect the state and structure of the bridge [4-6]. The changes that occurs between the parts and components of the bridge leads to thermal response of the bridge, induced strains, stress and also causes changes to the bridge piers [7]. The effect of temperature on bridge parts are usually slow and sometimes

Small, hence they are difficult to ascertain the changes visually. Monitoring and measuring the temperature changes of different parts can be done through transducers, sensors or data acquisition.

On a sunny day, the temperature of the surface of the bridge deck is much higher than the temperature of the underside of the deck, and this causes the bridge flexure to be drawn upward. For a typical curved bridge, this phenomenon has little effect on the reaction of pier section or internal forces such as stresses or strains. On the other hand, for a continuous bridge with several curves, this phenomenon changes the reaction of piers and cause thermally induced momentary stresses and strains along bridge flexure [16].

2.2.2 Strains

The displacement per unit length due to an applied stress is known as Strains. Some of the sensors that could be used BHM are resistive foil gauges, vibrating wire gauge and fiber Bragg gratings (FBGs). Resistive foil gauges consist of elastic plates with semiconductor wires forming a grid throughout the plate. The structure of the resistive foil gauge deforms under load, so also is the grid of semiconductor wires. There is a change in in resistance due to the deformation of the gauge and this change in resistance is then converted into voltage.

Another strain sensor is vibrating wire gauges. A tension wire inside the sensor is welded to the Bridge and a change in tensile strain will results to change in the tension of the wire. An electromagnet is used to induce vibrations in the wire and changes in frequencies is logged [10].

Fiber Bragg Gratings (FBGs) is a more recent and sensitive technology used in strain measurement [23]. Some of FBGs advantage over the other strain sensors include no electromagnetic interference, lightweight but they are very expensive [24].

2.2.3 Displacements

One of the important parameters that can provide valuable information about the health of a bridge is displacement and tiltmeter is a sensor that can be used to sense and monitor displacement in BHM. Tiltmeter has often been used to monitor ground movement in geotechnical but it is now been used in Bridge monitoring. Recent development in tiltmeter has drastically improve its reliability and functions. Tiltmeter now use a bubble level filled with electrolytic fluid that has electrodes that can detect the changes in the position of the bubble and store the data in a log table. Some other tiltmeter uses laser lasers [9]. Another displacement sensor is the displacement transducer which converts applied displacement into a voltage [14]

2.2.4 Loads

Bridges are designed to withstand the amount of loads they are expected to be subjected to. To predict the exact load the bridge will be subjected to is actually a difficult task to do; this is due to the uncertainties and unknowns. To address these challenges, load sensors are installed on the bridge to measure the actual load on the bridge and prevent overloading. The use of load sensors also helps in the future design of similar bridge. The main load sensors used in Bridges are piezoelectric and strain gauge sensor.

In the strain gauge method, A Transducer is attached to the strain gauge and when load is applied, the transducer is deformed due to the strains of the load. The level of deformation of the transducer is calibrated so as to be proportional to the applied load.

In the piezoelectric method, the main sensing materials is the piezoelectric crystals. An electric charge is created when the crystals are subjected to load strains. This electric charge is then converted into voltage for data acquisition system for analysis.

3 WIRELESS SENSOR NETWORK

In recent years, the advancement wireless communication and digital electronics have led to the design and development of low-cost, low-power, multifunctional sensors that are small in size.

A Wireless Sensor Network (WSN) consists of a set of sensor device that is spread over a geographical area [6]. These sensors can process data as well as sense signals. They are also capable of communicating with each other. WSN has found application in wide range of areas such as Environmental monitoring, battlefield, structure monitoring, medical application, sport and so on. The ability of these sensors to sense, process data and communicate with each other as well as its environment leads to the realization of WSNs. Wireless Sensor Networks have become a hugely important and significant part of daily lives.

3.1 Features of Wireless Sensor Network

Some of the features associated with most Wireless Sensor Networks (WSN) are;

(1) The sensor nodes are not mobile,

(2) Wireless Sensor Network can be implemented in harsh and remote environments, so failures are quite common in this condition,

(3) They are mostly very small, and hence requires small batteries which have short life time as power source,

(4) Communication in Wireless Sensor Networks are data-oriented instead of address-oriented; this means that routing can be prioritized and/or dropped depending on the content of the data, and

(5) To reduce unnecessary overheads, communication in Wireless Sensor Networks are done in small sized packets [5].

3.1.1 Benefits of Using Wireless Sensor Networks

Bridge health monitoring itself is not a novel idea. The conventional method of wired technology requires all the sensors being connected through a long cable linked to the control center. This causes the installation to be time consuming and expensive. The cost of maintenance of the system is also high. Also, the scalability of the system is also not easily achievable. Compared to the conventional method, WSN provides almost the same functionality as the wired network at a much lower price and compact system which permits the structure to be monitored more easily. The wireless monitoring system is not so visible on the Bridge structure as the wired sensor.

3.1.2 Challenges to Wireless Sensor Networks

For Bridge health monitoring, real-time monitoring and high-fidelity performance are essential requirements. Monitoring needs to be economical. The cost includes the system itself, installation, and maintenance. We do not want to disturb the Bridge structure being monitored, and introduce no hazards. Achieving the requirements needed for a wireless sensor in Bridge health monitoring system can be challenging. Here are some of the challenges faced with implementing a wireless monitoring system;

Accurate sample: This talks about the need to detect signals with no significant distortion and hence the need to have a precise sample of the signal. This is very difficult to achieve in a wireless network

Sampling frequency: This talks about the frequency at which the data is being sampled. A low variation in sampling interval is needed, that is, the intervals between each sampled signal should be almost the same.

Time synchronization: Sampling needs to start at the same time on all nodes although the sampling should be done over multiple nodes across the entire network. Furthermore, this need be done in spite of differences in the drift of each clock. Otherwise, shifts in signals between different nodes can give a distorted picture of the structure.

Reliable data transfer: If we fail to start some nodes, we will miss data for those points. Then we will have an imperfect picture of the bridge, which makes the analysis of the data very difficult.

Reliable data collection: It is very important that the data are transferred reliably. If the data are not transferred reliably, the correct or precise analysis of the data is impossible, hence the correct state of health of the bridge is not known.

3.1.3 Multiple Access Techniques

When the need to allow a large number of mobile users to share the allocated spectrum in the most the most efficient manner; multiple access techniques are used. This is because the available spectrum is limited, therefore sharing is required to increase the capacity of cell or over geographical area, by allowing the available bandwidth to be used at the same time by different users, making sure that the quality of service do not degrade within.

There are different types of multiple access techniques, these includes the following:

- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

In our work, we are more concern about the throughput for these techniques, rather than deviating more into their definitions. The next section explains detailed mathematical modelling for the three techniques listed above.

3.2 Mathematical Modelling of Throughput for Multiple Access Techniques

The throughput of different multiple access techniques are considered in this section (based on [20]). And using one of the procedures, data is transferred from sender to receiver, and the throughput resulting from these procedures is considered. There are no packet losses as a result of collision due to less difference between sender and receiver; no packets are lost as a result of buffer overflow. A perfect channel is being assumed for the calculation of throughput. Through the following equations, throughput is calculated for all access techniques (1):

$$T = \frac{8x}{\mathrm{delay}(D)(x)} \quad (1)$$

Where D is the delay, T the throughput, and x the number of bits passing through the frame.

3.2.1 Throughput of TDMA

By using (1), throughput is calculated. Delay with a packet as it circulates from sender to destination is calculated as per (2) [20]:

$$D = T_{oh} + T_{ack} + T_g + T_{sync} + T_{ta} \quad (2)$$

The different time delays are given in (2) and can be calculated by (3-6):

$$T_{oh} = \frac{Noh}{Fc} \quad (3)$$

$$T_{ack} = \frac{Nack}{Fc} \quad (4)$$

$$T_{sync} = \frac{Nsync}{Fc} \quad (5)$$

$$T_{data} = \frac{Ndata}{Fc} \quad (6)$$

where

T_{sync} is the synchronization time,

T_{data} is the time for data to reach end of frame,

T_{ta} = Turnaround Time,

T_{ack} = Acknowledgement time,

T_{oh} = OverHead time,

T_g = Guard time,

F_c= Communication Data Rate,

N_{oh} = Total overhead bits,

N_{ack} = ACK/NACK message bits,

N_{syn} = Total synchronized bits,

N_{data} = Total data bits.

3.2.2 Throughput of FDMA

The throughput of FDMA is close by to that of TDMA. The difference between throughputs of the two multiple access technique is very small. And by (1) the calculation for the throughput of FDMA and the delay which it experiences is calculated as per (7) [20]:

$$D = T_{oh} + T_{ack} + T_g + T_{data} + T_{ta} \tag{7}$$

In (7), the different time delays given can be calculated as per (8-10):

$$T_{oh} = \frac{Noh}{Fc} \tag{8}$$

$$T_{ack} = \frac{Nack}{Fc} \tag{9}$$

$$T_{data} = \frac{Ndata}{Fc} \tag{10}$$

where

T_{sync} is the synchronization time,

T_{data} is the time for data to reach end of frame,

T_{ta} = Turnaround Time,

T_{ack} = Acknowledgement time,

T_{oh} = OverHead time,

T_g = Guard time,

F_c= Communication Data Rate,

N_{oh} = Total overhead bits,

N_{ack} = ACK/NACK message bits,

N_{syn} = Total synchronized bits,

N_{data} = Total data bits.

3.2.3 Throughput of CSMA/CA

By the formula given in (1), the CSMA/CA throughput is calculated. By adding the delays of all elements of frame while it gets to the receiver, as per (11) [20], the total delay D is calculated:

$$D = T_{bo} + T_{ack} + T_{ifs} + T_{data} + T_{ta} + T_{rts} + T_{cts} \quad (11)$$

Where

T_{bo} is the Back Off Period,
T_{rts} = Resquest To Send
T_{cts} = Clear To Send
T_{data} = Transmission Time of Data,
T_{ta} = Turnaround Time,
T_{ack} = Acknowledgement time,
T_{ifs} = Inter Frame Space

Now we calculate the delay times given in (11) as:

$$T_{bo} = bo_{slots} + T_{boslots} \quad (12)$$

$$T_{ta} = T_{data} + T_{ack} \quad (13)$$

where boslots is the Back off slots number and Tboslots the off slots time. Further,

$$T_{ack} = \frac{Nack}{Fc} \quad (14)$$

$$T_{ifs} = T_{data} - T_{ack} \quad (15)$$

F_c is the Communication Data Rate, N_{ack} the ACK/NACK messafge bits, and Turnaround times $T_{turnaround}$ and T_{ack} are equal to zero if there is no acknowledgement.

4 THE PROPOSED WSN SIMULATION METHODOLOGY

Matrix Laboratory is the environment we built our simulation model, MATLAB is a software package developed by MathWorks Inc., for high performance numerical computation and visualization. The software provides an interactive environment with hundreds of reliable and accurate built-in mathematical functions, it has the ability to combine flexibility, reliability, and powerful graphics which makes it a premier software package for scientific researchers.

MATLAB is very easy to learn and use, it allows user-developed functions, access to Fortran algorithms and C codes by means of external interfaces. MATLAB has toolboxes for special applications such as system identification, neural networks, fuzzy logic, signal processing and control systems design, it has also been enhanced by the very powerful Simulink program [21].

Simulink is a software package for modelling, simulating, and analysing dynamical systems. It provides comprehensive block library of sinks, sources, linear and nonlinear components with a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. This interface enables you to draw the models just as you would draw with pencil and paper. Using scopes and other display blocks, the simulation result can be displayed while running the simulation, the result could also be transferred into MATLAB workspace for post processing and visualization; simulating and analysing models in Simulink and MATLAB is possible since both are integrated together [21].

4.1 Simulating a Simple WSN in Simulink MATLAB

A simple WSN model was built as shown in the figure 1 below [22]. There are three slaves sensors sending their measured data samples to a master node, we built the complete WSN system using MATLAB Simulink communication blocks; the following communication blocks, transmitting nodes architecture, communicating channel and receiving master node architecture. In order to undertake the physical layer communication with respect to different channel parameters such as Signal to Noise ratio, interference, and attenuation, Bluetooth was chosen. The simulation model was examined using different topologies under various conditions and numerous results were collected.

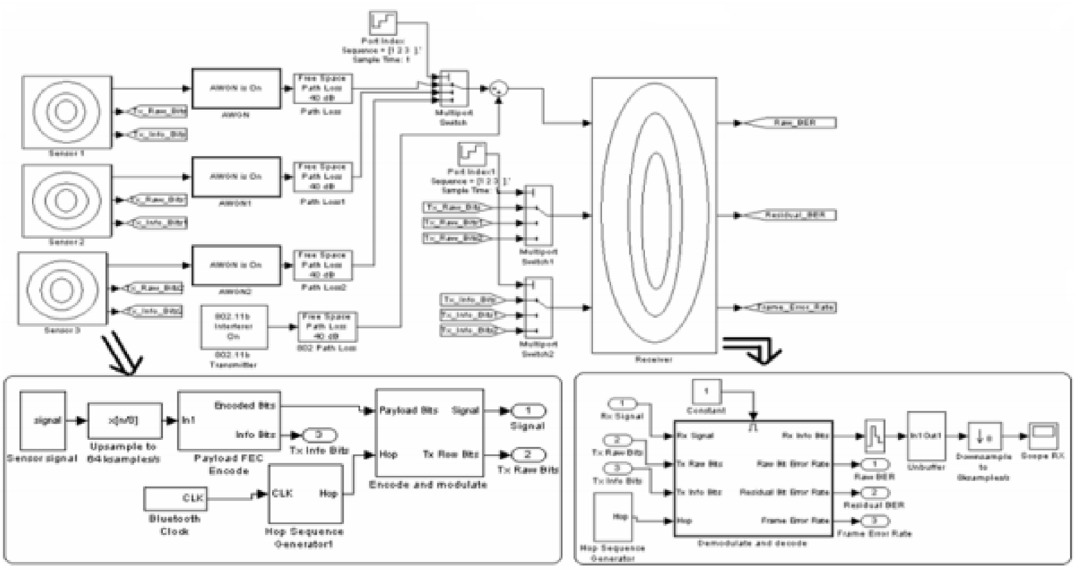

Figure 1. Simple WSN model

4.1.1 The Transmitter Model

Bluetooth technology which is a short range radio link technology that operates in the 2.4GHz Industrial, Scientific, and Medical (ISM) band was considered as the backbone of the transmission operation [22]. In the transmission system Gaussian frequency shift keying (GFSK) was used over a radio channel with maximum capacity of 1Mbps

The transmitter block consists of the following blocks:

- Sensor signal stage: Represented by a sensor to sense the physical signals such as temperature, pressure, vibration…etc, after sensing these signals are transduced into an electrical signal. In addition, this stage includes the A/D convertor which converts the signal from Analog to Digital using 256 quantization level.
- Up-sampling to 64ksamples/s: Up-samples the input to a higher rate by inserting zeros between samples.
- Payload FEC encode: Encodes the data to enable error correction (an FEC encoder may include a binary convolutional encoder followed by a puncturing device).
- Bluetooth Clock: Each Bluetooth device has a free-running 28-bit Bluetooth clock. The clock ticks 3,200 times per second or once every 312.5 µsec, representing a clock rate of 3.2 KHz.

- Hop Sequence Generator: This devices communicate with each other, they must transmit and receive on the same frequency at the same time. The hop sequence generator generates a sequence of hop frequencies in the range 0 to 78. It can generate either the connection state hop sequence, a random white sequence, or be fixed.
- Encoder and modulator: The 366 data bits are transmitted at 1 Mbps and modulated using Gaussian frequency shift keying (GFSK). GFSK effectively transmits +150 kHz signal relative to the carrier for a 1bit, and a 150 kHz signal for a 0 bit. The carrier signal is generated in the Simulink model by a baseband MFSK block set to 79 symbols and a separation of 1MHz. If a hop frequency value 0 is input, a -39MHz complex sinusoid is generated. If a 1 is entered, a -38 MHz complex sinusoid is generated and so on. In the model, the hop sequences are generated by a simple random number generator, not using the actual method specified in the standard. The transmitter is turned off after 366 bits using a Gain block to multiply the frame with a mask of 36600 ones and 26500 zeros.

4.1.2 The Communication Blocks

- AWGN Channel: The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal.
- Path Loss: This block reduces the amplitude of the input signal by an amount specified. The loss can be specified directly using the “Decibels” mode, or indirectly using the “Distance and Frequency” mode. The reciprocal of the loss is applied as a gain, e.g., a loss of +20 dB, which reduces the signal by a factor of 10 corresponds to a gain value of 0.1.
- 802.11b interferer: This block adds signals that have the same frequency of the data signal to make interference between the data signal and other signals (i.e. a Wireless Local Area Network (WLAN) transmission).
- Multiport Switch: In order to simulate the multiple access and multiplexing functions of the channel, this block was used. It chooses between a number of inputs. The first input is called the control input, while the rest of the inputs are called

data inputs. The value of the control input determines which data input is passed through to the output port.

4.1.3 The Receiver Blocks

- Hop Sequence Generator: same as mentioned earlier.
- Demodulation and decoding: This block is used to extract the original information-bearing signal from a modulated carrier wave, and to recover the information contends in it.
- Zero-Order Hold: This block samples and holds its input for the specified sample period. The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are held for the same sample period.
- Un-buffer: This block un-buffers an Mi-by-N frame-based input into a 1-by-N samplebased output. That is, inputs are un-buffered row-wise so that each matrix row becomes an independent time-sample in the output. The rate at which the block receives inputs is generally less than the rate at which the block produces outputs.
- Down-sampling to 8ksamples/s: This block down-samples the input to a lower rate by deleting the repeating samples.
- Scope RX: It was used to display the received signal and compare it with the original signal to discover the system behavior.

4.2 Simulation Results

The basic model of the WSN build is shown in Appendix 1. This show the three wireless sensor input, AWGN block and interferer. The function of this blocks is as described in previous chapter. The three input sensor are vibration sensor, strain sensor and temperature sensor as shown in Appendix 2, Appendix 3 and Appendix 4 respectively. Appendix 5 show the model of the demodulation and decode block used at the receiver.

When the system is without noise or interference, that is, the AWGN and 802.11b interferer are turned off, the results received is as shown in Appendix 6. It shows the three input signals combined with no interference or distortion to the signal.

When AWGN of Signal-to-Noise (SNR) of 20dB is added to each of the input signal and the 802.11b interferer is switched ON, the result received at the receiver is as shown in Appendix 7. It shows the three input signals combined and some noise components and distortion in the received signal.

When AWGN of Signal-to-Noise (SNR) of 12dB is added to each of the input signal and the 802.11b interferer is switched ON, the result received at the receiver is as shown in Appendix 8. It shows the three input signals and some noise components and distortion in the signal but less than the noise and distortion in SNR of 20dB.

5 Recommendation

From the results, it can be seen that the noise still has relative effect on the received signal and for a correct analysis of any bridge health status, a reliable data set are important. Hence, the need to improve the system so as to make it as resistant to interference and noise as much as we can.

5.1 Conclusion

It can be seen that Simulink can be used successfully to model and simulate WSN for Bridge Health monitoring.

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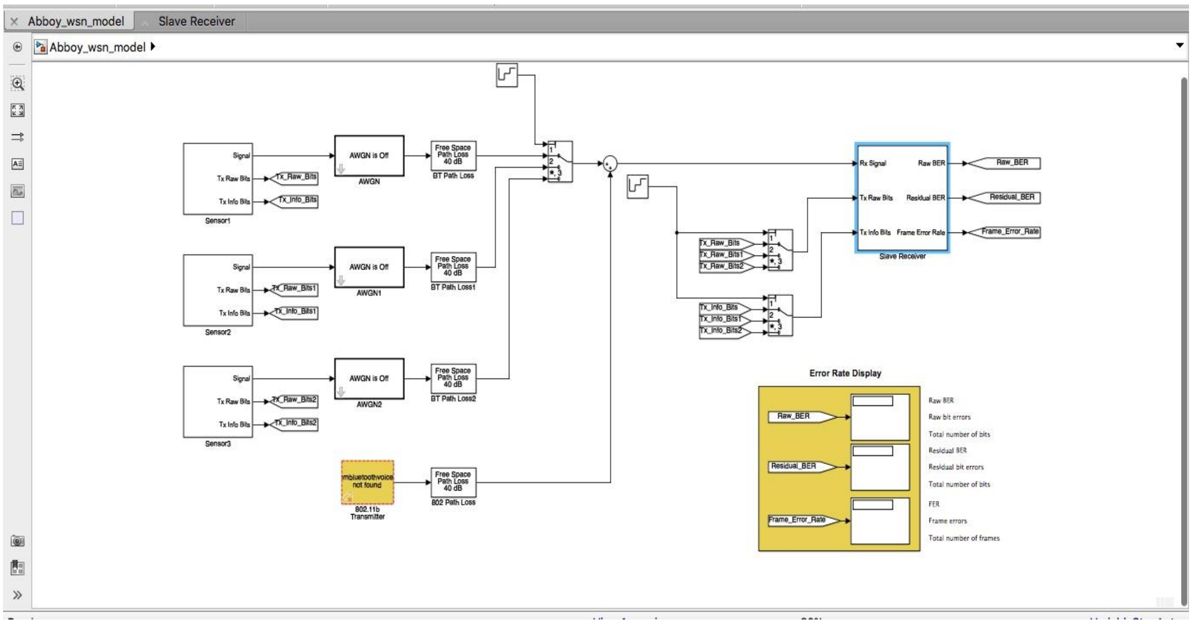
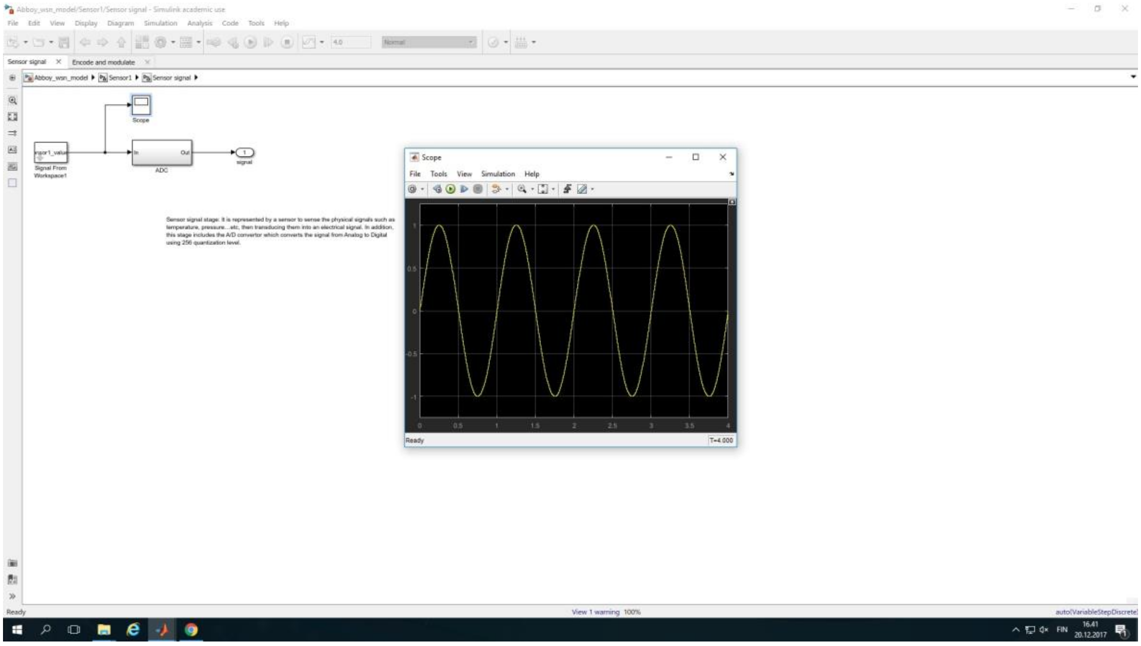
APPENDICES

Appendix 1. Screenshot of the basic model of WSN model

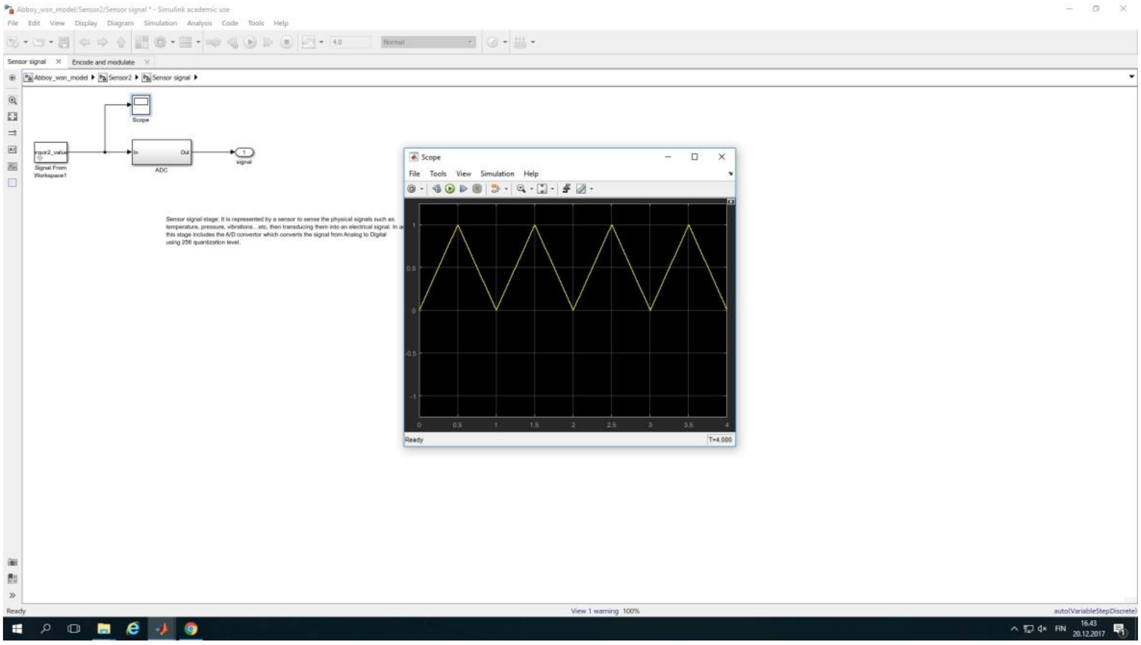


Appendix 2. Screenshot of the assumed input signal for vibration sensor



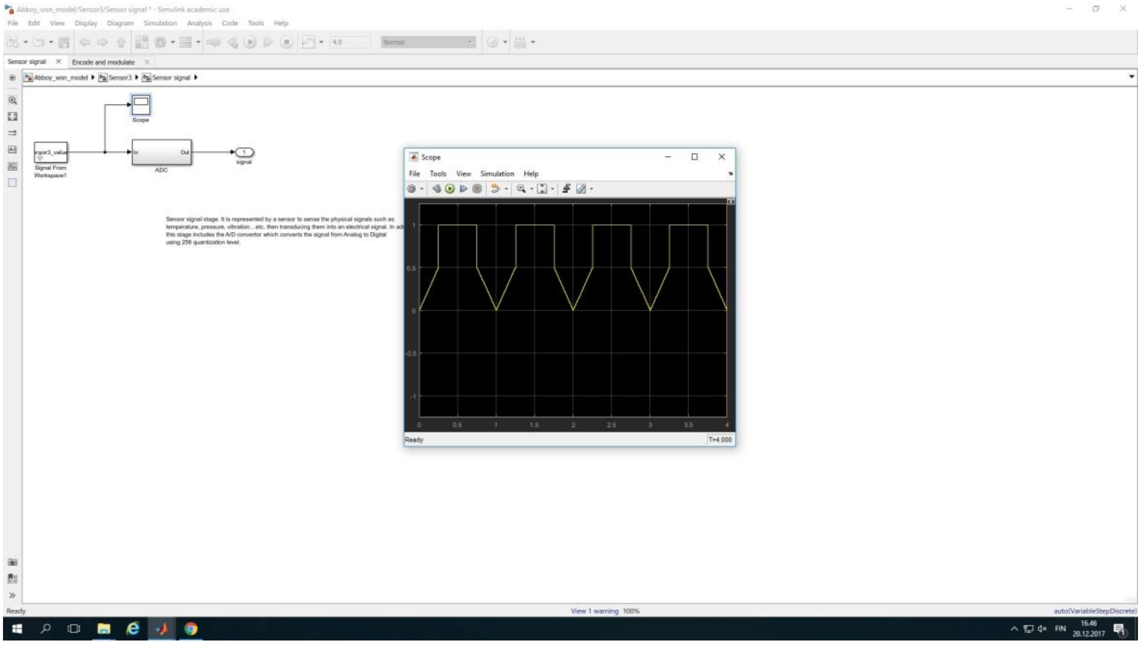
Sensor signal stage: It is represented by a sensor to sense the physical signals such as temperature, pressure...etc, then transducing them into an electrical signal. In addition, this stage includes the A/D convertor which converts the signal from Analog to Digital using 256 quantization level.

Appendix 3. Screenshot of the assumed input signal for strain sensor



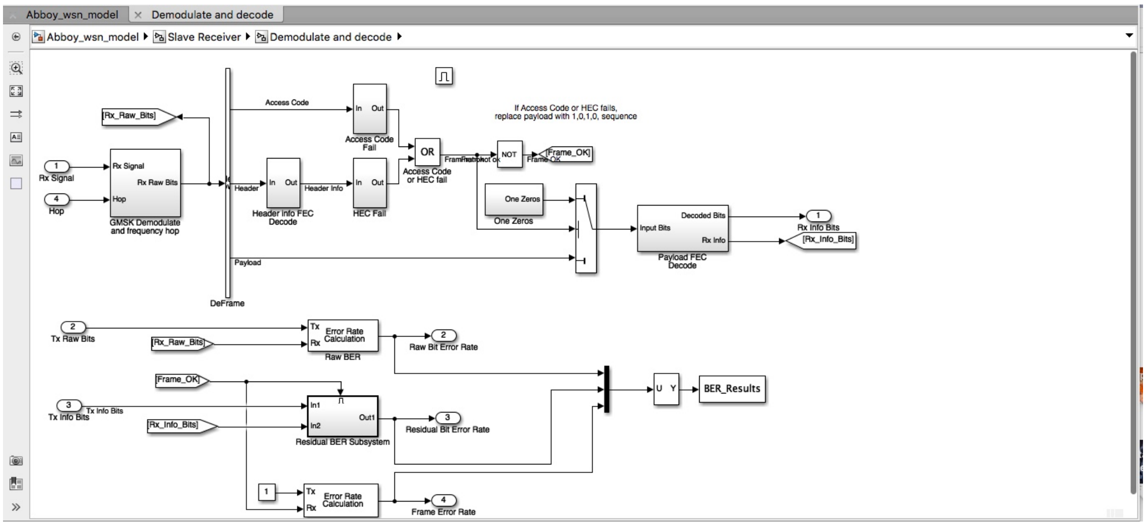
Sensor signal stage: It is represented by a sensor to sense the physical signals such as temperature, pressure, vibrations…etc. then transducing them into an electrical signal. In a this stage includes the A/D convertor which converts the signal from Analog to Digital using 256 quantization level.

Appendix 4. Screenshot of the assumed input signal for temperature sensor



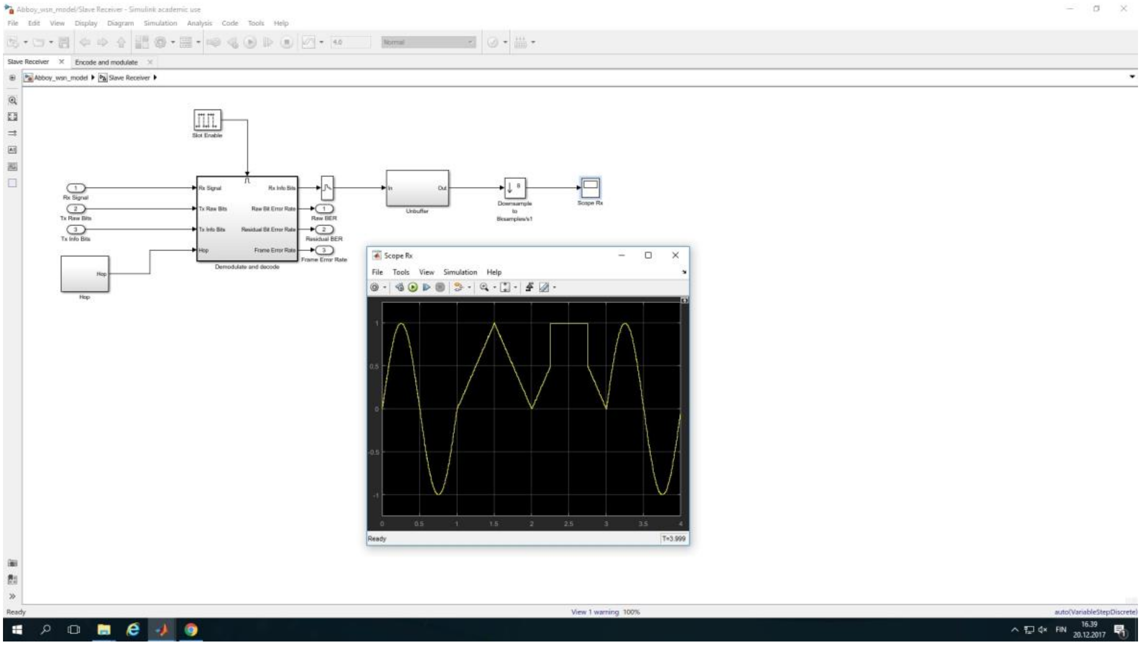
Sensor signal stage: It is represented by a sensor to sense the physical signals such as temperature, pressure, vibration…etc, then transducing them into an electrical signal. In ad this stage includes the A/D convertor which converts the signal from Analog to Digital using 256 quantization level.

Appendix 5. Screenshot of the model used in demodulation and decode block of the receiver

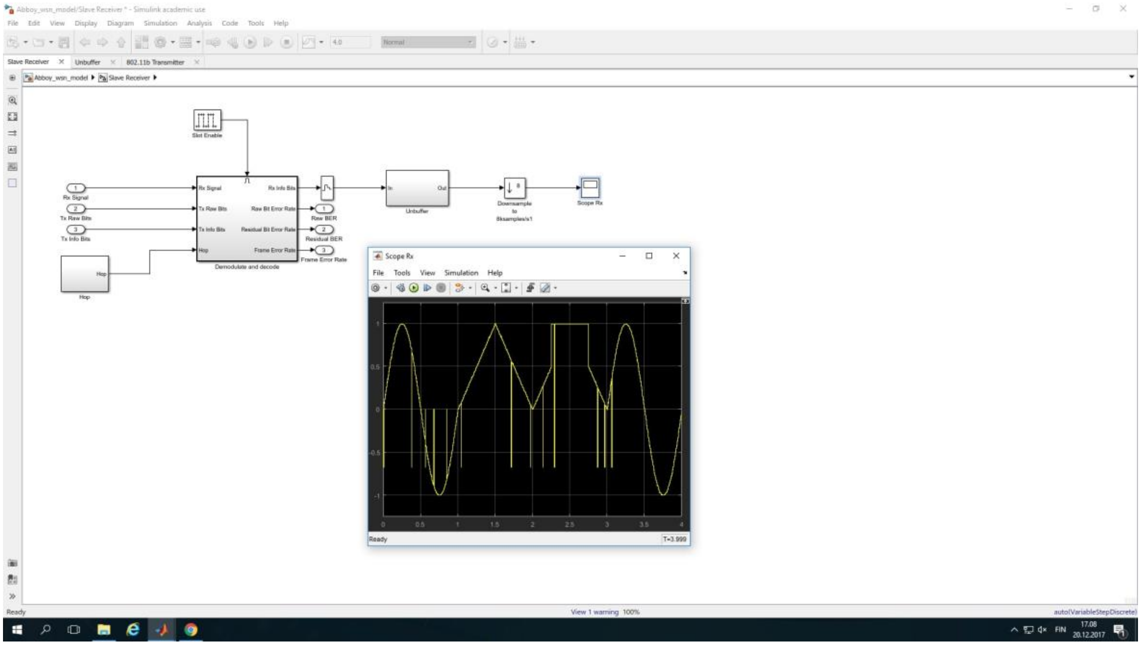


If Access Code or HEC fails,
replace payload with 1,0,1,0, sequence

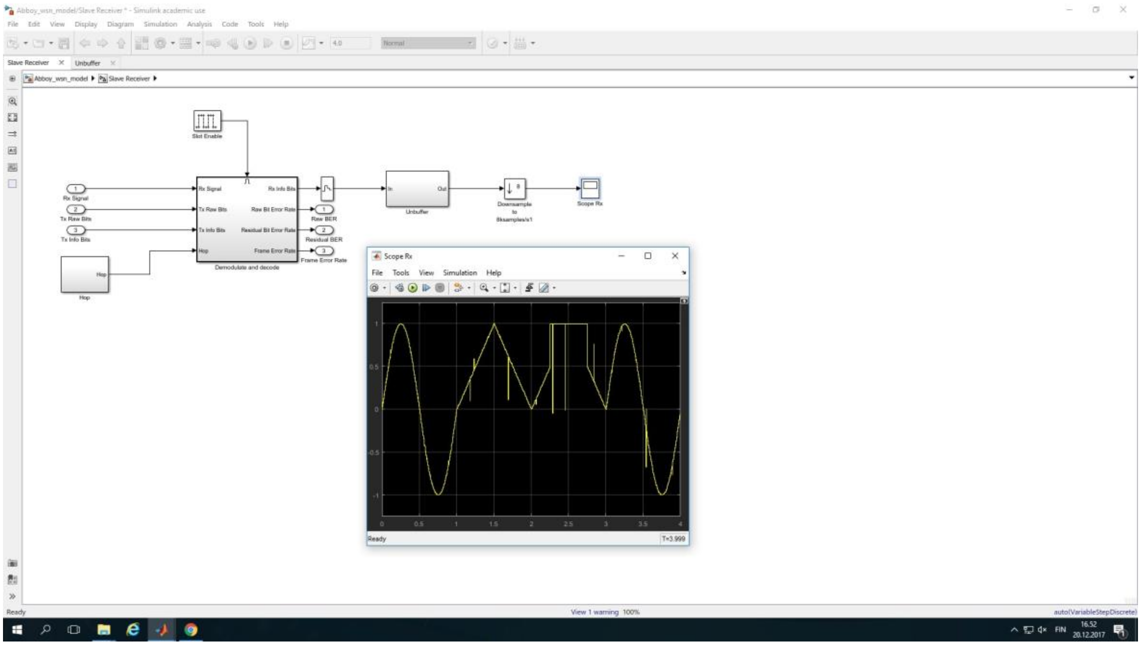
Appendix 6. Screenshot of the received signals at the receiver



Appendix 7. Screenshot of the received signals with SNR of 20dB



Appendix 8. Screenshot of the received signals with SNR of 12dB



Appendix 9. Screenshot of the received signals with SNR of 20dB and 802.11b interferer