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Smart University Utilising the Concept of the Internet of Things (IoT)

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***Abstract* — the revolution of the Internet of Things (IoT) will change our perception of computing moving into the next decade, simplifying everyday tasks, to a simple tap on a smart device. This paper will primarily look at a Smart University utilising automation and IoT to improve its sustainability and use for Students and Staff. Research areas to be considered; students count, environment management i.e. lights, blinds, and temperature, this paper will identify some currently available products and software available on the market which could make this possible. A consideration towards the future scalability of the smart university and to the potential of automating other areas will also be discussed. In addition to the research, a model of a smart university will be demonstrated using network simulation software known as QualNet. This will show how the network performs under simulation conditions.**

Keywords – Simulation, QualNet, Internet of Things, Smart City, Wireless Communication

I. INTRODUCTION

This paper will look to identify some of the fundamental principles required to implement a smart university model. Following the introduction, a review of the concepts and related works into the field will be discussed. Section three concentrates on the proposed solution to be used based on the concepts identified from section two. Section four will focus on the results and findings from the simulation experiments.

A. A brief overview of the Internet of Things (IoT)

As discussed in the journal "2013 Fourth International Conference on Computing for Geospatial Research and Application" [1] it defines the IoT as a network containing a number of smart objects. Primarily identifying mobile phones, tablets, home appliances and industrial machines connected to the internet. It is assumed that future devices will be connected through a network of internet networks [1]. Looking at the overall impact of the technology it is said that there will be 50 – 100 billion devices connected to the internet by 2020 [2]. Currently Smart Cities are identified as the focus for IoT growth as by IHS Markit [3] "There will be at least 88 smart cities all over the world by 2025"

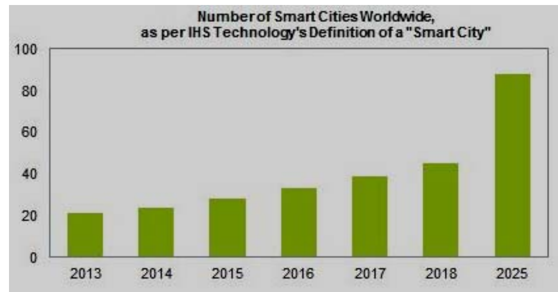

Figure 1 – No. of Smart Cities Worldwide [3]

So what is a smart city? If you have ever wondered how long is the bus going to be, or why do the bins at that restaurant always overflow? Smart Cities are introducing Wireless Sensor Networks (WSN) located across the city attached to bins, buses, car parks etc. These devices will then communicate with a central database across the internet to plan rubbish collection, send signals to bus stops to let you know when the next service is due and an aid to stop you from endlessly driving around to find parking spaces a simple app on your smart device will notify you of locally available spaces. [4]

II. CONCEPTS AND RELATED WORKS

A. Counting students within the classroom setting

Using a system of manually recording names on paper or alternatively a non-technological approach i.e. a register can be utilised for this purpose. However, this paper will identify that it could be possible to show a student's attendance using a Radio-Frequency Identification (RFID) system along with face detection camera and software.

So what is RFID? [5] This is a technology that uses both fixed and portable units to access information stored on a tag or smart card, the most common use of RFID is to gain access to a building. RFID technology is used in many supermarkets to process online shopping via the use of barcode scanning. How can RFID be implemented to count students? At the entry to each classroom or lecture theatre there will be a static wall mounted RFID reader, a student will scan their ID card across the reader thus counting the student into the class, many of these readers can record the time a student accesses the classroom or lecture theatre. Looking at options that can work alongside the RFID technology it was decided that Face Recognition could provide a backup solution in the event of the RFID readers failing to operate.

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What is face recognition and how does it operate? The use of the face has the benefit of being non-intrusive and passive as compared to other biometric modalities (such as fingerprints and iris). Face recognition systems must be able to identify a face captured previously from a still image [6]. How will this operate in the classroom? As students enter the classroom, a camera situated adjacent to a smart interactive board or projection screen will automatically scan the students against a database of pictures taken upon registration with the university.

After reviewing the marketplace the most cost-effective system was the Panasonic WV-SW174W [7] after looking at the specifications [8] it was clear that this camera offered the usability and scalability required. The software for managing the imaging database will be provided by Cognitec [9] as one of the leading face recognition companies their FaceVACS-DBScan software [10] should provide the necessary usability and accessibility to monitor students attendance within the classroom. This system will also have a secondary use should the university wish to employ it as a security measure as this camera is capable of recording both live pictures and audio.

B. Managing the Classroom Environment

The lighting needs to have a wireless sensor network; working together using motion detection and lux sensors that will gauge the light to ensure that on darker days, the lights will increase to a level as set out in the management software package. Lux is the unit reading and is defined by Green Business Light [11] Lux; a measurement of the light intensity also known as “illuminance” or “illumination” for example; 1 lux is equal to the illumination of a surface one metre away from a single candle. The list below highlights as to what the average Lux ratings are in varying environments.

- Outdoor average sunlight 32 000 to 100 000
- Warehouse aisles 100-200
- A bright office about 400
- Building corridors can be around 100

Taking into account that various classrooms across the campus are going to vary in size it should be noted that some rooms shall require more than one sensor, placement of these sensors will be vital to the successful operation of the lights in conjunction with motion detection sensors to monitor movement within the learning environment. In order for daylight-linked lighting to be advantageous, it is a requirement to make sure that the room or location under concern is suitable for it. Several influences affect the actual availability of daylight that can be applied to save energy. Factors to be considered are geographical setting, the positioning of room, proportions of the room and obstacles to daylight [12]. To ensure that the locations across the campus are all taken into consideration, it would be essential to run simulations using a software package to determine the potential savings and to demonstrate the actual operation of the lighting sensor network based on pre-defined scenarios. DIALux [13] is just one of the available packages that can be used, during the *“2014 IEEE International Conference Power & Energy (PECON)”* [12] it was discussed as to how to calculate the necessary Lux levels, and to identify factors that will prevent successful operation of Daylight-Linked Lighting Control. This system would seem to be a vital consideration for any potential sensor network to work; this will require additional extensive research to ensure that the lighting levels that are required can be achieved.

Much like the lighting, the motion detectors will perform an invaluable role in the management of lighting control. Motion detectors/sensors have been used within the home but also in a commercial environment, figure 2 below shows some of the domestic applications

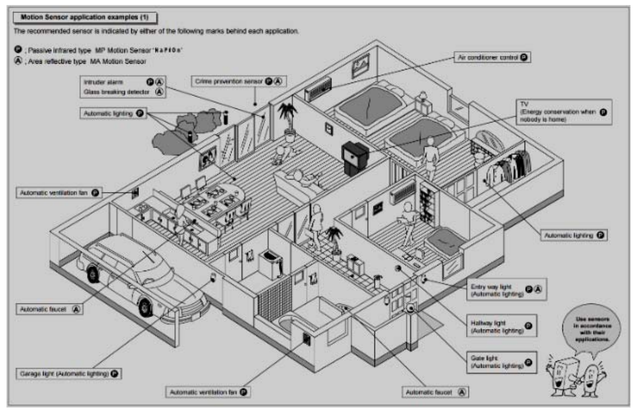

Figure 2 – Motion Sensor application examples [14]

So how will the Smart University utilise Motion and Passive Infra-Red (PIR) sensors [14]. Firstly, they are linked to the Lighting Sensor Network (LSN), utilising wireless network protocols ensuring communication between both networks is compatible. Data collected from these sensors will be collated into the management software database to be held centrally and monitored by University staff.

Passive Infra-Red (PIR) is the best application to work in conjunction with the motion detectors, they are exceptionally cost effective and simple to install with the ability to join an existing wireless network. Firstly, PIR motion sensors do not call for any signal after sensing an object entering its field of vision. Secondly, PIR motion sensors can operate in darkened areas or areas of low luminance, as they identify a change in the ambient temperature. Handling data from a PIR sensor is much easier than other forms of detection, therefore, scaling lighting systems based on PIR sensors does not cost much and will not necessitate huge computational power [15].

After an extensive review of the marketplace, I have taken the option of the following Motion Detectors and PIR sensors;

- Connect Sense: Light Sensor (figure 3) [16]
- Connect Sense: Motion Sensor (figure 4)

The sensors use wireless technology to access the Internet and have the ability to set up rules and be monitored via a PC.

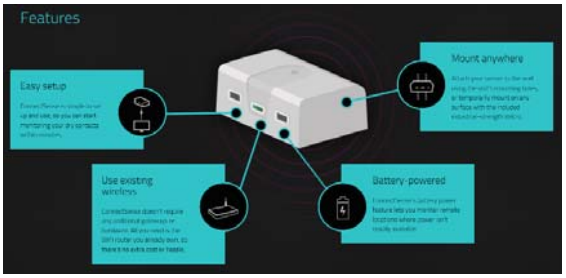

Figure 3 – Light Sensor Features [16]

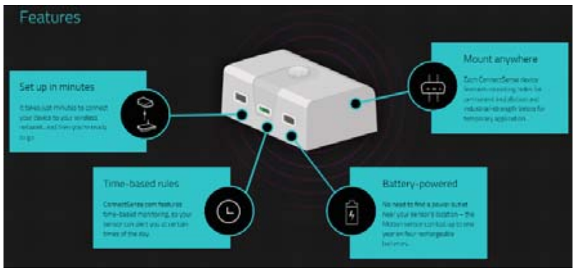

Figure 4 – Motion Sensor Features [16]

One of the additional concepts being looked into is the how the temperature and humidity can be controlled using blinds and automated windows. This section will identify some of the more commonly utilised products and solutions available in the marketplace.

After looking at many different solutions, one of the market leading companies Somfy provides a solution that will also work in conjunction with the temperature and humidity. Animeo IP provides automated control for the blinds via a weather station which is situated on the roof of the smart university this product has the ability to offer a wireless solution along with the flexibility to link with a building management system [17].

The mechanisation of the windows will require actuators to be placed on all opening vents. All vents/windows will be connected via a sensor network to gauge the room temperature, to ensure that the weather is accurate and that a vent will not open fully during rain showers, it will be networked to the Amineo IP's weather system as previously discussed in the blinds section.

The sensor network will use Digi Xbee Sensors as these are simple to install and connect to an existing network infrastructure [18]. Along with network, there will be further research into how the operation of the actuators will be operated, so programming or algorithm will need to be created to ensure that the vents operate at the correct temperature and humidity.

The largest concern when looking at the air conditioning systems is that people like to have rooms at different temperatures so to combat this solution looking at the Pelican wireless systems the 24-zone wireless zone controller appeared to be the best product available to combat this issue.

What is offered by using the Pelican Wireless System?

- *Internet Programmable*
- *Wireless Communication*
- *Simple Installation*
- *User-Friendly Interface*
- *Real-time monitoring and Analytical papering*
- *Energy Savings* [19]

The Z24 is a rooftop controller with the capability to link with up to 24 zones over Pelicans pioneering wireless network. It features the capacity to control up to six stages of heat and six stages of cool. For energy management, the Z24 is able to control the units based on outside air temperature. It also delivers data that can be used to maintain a comfortable environment. In bringing all of the concepts together, it should be noted that the smart university would need building management Software to retain data and control the necessary sensors across the campus and classrooms. A number of solutions have been reviewed from Johnson Controls [20], Trend [21] and Schneider Electric Global [22].

III. Blueprint Architecture Diagrams

This section focuses on the concept in diagram form and demonstrates the network structure being proposed for the wireless access points to each lab and some of the servers required (see figure 5 below).

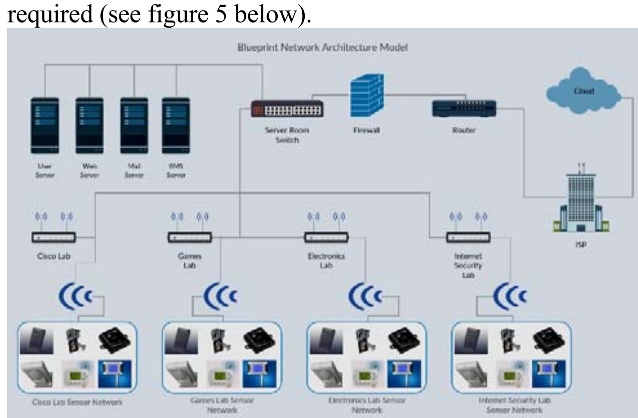

Figure 5 – Blueprint Network Architecture Model

Figure 5 is a conceptual blueprint diagram showing the servers, router, firewall, ISP, Internet and the wireless network access points, these following sensors are connected to it; Light, Humidity, Motion, RFID, Face Detection, Window, and Blinds. The servers will provide the necessary data storage for the sensors connected along the network, they will also provide the IT department to allocate end users with the access they require based on the privilege.

IV. Results and Discussion

The software used to test and simulate the wireless network as designed in the blueprint diagrams is Qualnet, supplied by Scalable Network Technologies, QualNet® is a design, testing, and training tool that "simulates" the performance of a real network. QualNet allows the user to create a wide-ranging environment for planning protocols, generating and animating network scenarios, this software also allows a complete analysis of the network performance [23]. A testbed was set up with the following protocols;

- Only routers could forward packets
- Use IEEE 802.11 as the MAC protocol
- Use IEEE 802.11 as the PHY protocol
- Assume IPv4 as the network protocol
- Use AODV as the routing protocol

Two connections were set up and configured in each lab to represent UDP client and TCP client; both of these configurations were to send a minimum of 500 packets. The following graphs show the results and explain the application, transport and MAC layers.

A. UDP and TCP simulation results

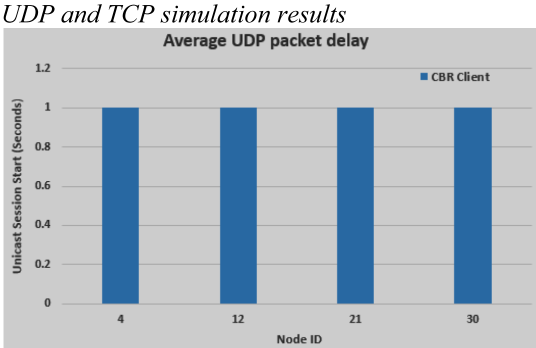

Figure 6 – Unicast Session Start (Seconds)

Looking at the results from figure 6, it shows that all the nodes associated with the UDP client will start up efficiently within one second of having any traffic. This is vital in a wireless sensor network due to the changes in conditions as defined in the management software.

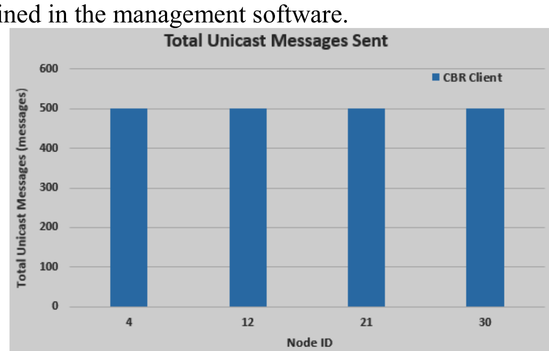

Figure 7 – Total Messages Sent (Messages)

Results from figure 7, identify that 500 packets of data requiring transmission have actually been sent. Each of the destination labs receive data without any loss. Meaning that, all of the nodes are correctly placed ensuring that there will be no one node taking valuable network resources.

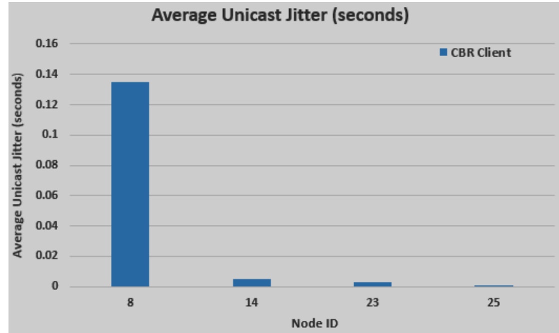

Figure 8 – Average Unicast Jitter (seconds)

An important factor in a network is jitter; this test is identify in figure 8. How much of a delay will there be prior to receiving a packet of data. Clearly, on nodes 14, 23 and 25 the delay is almost non-existent, however looking closely at node 8 having the delay of almost 0.135 seconds could cause substantial downtime or potential poor operation of the equipment or sensor. A possible solution to this could be to ensure that the traffic is prioritised across the network.

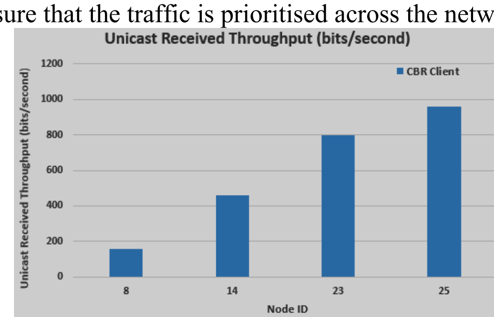

Figure 9 – Unicast Received Throughput (bits/sec)

When reviewing the results from the received throughput it is important to identify that this will highlight the performance of the proposed network and as to how long it would take to receive data sent across the network. In figure 9, node, 25 has the highest bits per sec rate and is capable of handling large amounts of data, however, node 8 will take a substantial time to receive large data traffic. It would be important to look into the placement within the network of these two nodes and possibly look at maybe splitting the channels that these nodes operate on to create a faster network.

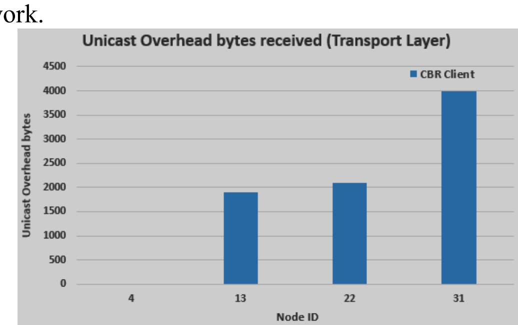

Figure 10 – Overhead Packets received at Transport Layer

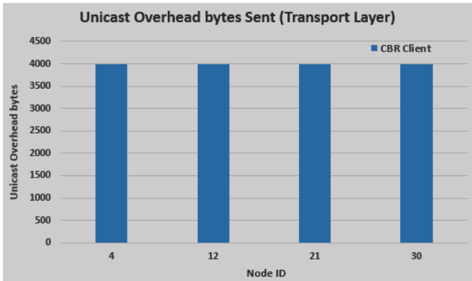

Figure 11 – Overhead Packets sent from Transport Layer

Results from figure 11 identify that nodes 4, 12, 21 and 30 send 4000 bytes of data. However, when this is compared to figure 10 nodes 13, 22 and 31 these are the only nodes, which receive the sent data.

- Node 4 sent 4000 – no data received
- Node 13 received less than 50%
- Node 21 received just over 50%
- Node 31 received 100%

Looking at the results, the most efficient node is 4, and the least efficient node is 31 during the testing simulation. Node 31 could suffer from packet loss, delay, and collision of data.

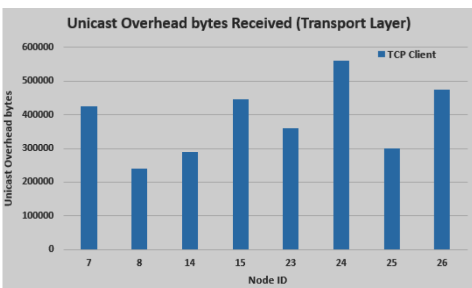

Figure 12 – Overhead Packets received at Transport Layer

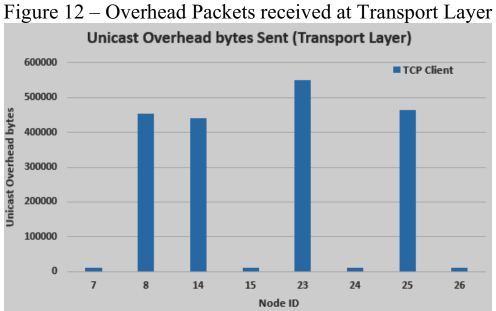

Figure 13 – Overhead Packets sent from Transport Layer

The results from figure 13 show that only four nodes are sending large amounts of data across the network. Potentially this could result in some loss, delay and queueing. In figure 12, it shows that the corresponding nodes in each lab receive high data; again, this could demonstrate on the simulation that there has been queuing and delays across the network.

B. MAC Layer simulation results

In this section it will concentrate on the following results from; Clear-To-Send (CTS), Request-To-Send (RTS) and ACKnowledge (ACK) packets

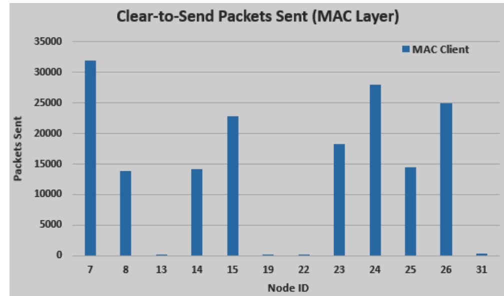

Figure 14 – CTS Packets Sent on Network

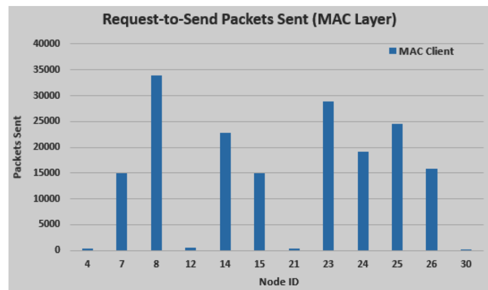

Figure 15 – RTS Packets Sent on Network

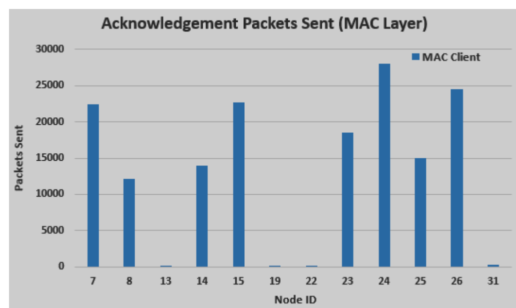

Figure 16 – ACK Packets Sent on Network

When examining the results from figures 14, 15, and 16 the MAC Layer the CTS, RTS, and ACK are all vital. However, like the overhead packets these could have a fundamental impact on the performance of the network. This will require further investigations to ensure that continuity can be achieved across the network.

C. UDP simulation utilizing Fade and Non Fade models

In this testbed multiple UDP connections were made across the sub-network and configure using the following guidelines;

- The time interval between packet generations is exponential
- The packet lengths are also exponential
- The average value of the packet lengths constant during the simulation
- Each connection should generate at least 500 packets
- One simulation “No Fade Model”
- Second simulation “With Fade” set to Rayleigh

The results have been analysed and compared to ensure that the testbed has performed as expected against the configurations above.

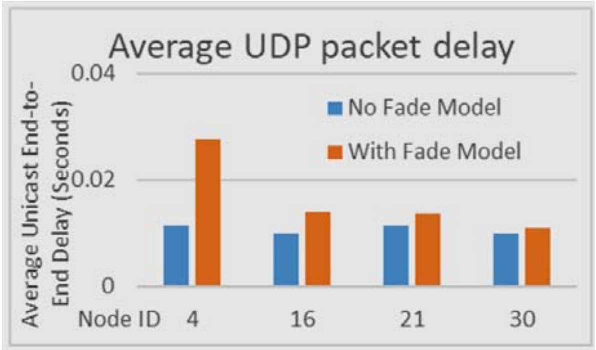

Figure 17 – Average UDP Packet Delay (Unicast End-to-End)

The results from this graph show that node 4 has a significant delay when you introduce the Fade Model as this simulates real-world environments from geographical, weather and building structures etc. this clearly shows that node 4 will require careful location within the classroom and maybe even its own dedicated channel to ensure the QoS is achieved.

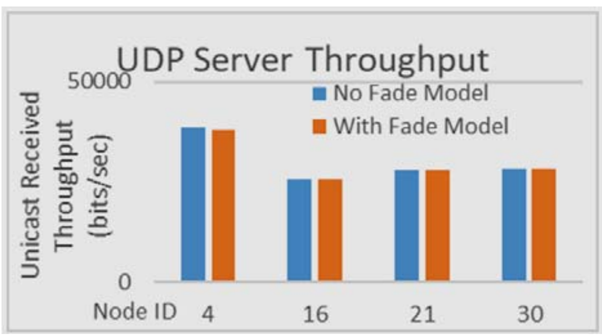

Figure 18 – UDP Server Throughput (Unicast Received)

Comparing the results from this simulation it has shown that there is little difference between no fade model and with fade, again node 4 appears to perform slightly better, this is in part due to its location within the network. To improve the testbed for future modeling larger amounts of data and more traffic would be required thus simulating a more conclusive real-world scenario.

V. Conclusion and Future Development

In conclusion, this paper has demonstrated that the wireless network for a smart university is very achievable; however, one of the identifying factors during the research is that for all of the sensors to operate as one, there will be a need to further discussion into building management software. This will need to be bespoke in nature to allow continuity in protocols, algorithms and network connectivity. In addition to the research, it has highlighted that the location of the sensor is vital to the success and connectivity of the network. The data integrity can be improved by understanding how the delay is interpreted within the results. This software whilst being accurate to an extent cannot allow for user error and also potential manufacturing tolerances and initial setup concerns. Smart universities will fast become a reality the introduction of the "Internet of Things" will enable far more automation that has been discussed in this paper. Further research into what the IoT could offer to the university will be vital to ensure that it is being used to its maximum potential.

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