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Emerging Network Technologies

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Table of Contents

Table of Figures	3
Abstract	4
Introduction.....	5
Related work	6
QAM - Quadrate Amplitude Modulation	6
QPSK – Quadrature Phase Shift Keying	9
ASK - Amplitude-Shift Keying	12
Modulation techniques evaluation	14
Simulation and model assessment	14
Plotted graphs	18
Wireless Network Smart Garden	22
NetSim Implementation.....	26
Results and findings.....	28
Conclusion	34
Appendix.....	35
References.....	39

Table of Figures

Figure 1:Phase jitter in 16QAM[24]	7
Figure 2: Constellation plot of 1024QAM[26]	7
Figure 3:8QAM encoded signal transmission.....	8
Figure 4: QAM formulation encoding	8
Figure 5:QPSK Signaling system	9
Figure 6:QPSK compilation formula	9
Figure 7:QPSK constellation diagram[29].....	10
Figure 8: QPSK cosine and sine	10
Figure 9:Simulink QPSK wave form and modulation[30]	11
Figure 10: ASK formulation (carrier signal is $\text{Acos}(2(3.2)\text{fct})$)	12
Figure 11: Coherent ASK demodulation[31].....	12
Figure 12: Envelope detector [31]	13
Figure 13: Simulink Simulation of ASK demodulation	13
Figure 14: Bit Error Rate calculation.....	14
Figure 15: Formulation for SNR.....	14
Figure 16: QAM in block formation.....	15
Figure 17: QAM in modular configuration.....	16
Figure 18: QPSK in block formation	16
Figure 19: ASK in modular formation.....	16
Figure 20:PSK modulation	17
Figure 21:PSK demodulation.....	17
Figure 22: QAM graph output under Monto Carlo.....	18
Figure 23: QPSK graph output under Monto Carlo	19
Figure 24: QAM BPSK QPSK under Monto Carlo	19
Figure 25: Theoretical outputs for QAM BPSK QPSK using AWGN	20
Figure 26:Theoretical line of Rayleigh interference on QAM BPSK QPSK	20
Figure 27: Theoretical lines of interference with AWGN and Rayleigh	21
Figure 28: Smart park design and logical layout	22
Figure 29: Strawberry smart bench.....	23
Figure 30: Smart Display providing local data	24
Figure 31: Cisco Aironet 3502i.....	25
Figure 32: NetSim Smart Garden Design	27
Figure 33: Accumulative data on ten smart garden tests	28
Figure 34: Ad-hoc On-demand Distance Vector routing results	29
Figure 35: Application Metrics CBR, HTTP	30
Figure 36: 802.11 metrics data for wireless devices.....	31
Figure 37: Wireless sensor node metrics	31
Figure 38: Overall simulation network metrics	32
Figure 39: Network Queue metrics.....	32
Figure 40: IP metrics.....	33

Abstract

This paper collects an assessment of the modulation techniques frequently applied in the real-world market to support communication media in transmitting data. An analysis on the following fields were examined such as Quadrature Amplitude Modulation (QAM), Amplitude Shift Keying (ASK) and Quadrature Phase Shift Keying (QPSK). Crucial and essential concepts of modulation are therefore discussed throughout the report showing data present in this research report about the techniques employed in modulation and its uses. This is validated in the demonstrations of modulation proving the simulation reproduction of real world assignments and methods. The simulation therefore highlights the systems required for testing different modulation techniques seeing the mathematical data and compilation used in an implemented framework. The data output shows the vectors of the modulation with performance distinctions and the favourable circumstances and conditions aligning to sensor networks. The parameters defined in the modulations were equipped with variable inputs of Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

Keyword-components; Quadrature Amplitude Modulation (QAM), Amplitude Shift Keying (ASK), Quadrature Phase Shift Keying(QPSK), Bit Error Rate (BER), Signal to Noise Ratio (SNR), Modulation, demodulation, Simulation, Communication.

Introduction

To empower digital communication [1] such as wireless media [2] invokes the necessities of crucial methods, specifically the use of modulation [3]. Modulation effectively positions an engagement of techniques which produce a variation of a single or numerous features of a periodic waveform. This wave form is named the carrier signal effectively acting as a base to the transmission on which the modulation of a signal comprising the data to be communicated works within. The assemble of data means information can be successfully and efficiently rendered and transmitted as a dynamic variant of the signal. The appropriate communication spectrum variable changes in the data carrier signal. Wireless productivity in the spectral range[4] is a significant aspect due to parting wireless frequency groups which are accessed with intercontinental bands, local national bands and continent specific bands for interoperability and best practice. Government organisations such as the Federal Communication Commission(FCC)[5] in US or Body of European Regulators of Electronic Communications (BEREC)[6] for the EU and Office of Communication (Ofcom)[7] for the UK are setup to monitor and control signals.

The frequencies assigned to end users and industry means modulated communication methods and distinctions of modulation are essential allowing exponential development in information rate broadcast capabilities and its coverage (cell).Spectrum effectiveness [8] means data can be employed into a signal under specific bands for which an example can be the 60GHz range having a worldwide licence free[9] band having an effectual data rate well above the average. Other technology's which provide the data rate however not the distance of transmission such Intel's 7Gbps technology [10].

Modulation is measured in bits per second per Hertz also represented as (b/s/HZ)[11], [12]. The spectral landscape are vast when equated to the traditional analogue[13] systems with power efficiency as well. Efficiencies in digital modulation [14] enable superior capability to overcome mistakes in transmission with encryption scaled to suite as well. A noise decrease or dissolvent points diminish interference. In systems comprising of digital and analogue, three priority features assemble the signal, whilst the phase and amplitude create a carrier signal. The result means manipulation of adjustable inputs are developed into protocols such as; Quadrature Amplitude Modulation (QAM)[15], Phase Shift Keying (PSK)[16],Amplitude shift keying (ASK)[17], Frequency Shift Keying (FSK)[18] and Quadrature Phase Shift Keying (QPSK)[19]. However, utilising the techniques, and multifaceted advanced modulation with b/s/HZ enable enormous information transmissions of varying range and complexity with modulation such as 64 or 256. QAM modulation is seen frequently in business integrating into mobile systems (3G/4G LTE) [20] and broadcasting systems (Free view HD)[21].

Related work

Modulation methods are used for the purpose of efficiently sending data over different media utilising frequency arrays on the different spectrums. The primary techniques utilised today are QAM, ASK, QPSK and BPSK, each having unique strengths and purposes. The equations in addition to wave form structures principally sine waves and constellation diagrams [22] produces variable data, displaying modulation characteristics. Variables stated previously feature fade environments better known as Rayleigh [23] applied to the situational circumstances compiled using modulation techniques in the simulations.

QAM - Quadrature Amplitude Modulation

QAM is a technically complex modulation having a higher degree of difficulty and efficiency over other techniques, immensely different with the likes of ASK and QPSK. The capabilities to alleviate difficulties in the face of noise demonstrates a refinement of the modulation signal, thus allowing enormous data transmissions. The physics topographies in respects of QAM integrate an expanse of amplitude and phase encompassing qualities of a large output area and the transmission of signals reaching greater expansions of landmass covered compiled with greater data expulsions. Propelling the complex messages by the means of modulating the amplitudes of streams means the modulation of the carrier can contain two or four streams if its QAM and greater. The streams in QAM reveal the protocols ability to expansion such as 64 QAM which delivers eight bits per symbol equating to modulation rates if the example below was to be 36,000bps.

$$r = \log_2 64 = 8 \rightarrow S = (1/8) \times (36,000 \text{ bps}) = 6000 \text{ modulation rate. [23]}$$

Flexible QAM variations such as 8QAM, 16QAM, 64QAM and 256QAM can propel to 1024QAM. The methods successfully use alpha numeric configurations letting bits transmitted increase to that of 4 to 8 bits per symbol consequently amassing greater data rates. The greater complexity convolution is the present distortion resulting from noise in the phase account for the considerable Bit Error Rate (BER) whilst transmission is happening. The figure below illustrates a 16QAM chart effected in the face of noise (phase jitter), this jitter distorts the broadcasted modulation.

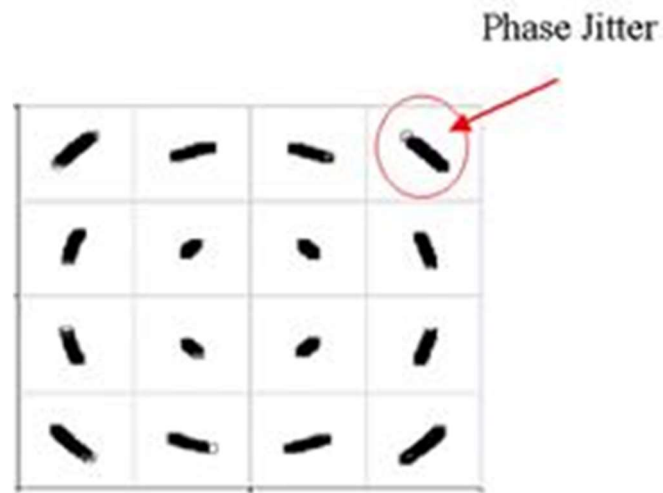


Figure 1: Phase jitter in 16QAM[24]

The distorted image above shows the effect of jitter, the complexity of QAM provides more power to the effects of jitter with greater sensitivity required seen here in the 1024QAM constellation (Fig 2). Utilising Phase Noise Level Density (PNLD)[25] which is articulated by the units of db/c/Hz or arithmetically:

$$\text{PNLD} = -10 \log I/I_0$$

The representation of amplitude and the phase noise where I = noise concentration pitches in dB, $I_0 = 10^{-12}$ is synonyms with noise levels.

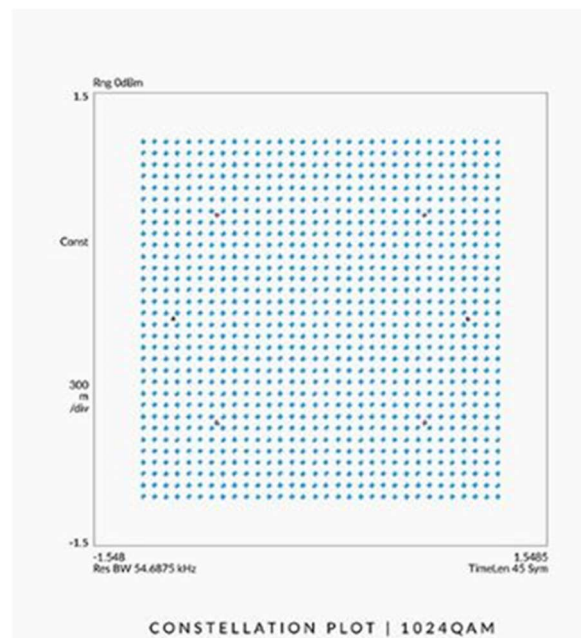


Figure 2: Constellation plot of 1024QAM[26]

QAM is inherently proficient in spectral occupation however a weakness derived from its development in the scheme is during the process of demodulation particularly in the occurrence of noise. The improved magnification of signals has to be present enabling a definitive number of received bits and minimalizing

BERs. In spite of noise, constructive features overcome the flaws, this makes it a dependable modulation fulfilled within media distribution industries.

The adapted technology is seen with the broadcast of television through the media of cable[27] or wireless schemes, mobile and satellite systems.

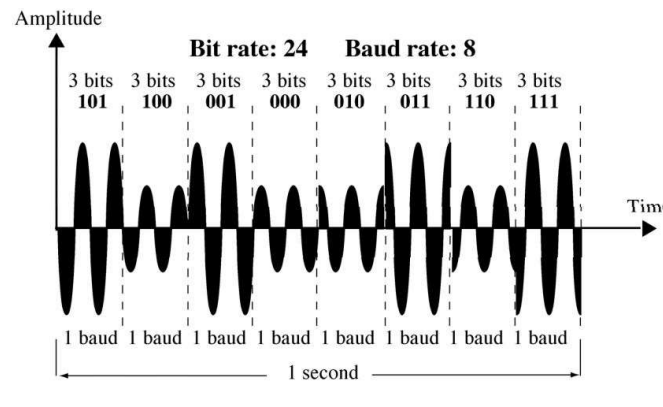


Figure 3: 8QAM encoded signal transmission

Figure 3 exemplifies the effective encoding operation works within QAM, specifically 8QAM in the image above showing the process of a signal being encoded by means of the QAM method. In a linear method[28] both the phase in addition to amplitude results in a reduction of signal alteration from the pliability of the signal wave.

Modulation formulation for multiple bit encoding incorporated into each signal component illustrated below:

$$D = \frac{R}{b} = \frac{R}{\log_2 L}$$

Figure 4: QAM formulation encoding

The equation above represents D as: modulation rate (baud), R meaning: data rate (bps) whilst L equivalents the number of distinctive signal components, lastly b represents: bits per signal component.

QPSK – Quadrature Phase Shift Keying

Two functions of Quadrature Phase Shift Keying is the use of a sine and a cosine whilst BPSK and ASK is just the application of one. Fluctuating the phase in the different carriers enable it to send two bits for individual signals. The resulting dimensions of modulation is distinct in its functions, subsequently QPSK has a two dimensioned signal. The two singular signals are sine and cosine.

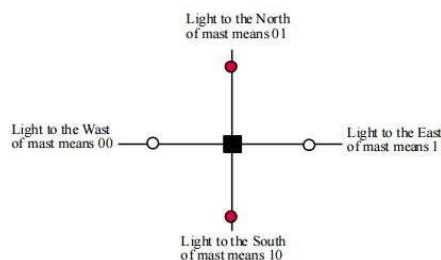


Figure 5: QPSK Signaling system

The QPSK figure above illustrates an altered procedure with the 4 point configuration able to deliver two bits at once .e.g. modulating two red points or two white points at a time.

The I channel amplitude in the constellation diagram in addition to Q demonstrating a signal or symbol being modulated. Both the I and the Q amplitudes transfer into a cosine sine or a phase angle.

The QPSK formula of its waveform.

$$s_i(t) = A \cos[\omega_c t + \varphi_0 + \varphi_i(t)]$$

Figure 6: QPSK compilation formula

The formula in indefinable components: s_i = PSK independent phase I waveform signal, t = time interval, A = the amplitude peak achieved

ω_c = The radians/s represented in carrier frequency

φ_0 = The angle of phase

φ_i = One through to four phase ranges

The variable phase sinusoidal waveform retaining the amplitude and frequency constant verified in the 90° quadrature phases below in Fig7.

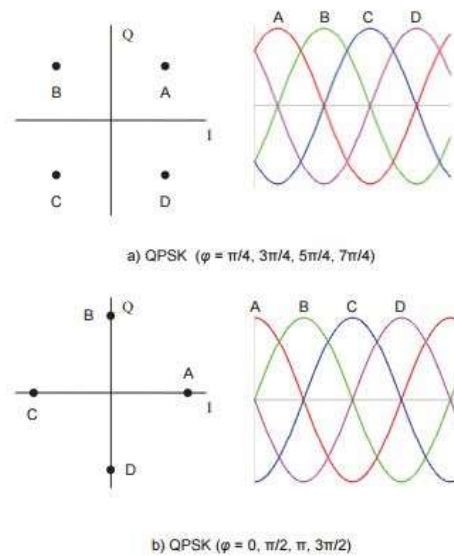


Figure 7: QPSK constellation diagram[29]

Shown below exhibits some of achievable symbol classifications in the QPSK modulation scheme presenting phases of either cosine or sine.

Symbol	Bits	Expression	Phase, (Deg.)	Carrier Signal	I	Q
S1	00	$\sqrt{\frac{2E_s}{T}} \cos(\omega t + \pi/4)$	45		$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$
S2	01	$\sqrt{\frac{2E_s}{T}} \sin(\omega t + 3\pi/4)$	135		$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$
S3	11	$\sqrt{\frac{2E_s}{T}} \cos(\omega t + 3\pi/4)$	225		$-\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$
S4	10	$\sqrt{\frac{2E_s}{T}} \sin(\omega t + \pi/4)$	310		$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$

Figure 8: QPSK cosine and sine

Fig 8 displays exactly how the phase degree relative to a QPSK constellation diagram is interpreted such as 00 meaning 0 degrees or 01 representing 90 degrees, 11 interpreted as 180 degrees and 10 signifying 270 degrees. The two fluctuating phases allows two bits to be sent inside of a two dimensional signal.

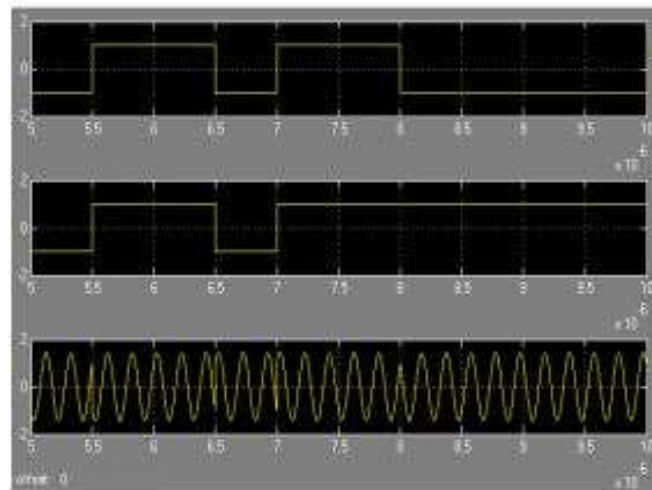


Figure 9: Simulink QPSK wave form and modulation[30]

Fig 9 validates the theory behind the modulation implementations demonstrating that splitting the overall bit rate of QPSK over that of BPSK which means a weaker transmission capability, however radio-frequency required in order to transmit QPSK is only half of the required frequency used in BPSK[19]- [15].

ASK - Amplitude-Shift Keying

Amplitude shift keying is an old however effective modulation method of transporting relatively consistent however limited amounts of data at a time when compared to modern standards such as QAM. Below is an assembled representative formulation of ASK. A singular binary number is signified by the presence of a carrier when in a continual amplitude state, whilst the zero digit is defined in the presence of nothing from the carrier.

$$s(t) = \begin{cases} A \cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases}$$

Figure 10: ASK formulation (carrier signal is $A \cos(2(3.2)f_c t)$)

With modulation there is of course demodulation from which it is derived on to two components coherent and non-coherent. The simple application of a coherent demodulation approach is when the use of a duplication in the process of a carrier signal on the receiving side of the process. In addition to that primary approach the system ensures complete phase data is utilised. The second element which can be seen when demodulating a signal through ASK would be a non-coherent procedure in which the model does not accommodate the replicated carrier making use solely of the amplitude and the frequency or any other comparative qualified phase data. As stated the coherent demodulation of ASK can be completed using a lowpass filtration method through which the signal is processed moving high frequency transmission out of the effective range are generating a signal structure seen below.

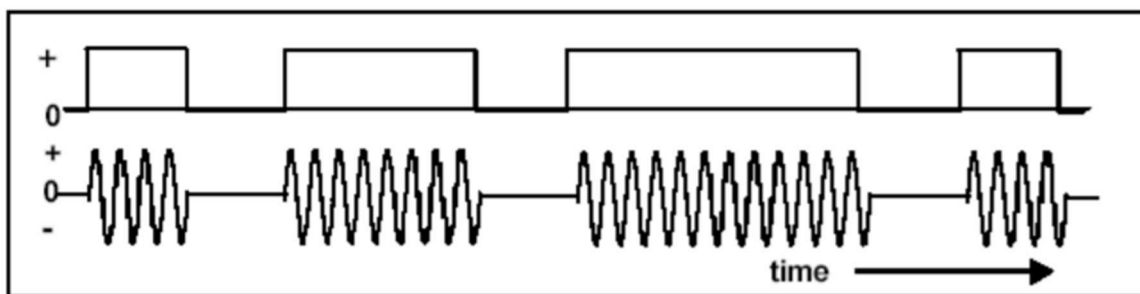


Figure 11: Coherent ASK demodulation[31]

The Non-coherent method to demodulate the ASK signal can be seen below where the use the amplitude data through the established envelope detector.

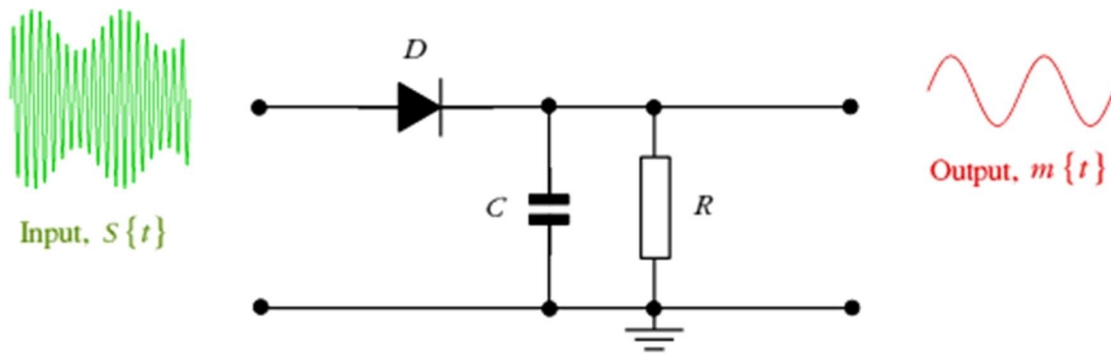


Figure 12: Envelope detector [31]

Amplitude Shift Keying (ASK) changes dynamically with digitised data if the wave amplitude from the carrier signal to two levels or more.

An ASK example developed in basic communication transmission scenario where a binary number is sent such as 11010101101. This is then broken into down through the two amplitudes as 1 and a 0, this is represented as binary amplitude shift keying (BASK)[31] in addition to On Off Keying (OOK). The binary assembly is then divided into a number of pulses which are the bits in the digital data. Ultimately however ASK modulation technique is vulnerable to unexpected gain fluctuations and inefficient. The technique is primarily used through optical fibre.

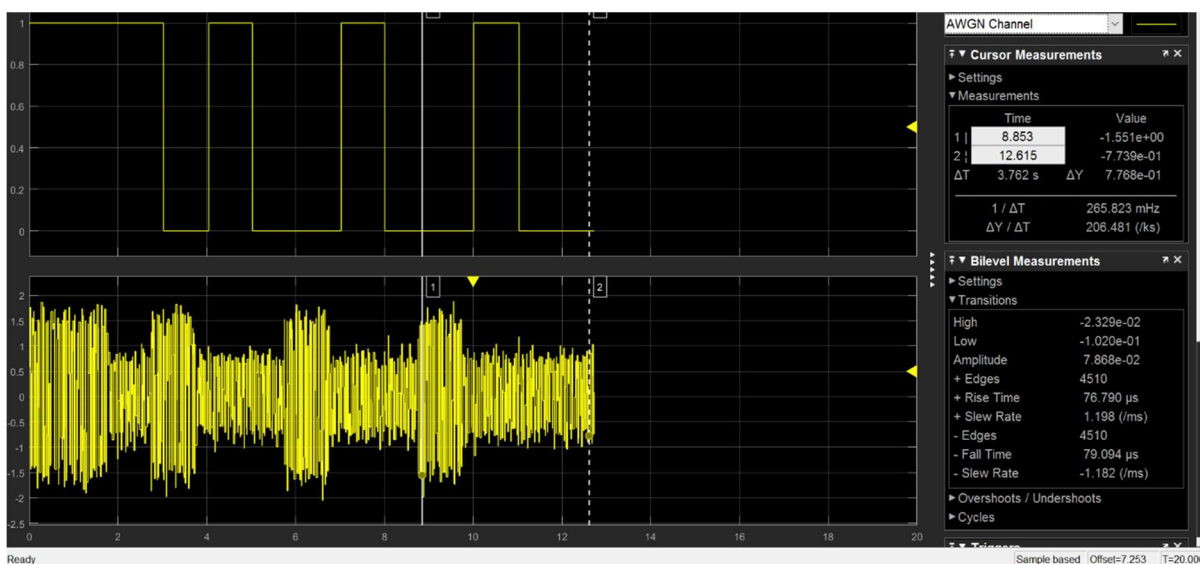


Figure 13: Simulink Simulation of ASK demodulation

Modulation techniques evaluation

The examination of modulations used in industry such as QAM, ASK and QPSK methods are simulated via MATLAB R2017b Simulink [32] which will deliver the confirmation of technological distinction and evidence required. The variables of Signal to Noise Ratio (SNR) in addition to Bit Error Rate (BER) will be developed into the wireless sensor network for the university garden. The introduction of these variables means that BER precisely measures exactly what errors were produced in the process of transmission. BER however is metric not only applied in wireless analysis's but also for the wired instalments within the networks i.e. CAT7, optical fibre and coaxial cabling. If during the testing there have been any noise and interference which may be as a result of Electro Magnetic Interference (EMI) or Radio Frequency Interference (RFI) as the transmission of data is active then possible alterations may be evident in the results changing the transmitted signal wave through which the data is affected. The application of BER highlights the substantial network detail thus enabling the capability to extract and eliminate weaknesses finding the solutions [33].

$$BER = \frac{(number\ of\ errored\ bits)}{(total\ number\ of\ bits)}$$

$$BER = \frac{(error\ count\ in\ measurement\ period)}{(bit\ rate\ x\ measurement\ period)}$$

Figure 14: Bit Error Rate calculation

SNR processes the scope of the signal, the measurements of the noise from the incompatible outputs, signals and produces of the performance can be multiplied or is slowed down as a result. If in a scenario the noise ratio component is greater than that of the signal the amplification empowering the signal has to be implemented consequentially resulting in greater performance. The formula below represent the equation for SNR.

$$SNR = \frac{P_{signal}}{P_{noise}} = \left(\frac{A_{signal}}{A_{noise}} \right)^2,$$

Figure 15: Formulation for SNR

Simulation and model assessment

Expanding on the data analysis developed through modulation research and testing, the deployed scenarios constructed using MATLAB R2017b Simulink simulation application test the physical layer, leading an investigation through experimentation. Developing the modulation systems in the project, the evaluation of the enacting performance when variable levels are present of channel interference. Using Simulink, the modulation models ASK, QPSK in addition to QAM were assessed reviewing the processes and performance on the steady empowerment of increasing noise levels affecting the channel performance. The next element in this study on modulation is the Bit error rate (BER) vector from which the examination from the effects against signal-to-noise ratio (SNR) performance is reviewed. Utilizing QAM, QPSK and ASK modulation techniques within the simulation, the process of modulation and demodulation is demonstrated. The system models in order to replicate or simulate real data creation require the use of Bernoulli binary generator, modulator (QAM, ASK and QPSK), Additive White Gaussian Noise (AWGN) channel[34], demodulator, error rate display output, lastly the use of “to work” block as shown in figures below. The assembly of the component stated above in the following models allow for the determination of the best modulation implementing additional vectors finding the best technique is. To present distinctions and differences of modulation, the introduction to the models of 0-9Db distinguishing intensities of Signal to noise ratio(E_b/N_0) were applied; in addition, the concentrated bit rate as applied was $1e8$ (100000000) whilst max errors are configured to be 100. The stipulations as stated above are consistent through the model analysis creating equality for a nondiscriminatory and complete test. Once more, theoretic testing demonstrates the applied mathematics for modulation and SNR/ BER if an abnormality in testing whilst using AWGN in addition to Rayleigh.

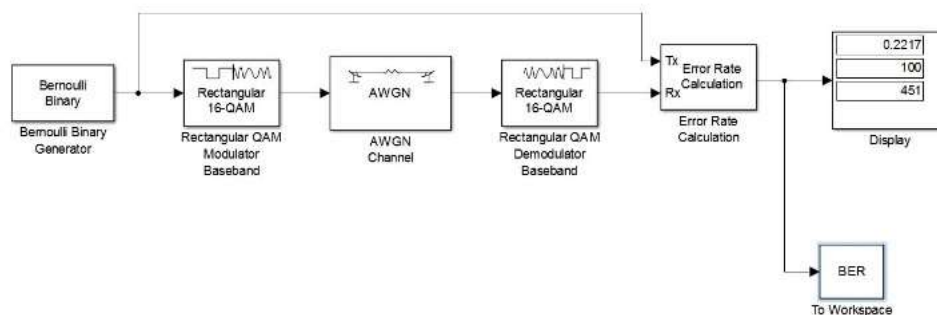


Figure 16: QAM in block formation

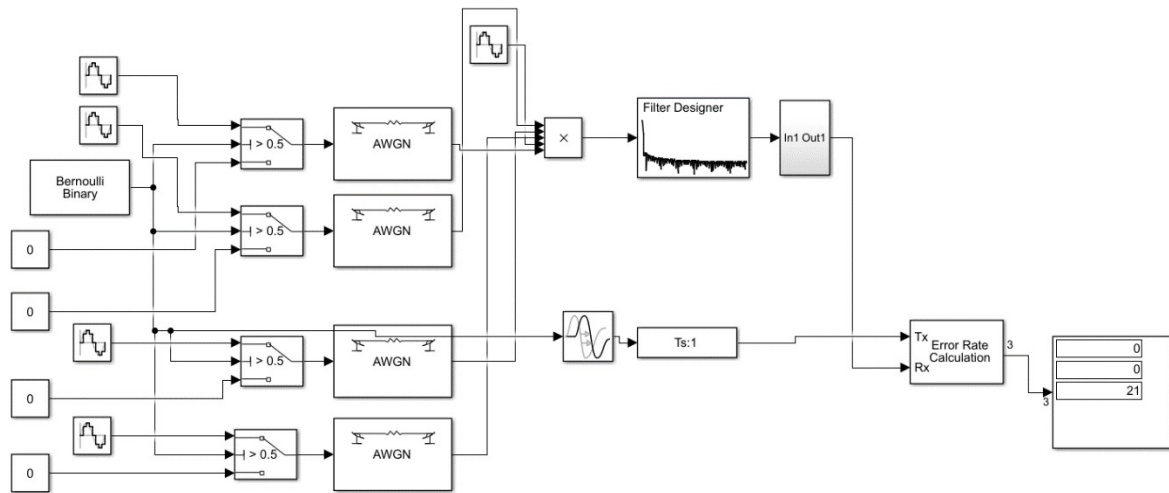


Figure 17: QAM in modular configuration

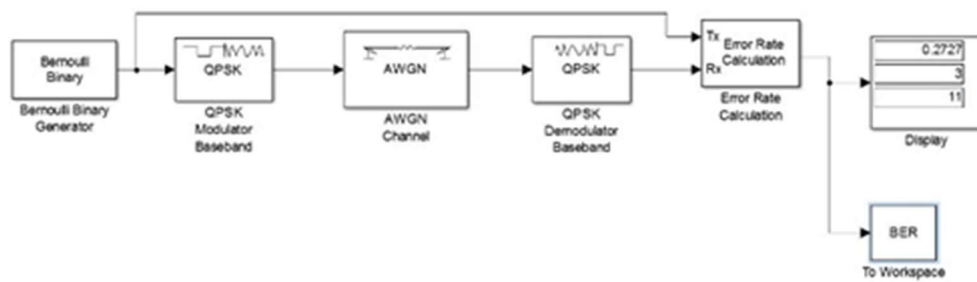


Figure 18: QPSK in block formation

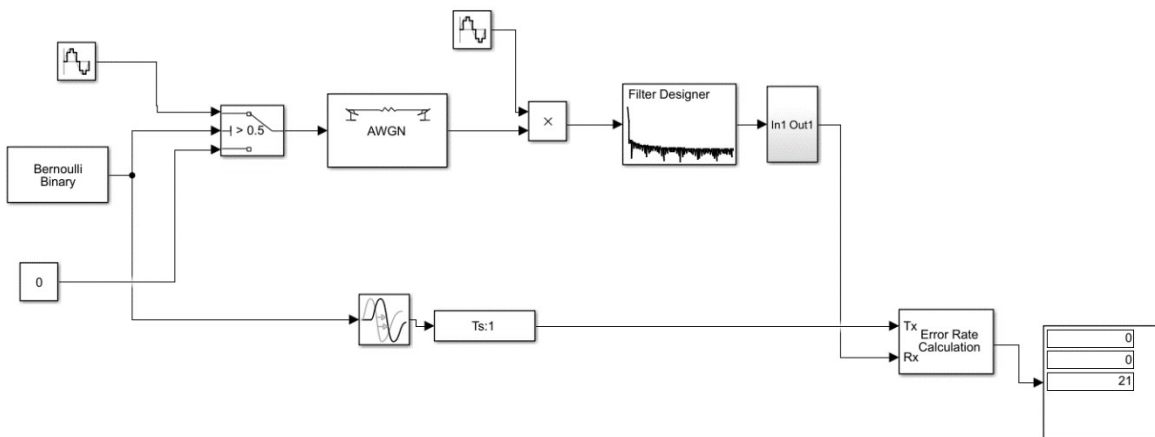


Figure 19: ASK in modular formation

In addition to these models of QAM, BPSK and QPSK, the breakdown of PSK modulation and de modulation can also be shown here. However, these are more complex than a Matlab Simulink block.

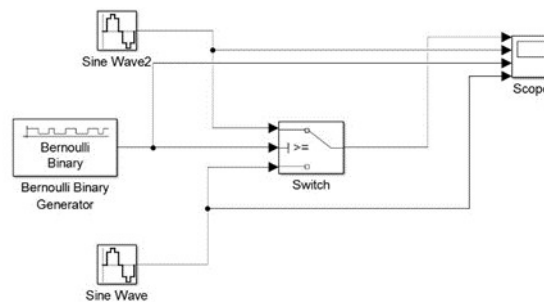


Figure 20: PSK modulation

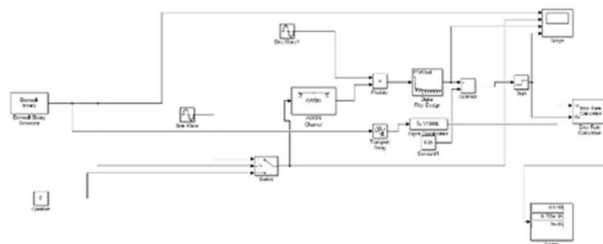


Figure 21:PSK demodulation

The Figures 20 and 21 show the modulation component assembly required for block and modular creations of the PSK modulation and demodulation architectures. The following figures under plotted graphs determine the effects of implementing SNR and BER. The output attempts to provide the data in the graphs with a 9dB model recurrently on the different modulations thus showing the variable performances from both the SNR and BER implementations. However, whilst testing it was determined from the output data that the Matlab simulations within the Simulink environment could not accurately create the results expected. Although the results gained were limited in terms of relational or non-relational a present curve should be seen rather than a line.

Plotted graphs

Throughout testing all the elements and configurations are constant, the Error calculation in addition to the AWGN channel are matching. AWGN comprised to having the mode at “signal to noise ratio (E_b/N_0)” with E_b/N_0 (Db) configured to be zero. The other consideration of “Error Rate Calculation” and the “target numbers of errors” was configured to one hundred while the “maximum number of symbols” had been configured to 100000000, termed as $1e8$.

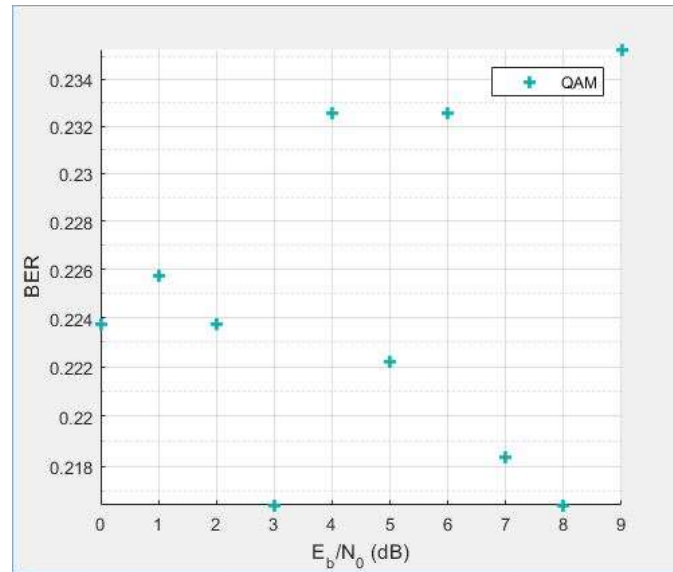


Figure 22: QAM graph output under Monto Carlo

The outcome from the test shown above in Fig22 exemplifies the results from QAM[35] when the process has gone via Mono Carlo testing approach. The result is not as expected however, the expected formation would have depicted a steady sloping line representing the power in (dB) being the noise and subsequently interference escalates and intensifies.

The modulation method QAM dynamically adjusts thus increasing the base foundation QAM signal subsequently prevailing a dominant signal over the others. However, the results produced demonstrate that

the simulations can represent a considerable nonconformity with the results, the pronounced feature from the results is that there is present inclined angle which does align.

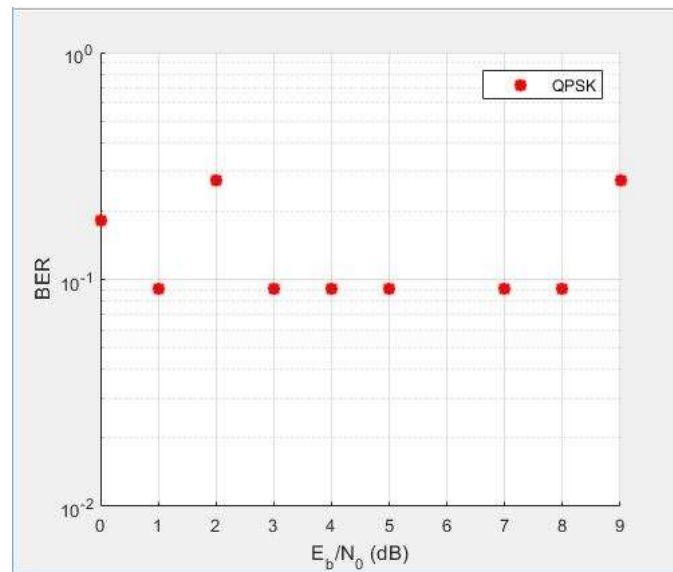


Figure 23: QPSK graph output under Monto Carlo

QPSK represented in Fig23 highlights the continual result as a result of the unique outcomes derived from Matlab which was observed earlier in Fig22 presenting no clear decline in BER but a stationary horizontal visualization.

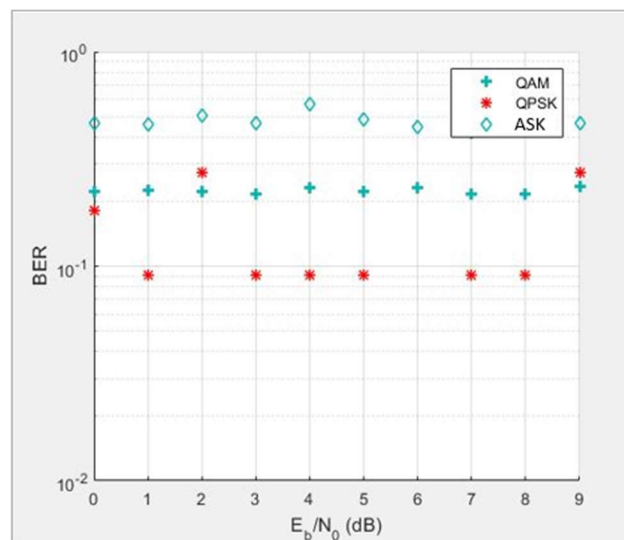


Figure 24: QAM BPSK QPSK under Monto Carlo

Fig24 is a compilation of the referenced modulations under the Monto Carlo Technique showing the varying levels of ability to dynamically deal with the BER and SNR.

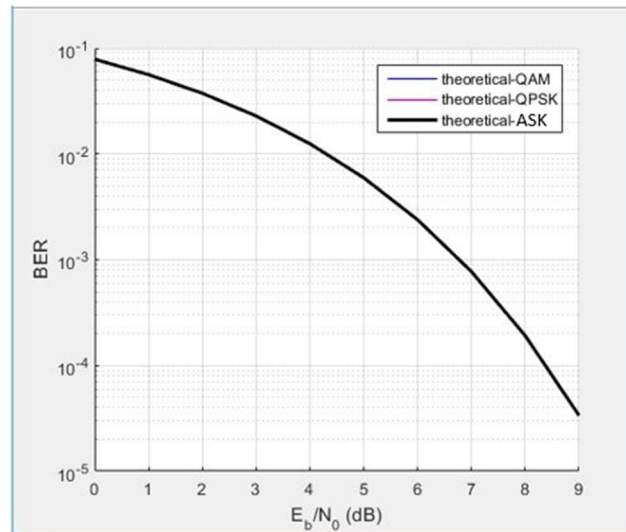


Figure 25: Theoretical outputs for QAM BPSK QPSK using AWGN

The above picture demonstrates the theoretical ability within Matlab Simulink and what results from the modulation through interference would be graphed as however Fig 26 demonstrates obvious problems in the computation. The angle seen as a representative for the modulation should not have the exact curvature for the modulation streams whilst operating with AWGN. The Graph should have more a defined segmentation such as the ASK having a lower BER ability with the noise omissions. Matlabs automotive properties with the intensification for the base signals meaning that QAM as a representative would have the highest productivity and adaptability whereas ASK or QPSK would have lesser properties.

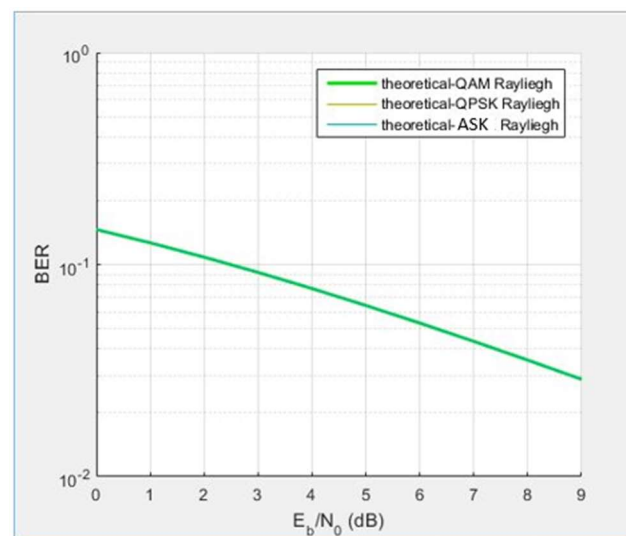


Figure 26: Theoretical line of Rayleigh interference on QAM BPSK QPSK

The image above Fig26 clearly marks the theoretic link if Rayleigh had been incorporated with the modulation methods. This however was expected as the trend in the simulation software presenting no differentiations for resulted modulation outcomes. Nevertheless, through particular obscure technical problems, the determination for that of QAM would incur problems however mitigate them to the best effect of the modulation with the smallest amount of damage compared to ASK and QPSK .

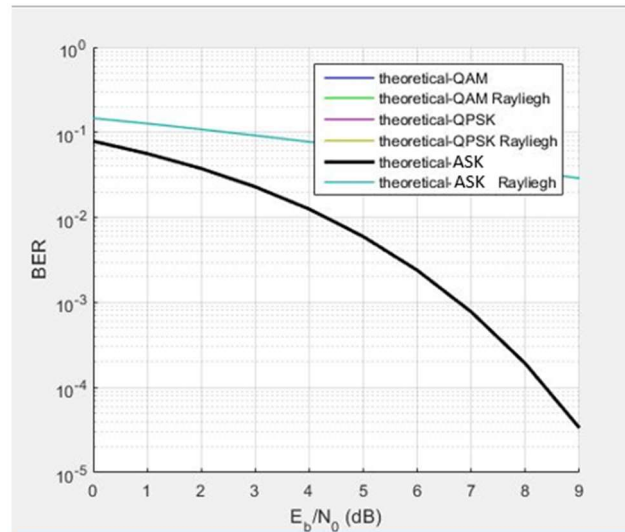


Figure 27: Theoretical lines of interference with AWGN and Rayleigh

Lastly, Matlab produced a computational assessment for both the theoretic capabilities for different modulation schemes whilst operating with Rayleigh or AWGN. Despite the graphs incorrectly configured output it demonstrates that that whilst tasked with AWGN, a noticeable decline in BER in comparison to Rayleigh.

Overall the conclusion can be drawn that the possibility of a misconfiguration may have occurred resulting in the graphs not representing what should be seen when dealing with the different modulations. In addition the simulation software itself incurred a number simulated buggy complications, this of course could have led to a likely issue when operating the software but due to that the summarization cannot be decisive within the adapted scenarios.

Wireless Network Smart Garden

The University of Wales Trinity St David is going through a rejuvenation process to implement an established Internet of Everything (IoE)[36], therefore the creation of a wireless sensor system that operates through its own process of local communication but also the university network meaning remote control and adaption. Therefore, pragmatism, was the most utilized resource approach to solving the problems resulting in cost saving resolutions that accommodate scalability and effective control over the smart garden and the data produced. The utilization of a number of sensors are essential for the system to work effectively gaining the data required so to efficiently run the systems. The introduction therefore of pressure sensors introduced into the seating areas, camera technology which diversifies into many components that are required to run a smart garden but mainly creating areas of interest that people walk through so to monitor movements such as primary entrances. The systems in that case would log all data such as face, motion and lighting in addition to noise so to create a peaceful inviting area that doesn't affect other students or lecturers. This also leads into utilizing smart devices incorporated into the grounds for interactivity and stress reliving methods such as smart mirrors that use local data to produce time, weather and interactivities for casual people walking along. These areas are maximized to efficiently monitor space whilst not giving the position of the big brother state being watched all the time meaning seamless integration into the environment. This ultimately means that free spaces and conditions of the area are well examined.

The approach to testing what is going on within the grounds is to first establish the exiting or entering people using a number of technology's and sensors measuring the scope of space inside the cameras views integrated into the smart displays located at every entrance. This allows the seat availability to be known to everyone entering the garden.

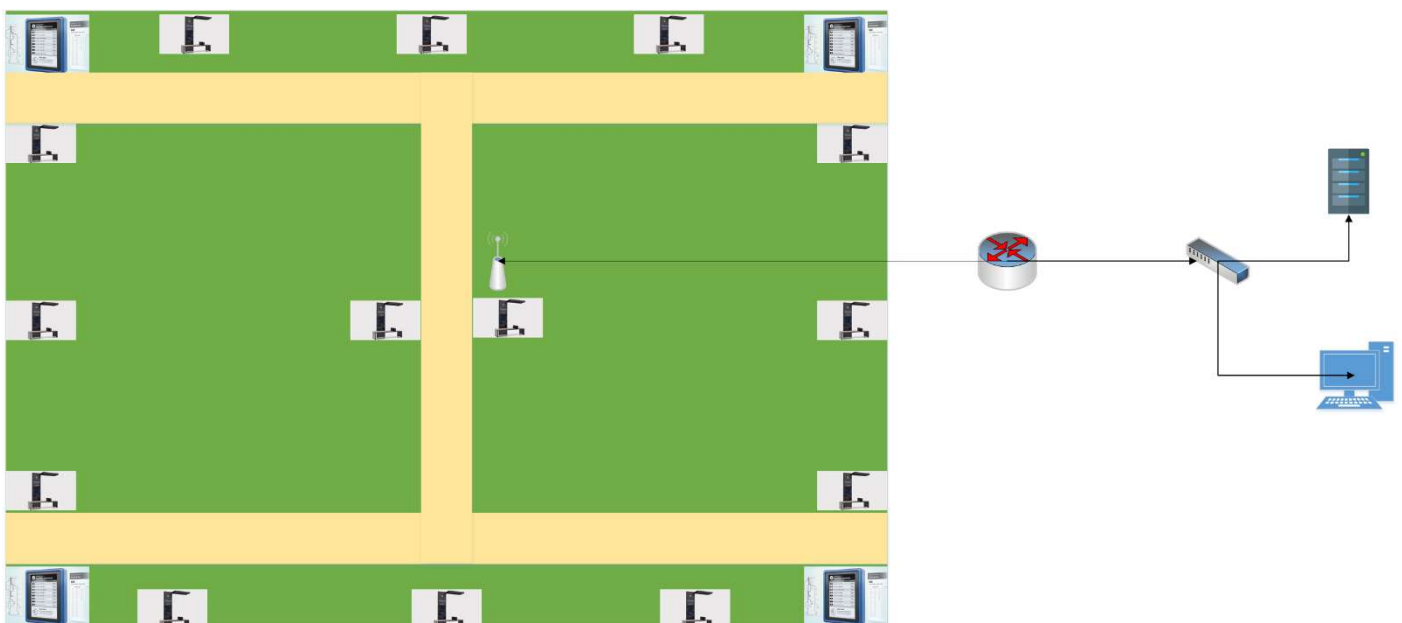


Figure 28: Smart park design and logical layout

The primary focus however is to detect exactly how many seats are free within the garden, therefore the approach to capturing data is designed and integrated into the smart benches[37] which have a number of sensory technologies such as the ones illustrated below in Fig29 detecting noise, temperature, humidity in addition to pressure sensors. Through the use of the pressure sensors the relay of information will be presented once proceed to the entrance smart displays[38], this then notifies the incoming students where to go if they wish to sit down. This as previously mentioned couples with camera technology to verify current user take.



Figure 29: Strawberry smart bench

The calculation for the catchment area is done at every entrance on the smart displays, therefore a suggested concentration zone formula has been created below.

$$C = (80') + 2.5 (L/H a)/22$$

Formulation breakdown;

C is the concentrated focus area

80' camera area optics

2.5 average width of area monitored

L/H represents length and height

(a) means average

Divide with the length 4 meters (22)

The cameras within the wireless displays are not identified in the company's reports however it would be believed to be of a similar quality as the this Samsung model(Samsung SNH-E6440BN) which would detect activity and facial recognition[38], this would then correlate to smart bench data. The displays are customized for each installation however the technology is effective HD content with slick UI design via customizable webpages.

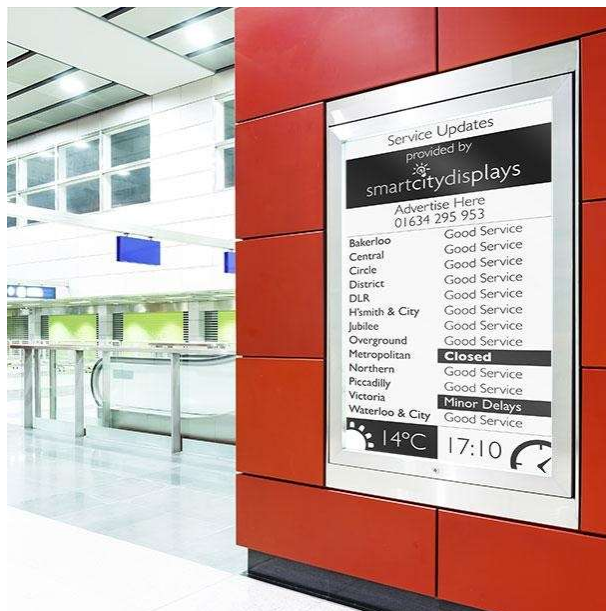


Figure 30: Smart Display providing local data

The application of using face detection/ camera technology is to generate a counter log. So if there are 50 seats and 30 people have entered it can be predicted that potentially 10 seats are in use. To consider people who are around the campus who may wish to know how busy it is in the garden communication technologies could be developed such as web displays around campus. The announcement would generate the data from the pressure detectors and atmospheric sensors display as seen in Fig30 date, time, temperature and availability around campus, this provides a non-intrusive efficient method of broadcasting a message to a lot of users without directly contacting them and being an expensive operation to setup and maintain. Over all this method provides the most inexpensive and directly viable option to tackle availability notifying both staff, visitors and students who wish to enter the garden. To enhance the active data process automation should be developed into the systems automatically authenticating the user and updating the smart display pages in the most effective way possible using If This Then That (IFTTT[39]) systems. The live data is actively and dynamically utilized signifying (IF) seats are available (Then) update the smart displays around campus to prorogate the immediate notification, ultimately (IF) a seat is available (Then) update the campus smart screens.

Fig28 indicates how the network logically is represented in regards to associated devices and wireless sensors in addition to the backbone link to the main university network via a principle core router. The possible disadvantages of using sole pressure sensor technology is that if you were to be carrying heavy books or a

rucksack or even laying across the seats it may be misinterpreted that a lot of people are sitting down and the benches are in use when in reality other objects and sitting arrangements are occurring. This is the reason why the camera facial technology is intertwined in the system as a verification. The camera its self is integrated into the smart displays, however the example one provided if added in addition utilizes the 2.4Ghz and 5Ghz spectrums. The use of H.264 [40] MJPEG for an encoding format, however H.265 [41] is the latest advanced efficient standard to use and would be superior, the operational capture is 1920x1080 at 30Hz, supporting wireless standards 802.11 b/g/n. The access point (Fig31) through which the wireless display boards communicate through in action to the wireless smart benches has respectable functionality operating at 2.4Ghz and 5Ghz, IEEE 802.11n[42] standard and the use of high end encryption standards, Transport Layer Security (TLS)[43] and Advanced Encryption System(AES)[44]. The antennae used on the devices are in the interior and Omni-directional connecting with all the different nodes around the immediate area.



Figure 31: Cisco Aironet 3502i

From this central connection to the sensory network, the data passes through to the central core infrastructure network, through that process it will be analyzed against a Access Control List (ACL[45])/firewall [46] within the router. The traffic would then be processed via another firewall featuring on the core routers checking the data against malicious injections or web vector attacks on the network. The network then routes the data to the appropriate processing end points such as an Apache webserver[47] and a MySQL[48] database, the data then is utilized to update logs, notification boards and smart displays. The future improvements have been discussed and incorporated within the report in regards to efficient, effective and self-sustaining methods of notification. The conclusion to operate with a native notification display board was applied for the purpose of 24/7 accessibility but also for simplicity of application. Further expansion would mean active camera broadcast however ethically this is an area that needs to be developed and researched to help everyone via different established communication methods.

NetSim Implementation

Using the NetSim standard version there is no method to dynamically and independently set diverse modulation schemes providing only the preconfigured ones that NetSim deem fit for different applications of use. Therefore it was impossible to deliver the variety of modulation schemes discussed in this report thus meaning that no distinct and compatible analysis could be made (Appendix 6-9). However during testing the ability to verify the results that are able to be extracted from the simulations were accurate running the simulation 10 times for each scenario to present the average and consistent data as possible. However again there were limitations in the length of simulation as the sheer amount of data and processing required is a lot meaning that when the tests were run for 100 seconds the NetSim server would crash display the error message is seen in (Appendix 1) thus resulting in only to simulate for 10 seconds which is virtually simulated as eight hours. Through testing however it can be seen the difference from a high Constant Bit Rate (CBR)[40] bitrate of 10,000bytes, compared to a standard sensor node bitrate at 1024bytes which is in effect a Variable Bit Rate (VBR)[49] which is more of a on request system meaning less load on the network but can also mean intense spiking of requested data producing a high pressure on the network bandwidth. The 10,000 byte CBR is representing the webpage data and transmission of collected sensor data simulating the effects off its data usage and which is a consistent contributor to the overall network.

Due to the fact that two different standards of communication were used in regards to the bit rate and the respected spectral use 802.11n and IEEE 802.15.4 in one system the attempt to dissimilate them could not be found due to the results converging into accumulated data. If it were achievable then the testing of different scenarios would be an area for future work to measure wireless standard positives and negatives on networks such as this smart garden concept under specific situations. The separation of the network and the simulated locations where the devices are stored meant that with a 40meter by 50meter area that there would be no signal drop however due to the amount of devices and the CBR that Tahoe[38] was applied to best prevent congestions and drops within the network. The distinctions however could not directly incorporate effects into transmissions such as the wireless components testing with Rayleigh and without in addition to not being able to add rain and weather vectors on the wireless devices.

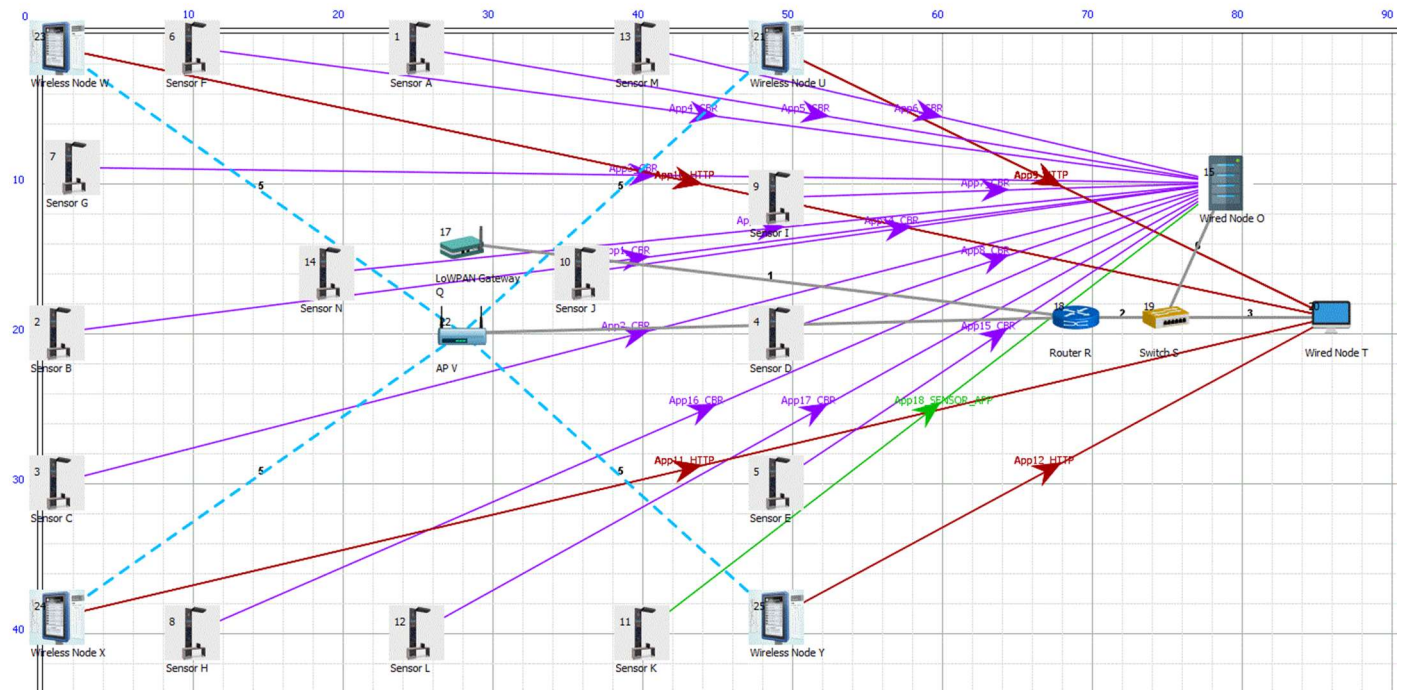


Figure 32: NetSim Smart Garden Design

Fig.32 demonstrates the NetSim smart garden network simulation. The scale and size of the components within the garden in addition to the design for the network represent a potential real model layout in regards to placement and position of components such as smart benches, smart displays and access point. As stated the design is of an approximant assumption of the garden with a given area of 40meters * 50meters. Within that the access points are positioned so that all the communication comes centrally into the yard so not to be advantages to some wireless points than others. The exterior network being restricted in NetSim to have to be connected directly to a router and not a layer 2 switch in addition to show any border gateway routers in this particular model. However from the central access points LoWPAN and standard access point (AP) the network is directly incorporated into the central university's structure. The limitations in the network model were however due to the choice of first simulation area.

During the process of creating the Netsim lab it was determined that Mobile Ad-Hoc Network (MANET) which is a independently configurable network that is a self-sustaining network of mobile wireless nodes forming random unstructured topological networks was not the best suit for the network. The MANET is mainly for dynamically changing environments in regards to movement of nodes however the project was using more statically structured devices orientated to have the most efficient structure and networks. In addition the design its self being self-sustaining requires more devices to be efficient as the lack of devices over distance results in poor signal quality and communication.

Results and findings

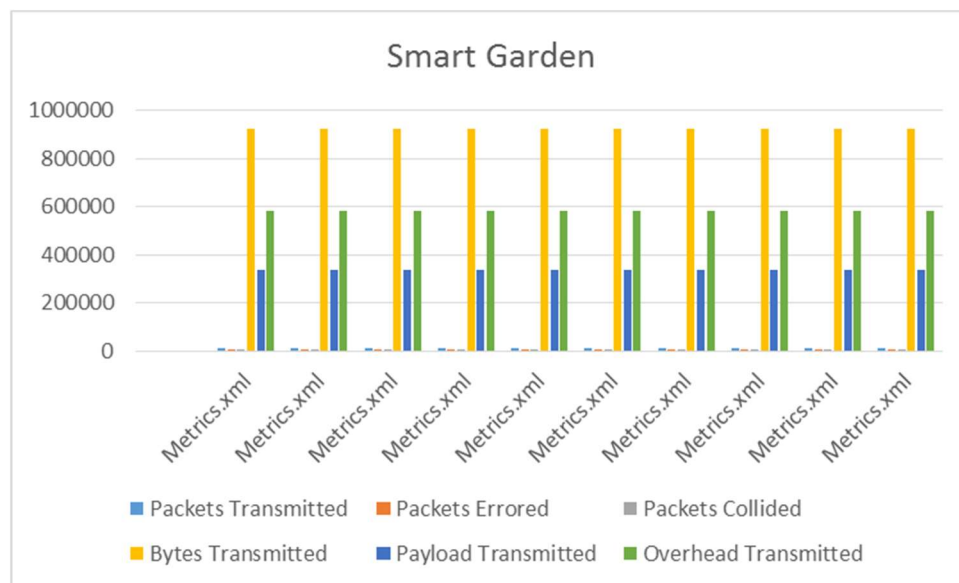


Figure 33: Accumulative data on ten smart garden tests

The image in Fig.33 demonstrates the accumulated data from all ten tests conducted showing the consistency of the network design. As you can see that despite the potential wireless interference from all the nodes and wireless devices the network is consistently stable. There was effectively no deviations from one simulation to the next. The stability of the network can be measured by the packet errors and the interference and noise by the overhead transmissions and packets collided, however the key metrics are incredibly low and almost indistinguishable from the bottom line. This proves that the testing of the network was consistent and that the network overall was consistent.

During the process of data accumulation and analysis, the attempt was made to edit the IP.dll file which can be seen below in (Appendix 2-5) however unfortunately the output did not work correctly un able to attach the IP data to the node. Despite that analysis setback other areas could be established and Brocken down in assembled output sheets which is expanded upon next.

AODV Metrics

Device Id	RREQ Sent	RREQ forwarded	RREP sent	RREP forwarded	RERR sent	RERR forwarded	Packet originated	packet transmit...	packet dropped
1	1	3	15	0	0	0	153	153	0
2	6	6	12	0	0	0	79	79	0
3	1	4	13	0	0	0	162	162	0
4	1	4	13	0	0	0	172	172	0
5	1	4	13	0	0	0	152	152	0
6	1	4	14	0	0	0	149	150	0
7	4	8	8	0	0	0	79	79	0
8	3	6	10	0	0	0	152	152	0
9	6	9	7	0	0	0	79	79	0
10	4	8	8	0	0	0	79	79	0
11	2	5	11	0	0	0	4	4	0
12	1	4	13	0	0	0	154	342	0
13	2	5	11	0	0	0	79	79	0
14	1	4	12	0	0	0	152	177	0
15	14	0	13	0	0	0	0	575	0

Figure 34: Ad-hoc On-demand Distance Vector routing results

The table above shows the Ad-hoc On-demand Distance Vector (AODV)[38] metrics within the simulation for the smart benches relaying data from the pressure sensors and other attached device data. The results are showing the elements captured so in total the packets originated from the nodes moving onto the corresponding receiver amount to 1645 packets originated from those devices transmitting in total 2434 and dropping not a single packet in the process highlighting the stability of the connection. Other field's such as PREQ sent which is the reactive routing mechanism when anything is needed and the same can be said for PREQ forward showing minimal packets sent relieving pressure of the wireless network.

Application_metrics

Application Id	Application Na...	Source Id	Destination Id	Packet transmit...	Packet received	Payload transm...	Payload receive...	Throughput (M...	Delay(microsec)
1	APP1_CBR	2	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
9	APP9_HTTP	20	21	135	9	186750.000000	6750.000000	0.005400	1984.425123
10	APP10_HTTP	20	23	120	8	166000.000000	6000.000000	0.004800	127478.418176
11	APP11_HTTP	20	24	135	9	186750.000000	6750.000000	0.005400	1605.183700
12	APP12_HTTP	20	25	135	9	186750.000000	6750.000000	0.005400	2298.747030
2	APP2_CBR	3	15	83333	7	4990000.000000	420.000000	0.000336	1015184.494286
3	APP3_CBR	7	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
4	APP4_CBR	6	15	83333	8	4990000.000000	480.000000	0.000384	8107094.168327
5	APP5_CBR	1	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
6	APP6_CBR	13	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
7	APP7_CBR	9	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
8	APP8_CBR	4	15	83333	26	4990000.000000	1560.000000	0.001248	1486978.480000
13	APP13_CBR	14	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
14	APP14_CBR	10	15	83333	0	4990000.000000	0.000000	0.000000	0.000000
15	APP15_CBR	5	15	83333	1	4990000.000000	60.000000	0.000048	8101229.980000
16	APP16_CBR	8	15	83333	1	4990000.000000	60.000000	0.000048	8672184.580000

Figure 35: Application Metrics CBR, HTTP

This application field relays the data interactions its self in regards to the type of data, the delay of the transmission, packets transmitted and received in addition to linking the node connections from source ID. It can be seen that as for delays that they were minimal with it being represented in microseconds however the highest delay achieved is 86 milliseconds and the lowest being 10 millisecond when converted meaning the delay is exceptionally small when In comparison to other standards means of communication such as fiber achieving 2-3 milliseconds of delay on a packet to account for transmission. The differences now can be extracted through application with the CBR and HTTP showing that the CBR on average actually produced the quickest times in regards to packet delay whilst HTTP produced the slowest times. However that is protocol specific and could be improved by means of caching and limitation fields preventing excessive data with similar results so effective internal querying.

IEEE802.11_Metrics

Deviceld	Interfaceld	Frame Sent	Frame Received	RTS Sent	RTS Received	CTS Sent	CTS Received	Successful Back...	Failed Backoff
19	1	30	21	0	0	0	0	30	1
20	1	82	118	0	0	0	0	82	32
21	1	28	19	0	0	0	0	28	6
22	1	30	21	0	0	0	0	30	1
23	1	30	21	0	0	0	0	30	1

Figure 36: 802.11 metrics data for wireless devices

Fig36 is showing the standard WI-FI metrics which is seen within the simulation between the smart displays and the wireless AP. The identification of the AP can be determined by the frames received suggesting device 20 was the AP, from that the successful and failed backoff can be analyzed[38]. The Backoff exponent is when the process of backoff is additionally implemented at time ($\text{Present_Time} + \text{BackOff Time}$). When the Backoff is effective, NetSim transmission procedure enacts aggregating packets from both the QOS buffer which is stored in Retransmit buffer. This is a interesting element of the metrics because it highlights that the process must occur in order for NetSim to operate the transmission procedure. From that, the frames sent and received produced predictable consistency as seen with the previous total metrics observed so far with minor deviations of normality during the process of transmission. From 21 and 30 frames received and sent on the smart displays to 19 and 28 on device 21 which could be down to data process or interference. The total frames sent amount to 200 frames and 200 received.

IEEE802.15.4_Metrics

Device ID	PacketTransmit...	PacketReceived	AckTransmitted	AckReceived	CCAAttempt	SuccessfulCCA...	FailedCCA	Totalbackoffti...	Averagebackof...	BeaconTransmi...	BeaconReceived	BeaconForward...	BeaconTime(MI...	CAPTime(Micro...	CFPTime(Micro...
1	137	70	5	104	1000	427	573	2562240.0000	3128.4982	0	0	0	0.0000	0.0000	0.0000
2	75	70	5	53	576	225	351	1469760.0000	2939.5200	0	0	0	0.0000	0.0000	0.0000
3	131	166	101	104	1115	427	688	3001600.0000	3031.9192	0	0	0	0.0000	0.0000	0.0000
4	166	191	129	123	1198	506	692	2973440.0000	2789.3433	0	0	0	0.0000	0.0000	0.0000
5	127	155	91	87	1015	386	629	2620480.0000	2977.8182	0	0	0	0.0000	0.0000	0.0000
6	104	129	67	80	626	294	332	1432320.0000	2717.8748	0	0	0	0.0000	0.0000	0.0000
7	82	69	6	51	577	241	336	1488960.0000	3014.0891	0	0	0	0.0000	0.0000	0.0000
8	144	113	51	89	1033	426	607	2582720.0000	3038.4941	0	0	0	0.0000	0.0000	0.0000
9	45	74	10	25	339	136	203	919040.0000	2993.6156	0	0	0	0.0000	0.0000	0.0000
10	72	72	9	45	612	239	373	1628160.0000	3077.8072	0	0	0	0.0000	0.0000	0.0000
11	16	67	6	3	199	64	135	601920.0000	2936.1951	0	0	0	0.0000	0.0000	0.0000
12	364	376	313	294	1805	1015	790	3846080.0000	2393.3292	0	0	0	0.0000	0.0000	0.0000
13	46	69	7	27	329	123	206	867840.0000	2763.8217	0	0	0	0.0000	0.0000	0.0000
14	95	93	29	74	665	299	366	1669440.0000	2954.7611	0	0	0	0.0000	0.0000	0.0000
17	764	1018	968	565	2268	1762	506	3920000.0000	1695.5017	0	0	0	0.0000	0.0000	0.0000

Figure 37: Wireless sensor node metrics

Fig.37 Shows the metrics for all of the smart benches in regards to how much data the smart benches were transmitting, the timing of the transmissions e.g. beacon time, Contention Access Period (CAP time) and Contention Free Period CFP time. CFP and CAP meaning a slot of time where entree to the Wireless Medium is available and free from contention. Interestingly on all nodes there was no period in which the CAP, CFP and beacon were delayed or effected during the testing of the simulations. However what is interesting is the

total backoff time in comparison to 802.11 metrics. When compared the 803.15.4 metrics are 230 milliseconds, far greater and the 20-30 millisecond region achieved with 802.11n causing a lot of data to be stored in retransmission buffer which is not good for the network and ultimately slows it down. For total frames sent taking four at random to align with the four from 802.11n metrics respectively the total packets sent amount to 514 whilst receiving 714 , again showing that the smaller packets holding less requiring frequent transmissions do effect the network and packet loss/congestion.

Network_Metrics

Link_id	Link_throughp...							Bytes_transmitt...	Payload_trans...	Overhead_trans...
		Data	Control	Data	Control	Data	Control			
All	NA	4181	7070	2	0	229	1055	920778	336482	584296
1	NA	902	620	0	0	0	0	115672	54932	60740
2	NA	938	756	1	0	0	0	197460	81060	116400
3	NA	36	147	1	0	0	0	39960	26250	13710
4	NA	36	164	0	0	0	0	41184	27000	14184
5	NA	36	364	0	0	0	0	50264	27000	23264
6	NA	901	611	0	0	0	0	157518	54060	103458
7	NA	1332	4408	0	0	229	1055	318720	66180	252540

Figure 38: Overall simulation network metrics

Fig.38 presents the most interesting aspect of network analytics in regards to actual data sent verses protocol requirements of bytes, payload and overhead transmitted showing that some links wither it be wireless or wired do take a heavy burden compared to other routes. This was expected, with primary network paths to follow such as the database processing server link for example. The chart in summary represents the protocols and network design having an effect for specific links and the transmissions that occurred on the links.

Queue_Metrics

Device_id	Port_id	Queued_packet	Dequeued_packet	Dropped_packet
16	1	583	583	0
16	2	1043	1043	0
16	3	82	82	0
20	1	82	82	0

Figure 39: Network Queue metrics

Queue metrics are the identifiable elements within the simulation where the identifiable effects of queueing are felt such as the dropped packets as seen above showing not one dropped packet, or queued and de-queued packets. The results show a 100% success rate for processing the packets without having to drop them meaning there was enough buffer or little data that lots of packets could be stored.

IP_Metrics

Device Id	Packet sent	Packet forwarded	Packet received	Packet discarded	TTL expired	Firewall blocked
1	177	0	3	0	0	0
2	108	0	5	0	0	0
3	185	0	100	0	0	0
4	195	0	128	0	0	0
5	175	0	90	0	0	0
6	174	1	65	0	0	0
7	103	0	3	0	0	0
8	176	0	43	0	0	0
9	104	0	2	0	0	0
10	103	0	3	0	0	0
11	27	0	0	0	0	0
12	365	188	123	0	0	0
13	102	0	2	0	0	0
14	199	25	3	0	0	0
17	1545	1506	8	0	0	0
18	1708	1700	8	0	0	0

Figure 40: IP metrics

Lastly in Fig.40 the IP metrics are showing that the firewalls did not block any of the authentic packets from the data created and processed from the nodes, in addition the distance vectors were not exceeded due to the close routing proximity's. Also that not a single active packet was discarded during testing. The most interesting development in this graph is the point to point communication and the direct efficiency so that very few packets had to be forwarded when compared to packets send and received for the majority of nodes except that of 17 and 18 which must have had a directionally stronger signal advantage compared to other nodes thus taking the burden of forwarded packets.

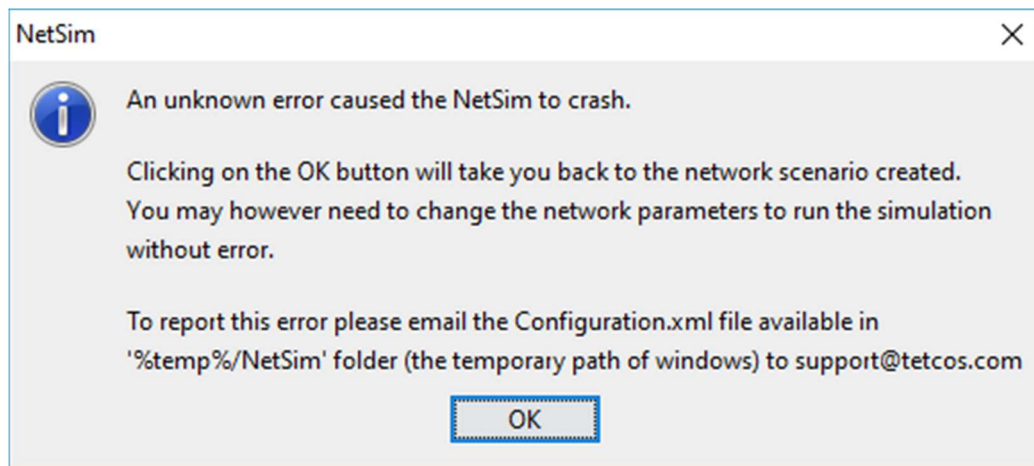
Conclusion

In summary, the tests conducted for tasks 1 and 2 are seen as a success to the degree that although not all the results were expected and some were better than other that it proved and provided evidence to support the theory. However, as stated the useable results justified the reasonable explanations to potentially why certain results and developments logically could have happened when some of the events expected did not. The data that was analysed and gained as shown within the results did however support the research conducted. Disappointingly, the findings could not be determined when finding the best modulation protocol due to the technical incapability's as a result of restriction and application design. The attention on ASK, QPSK and QAM modulation techniques demonstrated clearly with a robustness in the justification on the virtual predictions acquired through Matlab and NetSim. There were minor problems throughout testing such as not enough ram on the NetSim server to run certain long simulations however a consistency was made. Ultimately using simulation techniques in NetSim the process of how to solve the problematic applications in a practical and operational way.

The results gained from the smart garden were a victory, in the application as well as the deployment in a simple network showing the sophistication of the project, it's over all usability in addition to the expansive duplicability. Future improvements would develop and focus on diversifying the smart garden so everyone can make the most of it for people who are disabled to not only provide data for the project but help members of the campus community. Lastly, the report compiled many elements from modulation techniques and where they are used and deployed to simulated instances and applied in the available ways possible via the software such as NetSim packages.

Appendix

Appendix 1



Appendix 2

```

This function is called by NetworkStack.dll, whenever the event gets triggered
inside the NetworkStack.dll for IP. It includes NETWORK_OUT, NETWORK_IN and TIMER_EVENT.
*/
FILE *fp_ip = NULL;
_declspec(dllexport) int fn_NetSim_IP_Run()
{
    char s_ip[_NETSIM_IP_LEN],
        d_ip[_NETSIM_IP_LEN], t_ip[_NETSIM_IP_LEN], r_ip[_NETSIM_IP_LEN];

    switch(pstruEventDetails->nEventType)
    {
    case NETWORK_OUT_EVENT:
        {
            NetSim_PACKET* packet = pstruEventDetails->pPacket;
            NETWORK_LAYER_PROTOCOL nLocalNetworkProtocol;
            NETSIM_IPAddress dest;
            nLocalNetworkProtocol = fnGetLocalNetworkProtocol(pstruEventDetails);
            if(nLocalNetworkProtocol)
            {
                fnCallProtocol(nLocalNetworkProtocol);
                return 0;
            }
        }
    }
}

```

Adding the code into fn_NetSim_IP_Run.

Appendix 3

```

        case NETWORK_IN_EVENT:
        {
            NetSim_PACKET* packet = pstruEventDetails->pPacket;
            if(pstruEventDetails->nInterfaceId && NETWORK->ppstruDeviceList[pstruEventDetails->nDeviceId-1]->ppstruInterfaceList[pstruEventDetails->nInterfaceId-1])
            {
                //Call the local network protocol
                fnCallProtocol(NETWORK->ppstruDeviceList[pstruEventDetails->nDeviceId-1]->ppstruInterfaceList[pstruEventDetails->nInterfaceId-1]);
            }
            if(pstruEventDetails->pPacket==NULL)
            {
                return 0;
            }
            packet = pstruEventDetails->pPacket;
            //Decrease the TTL
            packet->pstruNetworkData->nTTL--;
            if(wireshark_trace.convert_sim_to_real_packet &&
                !DEVICE_MACLAYER(pstruEventDetails->nDeviceId,pstruEventDetails->nInterfaceId)->isWiresharkWriter)
            {
                wireshark_trace.convert_sim_to_real_packet(packet,
                    wireshark_trace.pcapWriterList[pstruEventDetails->nDeviceId-1][pstruEventDetails->nInterfaceId-1],
                    pstruEventDetails->dEventTime);
            }

            if (packet->nPacketType != PacketType_Control)
            {
                IP_TO_STR(packet->pstruNetworkData->szSourceIP, s_ip);
                IP_TO_STR(packet->pstruNetworkData->szDestIP, d_ip);
                IP_TO_STR(packet->pstruNetworkData->szGatewayIP, t_ip);
                IP_TO_STR(packet->pstruNetworkData->szNextHopIP, r_ip);
                if (!fp_ip)
                {
                    fp_ip = fopen("ip.csv", "w");
                    fprintf(fp_ip,
                        "Packet_Id,Device_Id,Interface_id,Source_IP,Destination_IP,Transmitter_IP, Receiver_IP\n");
                }
                fprintf(fp_ip, "%lld,%d,%d,%s,%s,%s,%s\n", packet->nPacketId,
                    pstruEventDetails->nDeviceId, pstruEventDetails->nInterfaceId,
                    s_ip, d_ip, t_ip, r_ip);
                fflush(fp_ip);
            }
        }
    }

```

Inputting code into Network_IN_Event

Appendix 4

```

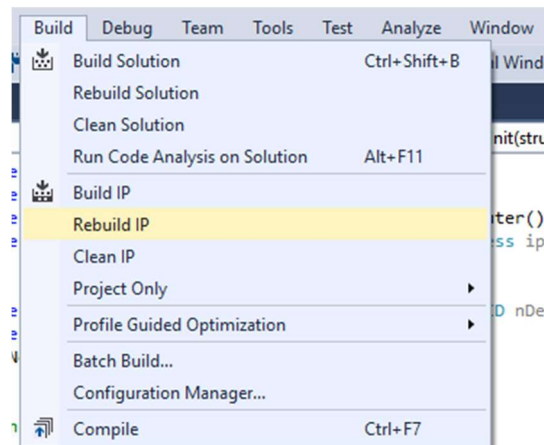
        switch(pstruEventDetails->nEventType)
        {
            case NETWORK_OUT_EVENT:
            {
                NetSim_PACKET* packet = pstruEventDetails->pPacket;
                NETWORK_LAYER_PROTOCOL nLocalNetworkProtocol;
                NETSIM_IPAddress dest;
                nLocalNetworkProtocol = fnGetLocalNetworkProtocol(pstruEventDetails);
                if(nLocalNetworkProtocol)
                {
                    fnCallProtocol(nLocalNetworkProtocol);
                    return 0;
                }
                if(packet->pstruNetworkData->nTTL == 0)
                {
                    //TTL expire drop the packet
                    packet->nPacketStatus = PacketStatus_TTL_Expired;
                    fn_NetSim_WritePacketTrace(packet);
                    fn_NetSim_Packet_FreePacket(packet);
                    pstruEventDetails->pPacket=NULL;
                    ipMetrics[pstruEventDetails->nDeviceId-1]->nTTLDrop++;
                    return 0;
                }

                if (packet->nPacketType != PacketType_Control)
                {
                    IP_TO_STR(packet->pstruNetworkData->szSourceIP, s_ip);
                    IP_TO_STR(packet->pstruNetworkData->szDestIP, d_ip);
                    IP_TO_STR(packet->pstruNetworkData->szGatewayIP, t_ip);
                    IP_TO_STR(packet->pstruNetworkData->szNextHopIP, r_ip);
                    if (!fp_ip)
                    {
                        fp_ip = fopen("ip.csv", "w");
                        fprintf(fp_ip,
                            "Packet_Id,Device_Id,Interface_id,Source_IP,Destination_IP,Transmitter_IP, Receiver_IP\n");
                    }
                    fprintf(fp_ip, "%lld,%d,%d,%s,%s,%s,%s\n", packet->nPacketId,
                        pstruEventDetails->nDeviceId, pstruEventDetails->nInterfaceId,
                        s_ip, d_ip, t_ip, r_ip);
                    fflush(fp_ip);
                }
            }
        }
    }

```

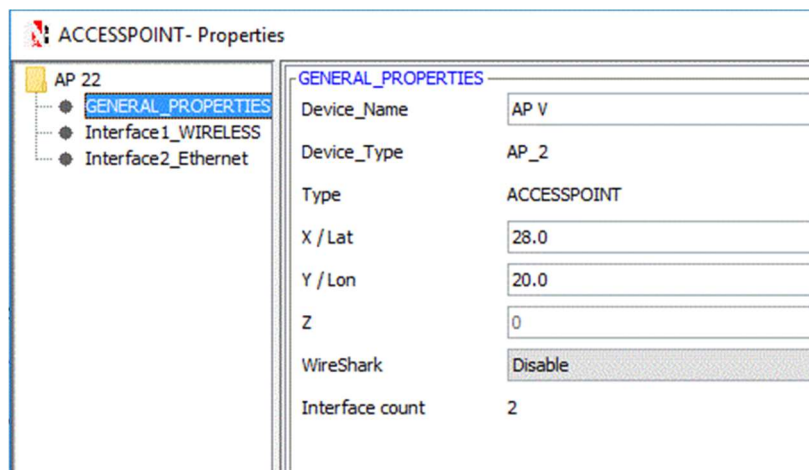
Inputting the code into network out event

Appendix 5



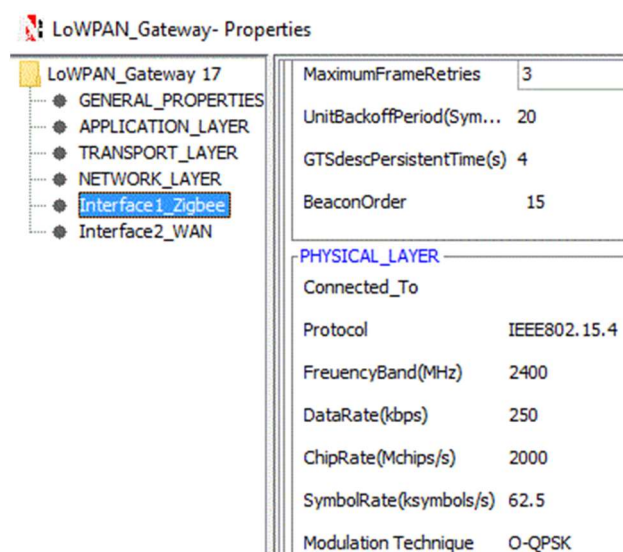
Rebuild IP work around as the direct way to rebuild wasn't working

Appendix 6



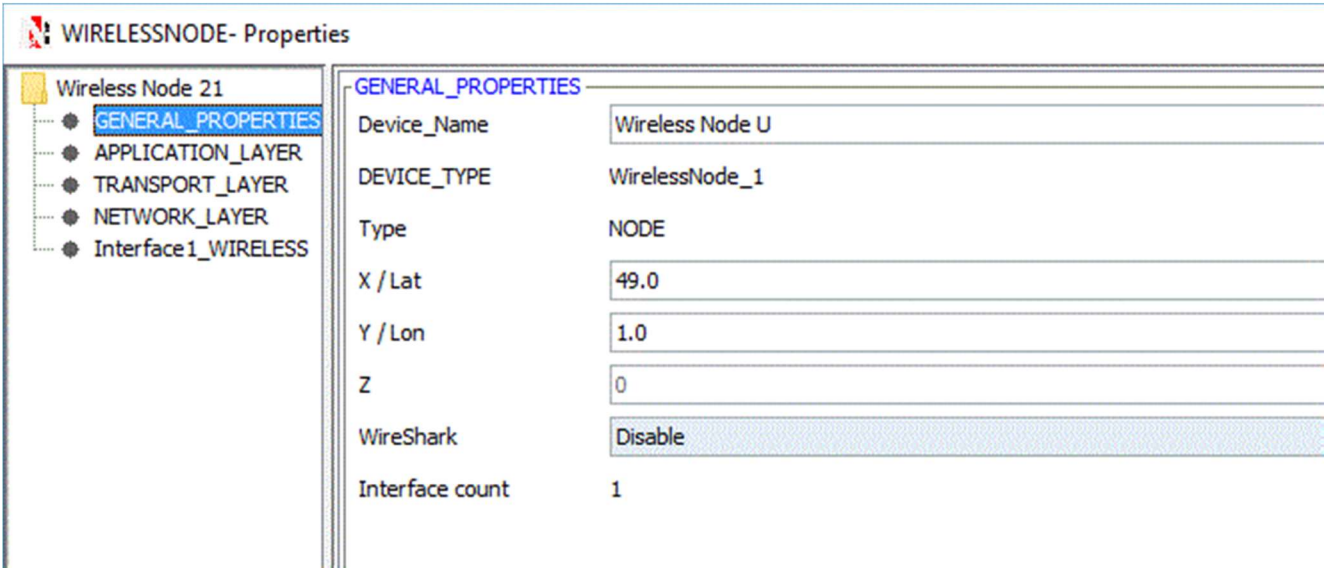
Access point has no clear way to change modulation.

Appendix 7



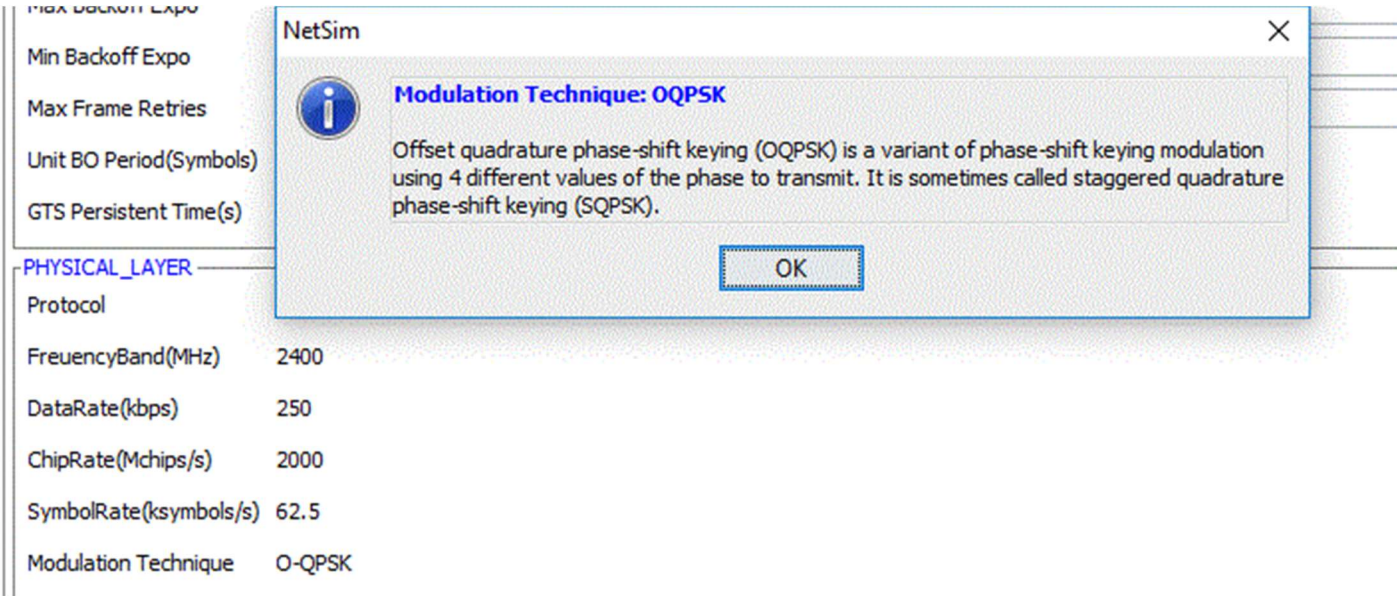
Lowpan modulation technique stuck at OQPSK

Appendix 8



No modulation choice in wireless nodes.

Appendix 9



Sensor unable to change from OQPSK.

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