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# UAV Bluetooth Communication Link Assessment for Emergency Response Applications

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***Abstract:*** **Over the last number of years Unmanned Aerial Vehicles (UAVs) have become increasingly popular in several fields such as agriculture and medicine. Recently UAVs have been used for the deployment within Emergency Response for visual scouting of an impacted area in addition to delivering supplies via payload. UAVs are also capable of acting as networking nodes using incorporated technology or by attaching independent hardware via the UAVs payload capability. The application of UAVs as a network node(s) can enable increased performance within the network as UAV based nodes can alter their current position due to their unique nature of mobility. Therefore, this study aims to assess the performance of aerial communication using UVAs which incorporate the use of a small Bluetooth 5.0 (BLE 5.0) node as a payload. In this research, the impact generated via Air-Ground Propagation on the Received Signal Strength Indicator (RSSI) measurement was investigated. In addition to this, this paper also investigates any performance difference displayed between different Transmission Power Profiles as this in turn affects the overall power consumption of the transmitting device. When operating at heights of 5, 10, and 15 Metres the maximum average loss was found to be 2.37 dBm among the Standard Transmission Power profile and a maximum average loss of 1.18 dBm occurring with the Enhanced Transmission Power Profile.**

***Keywords* — Air-Ground Propagation, Bluetooth 5.0, Emergency Response, RSSI, UAV**

## 1. INTRODUCTION

Natural disasters can strike at any moment, often resulting in widespread damage and disruption to communities. These events can present themselves in various forms i.e., Earthquakes, tsunami, Hurricanes, Tornadoes and Wildfires, to name a few. Some events can be predicated via Environmental Data sources such as Seismic activity, Weather Pressure etc. enabling protective measures to be taken to reduce the damage and risk to life. However, a path of death and destruction wherever/whenever is difficult to avoid completely. This damage can result in Million's worth of damage and the loss of countless lives much like Hurricane Katrina which struck the United States in 2005 destroying more than 200,000 homes, property damages upwards of $100 billion and resulting in nearly 2,000 deaths [1]. While preparations such as evacuation plans or disaster proofing buildings can reduce the overall impact inflicted, it cannot always be prevented. Additionally, while most of the damage inflicted occurs at the time of the disaster, the first 72 hours after are crucial [2] and how the response is handled is critical in reducing the number of fatalities.

Emergency responders are often the first line of defence in such situations and require reliable communication systems to coordinate their efforts and provide real-time data to aid with decision making. Therefore, real-time monitoring applications can be utilised during the response effort for accessing the current state of health of both the responders and possibly anyone present during the disaster via biometric sensors. This in turn, can not only identify individuals in need of medical care, but also priorities them in relation to their injuries/afflictions. Additionally, this data can also be used for tracking the users state of health over-time as health complications can develop over the course of the disaster event.

These complications are often a result of changes to the surrounding environment in relation to the event type. During natural disasters which involve fire, this can result in an increase in the temperature of the surrounding air. This increase can have a direct impact on the users' core and skin temperature. This becomes a primary concern as this can result in the user experiencing First-Third degree burns when in proximity of any fire source. Furthermore, long duration of increased core temperature can result in dehydration occurring. This has the potential to result in the user experiencing Seizures due to low levels of Electrolytes such as potassium and sodium present in the body [3]. This is because Electrolytes help carry electrical signals from cell to cell. When the body's natural levels of Electrolytes are depleted this can result in the electrical messages between nerves to become mixed up, thus resulting in involuntary muscle contractions. along with the possibility of a loss of consciousness occurring [3].

Oxygen monitoring is another vital sign which requires close monitoring especially in the presence of fire and airborne debris. If the user does not have access to sufficient oxygen supply it can result in oxygen deprivation occurring which in turn can result in difficulty breathing, reduced reaction time and loss of consciousness [4]. In addition to environmental factors such as temperature and the gaseous make-up of the surrounding air, natural disasters can also result in physical damage to the user occurring due to falling debris. This often occurs because of damage inflicted to the structural integrity of surrounding man-made or natural structures such as Buildings and Trees. The impact caused by falling debris can result in blood loss occurring in the event of an open wound developing upon physical contact or result in poor blood circulation in the event the user becomes pinned by the debris.

Furthermore, natural disasters are often stressful environments which in turn can result in the body producing increased adrenaline. This in turn can result in Tachycardia and increased Blood Pressure, which could result in complications such as the formation of Blood Clots which could result in stroke or heart attack. Additionally, the chance of Heart failure increases due to the added strained resulted by the increased beats per second produced by the heart [5].

While firefighters and other emergency response staff are often trained to cope with the additional stress associated with these scenarios, prolonged exposure over service time increases the chance of health problems developing. It was found in [6] that approximately 45% of on-duty fatalities each year for firefighters located in the United States were found to be related to a Cardiovascular event. The impact of these scenarios was investigated in [6] which showed that "Exposure to extreme heat and physical exertion during fire suppression activates platelets, increases thrombus formation, impairs vascular function, and promotes myocardial ischemia and injury in healthy firefighters".

Aside from Physical damage from debris, structural damage can also result in damaged gas lines and exposed electrical wires which could result in further harm occurring to both trapped survivors and Emergency Response workers entering the area.

Therefore, in scenarios containing any of these various dangerous factors, it is possible to identify these dangers beforehand by scouting the area via Unmanned Aerial Vehicles (UAV) equiped with sensor and camera payloads for remote surveying and environmental assessment. The implementation of UAVs for Emergency Response applications is explored in the following section.

## 2. IoT Drone Deployment for Emergency Response

UAVs, also known as drones, are promising adaptive technology which can provide elegant solutions for a wide variety of fields with applications such as Aerial Photography [7], Payload delivery systems for commercial and Industrial applications [8] etc.

More recently UAVs equipped with a camera have been deployed for Emergency response applications. This has become beneficial for Emergency Responders as it enables them to obtain a visual assessment of the current situation. Furthermore, UAV's enable a wider scope of the area by achieving a bird's eye view. This in turn enables additional information for Emergency Responders related to the impact of nearby areas which enables for improved planning and execution when deciding how to respond. The functionality of integrated cameras can also have an impacted on the intended application. While high-definition cameras can provide Emergency Responders with a visual representation of the overall damage inflicted, alternative devices can be implemented into the UAVs design such as Thermal Cameras. The implementation of Thermal Cameras enables detection of different heat patterns across the surrounding area. This in turn, can not only determine the intensity of the heat sources and identify areas which are unsafe to enter but is also capable of detecting survivors via their heat signatures for Search and Rescue operation [9].

Recently, UAVs have been used in combination with the Internet of Things (IoT) for enhanced remote data collection applications. This is achieved either by having the UAV function as a node within the system via incorporated hardware or through deployment with an external independent system attached via payload [10]. This incorporation becomes vastly beneficial as the added mobility of the UAV enables the collection of data within regions that would otherwise prove difficult to reach. This in turn enables the deployment of a mobile base station/ bridging node for increased data coverage and establishment of temporary networks in the event of cellular and Wi-Fi-based network failures. The concept of deploying UAV based node/base stations has been previously explored by [11] as an Internet of Drones (IoD) cellular network topology. A similar concept to this was proven by Nokia who developed an ultra-miniaturized 4G base station which was successfully mounted onto a commercial quadcopter as a means of providing cellular coverage across a remote area in Scotland [11].

For Emergency Response deployment, IoD applications can enable several opportunities such as location scouting, remote monitoring of environmental data i.e., Gaseous, Particulate Matter and/or Temperature. In addition to data collection applications, UAV based nodes are also capable of operating as communication links. These links can enable increased signal coverage via Mesh Network topology by increase the number of data collection points available [12]. Furthermore, unlike conventional Node, UAVs have the unique advantage of mobility, this enabling them to maximise the systems overall performance. This can be achieved by altering the location of the UAV node with neighbouring devices. By altering their respective horizontal position, the UAV can enhance the overall connection strength between neighbouring nodes/user end devices within the vicinity. This becomes beneficial for scenarios when squad members are required to spread out from their current group when conducting search and rescue operations enabling reliable communication within their mesh network while spread out.

Additionally, UAVs are also capable of adjusting their Vertical positioning by increasing/decreasing their current altitude. This in turn enables UAVs to establish connection between users located at different elevations i.e., users located on different building floor or along steep hills/cliffs.

To ensure the best signal strength is achieved at any given time, specialised algorithms can be implemented which enables the UAV to alter both its current vertical and horizontal position as a means of repositioning itself in the most optimum communication location [13]. His is achieved either by establishing a new Line-of-Sight (LoS) or alternatively establishing a more optimum No-Line of Sight (NLoS) which itself obtains signal coverage via strong reflections and/or diffractions whenever a clear path is unavailable between the UAV node and neighbouring devices. This application can become imperative for Emergency Response situations as the surrounding area is always subject to change thus altering the performance of current configurations.

While mobility and height are important factors in relation to the overall performance efficiency of the communication system, the overall UAV flight time is another crucial factor to consider when deployed as it evaluated the devices practicality/suitability for its intended purpose. Primarily flight time is based on the power consumption of the UAV regarding the power source(s) capacity. However, when carrying a payload, flight time reduces as more thrust is required to lift the UAV thus resulting in higher energy consumption by the rotor motors [14]. Furthermore, flight conditions can also impact flight time, Temperature and Wind speed being the most influential.

External temperature can have an impact on the overall performance of the battery source. This is due to the chemical reaction which occurs for batteries to produce their power. During cold conditions, this results in a slower reaction rate, thus decreasing the time in which the battery reaches the threshold in which the demanded power is greater than the power produced during battery discharge [15]. Strong winds, however, can often result in the UAV to fly off course. This in turn, results in increased power consumption from the motors as a means of counteracting this force as a means of re-establishing and maintain airborne position and maintaining stability [16].

Therefore, maximising the overall flight time of the UAV node is a primary concern especially when intended for Emergency Response deployment. While Power efficiency can be achieved through the devices design i.e., implementing brushless motors, increased battery capacity etc. reduction of weight is the most optimum. This is because a reduction of weight reduces the amount of thrust required. This in turn also increased the devices mobility in both speed and agility. This, however, creates a confliction of power capacity. This is primarily because while providing a bigger power source would theoretically provide an increase in flight time, the increased weight of the battery resource results in higher power consumption. However, a limit will eventually be reached in which increased battery capacity will either have a marginal difference or negative impact on flight time.

Therefore, the overall all power consumption of the device needs to be low to maximise flight time. This is an important factor to consider when determining the wireless communication method and its implementation into the design of the drone. This can be achieved either by utilising the devices own communication capabilities or by attaching a communication node as a payload.

Therefore, for this study Bluetooth Low Energy (BLE) 5.0 was chosen as it provides sufficient transmission speed, coverage, data capacity, and material penetration resistance for this application. Additionally, BLE offers a low power consumption rate which would present a minimal impact on the UAVs flight time if attached as an independent payload. The following section expands on these benefits regarding BLE for Emergency Response purposes.

## 3. Bluetooth 5.0 Communication Link

Bluetooth Low Energy (BLE) has become an increasingly more popular method for achieving wireless communication between devices. This is primarily due to low power consumption which enables long-term applications, as these devices can remain operational over a series of days, weeks, months, or years depending on the power source capacity [17]. The overall power efficiency of BLE 5.0 enables double of that of BLE 4.0 [18]. As a result of this improvement, BLE 5.0 devices can operate for twice the amount of time compared to BLE 4.0 devices. This feature becomes particularly beneficial for UAV-based nodes as it minimizes the impact on flight time cause by lower power consumption, thereby maximizing the device’s operational lifespan before requiring battery charging/replacement. BLE 5.0 also offers various new improvements over previous iterations due to the new protocols associated with BLE 5.0 in terms of communication range, data capacity and reduced latency.

The latest Protocol has increased the overall range of BLE to enable full home/building coverage offering short-range communication of around 200 metres [19]. However, this range does depend on the transmission/reception power profile in addition to the chipset used. For instance, Nordic's nRF52832 and nRF52840 chipsets are both designed for BLE 5.0 communication. However, the nRF52832 chipset is primarily designed for short-range communication applications offering a maximum Transmission power of +4 dBm [20]. Whereas the nRF52840 chipset is designed for long-range applications enabling a maximum communication range of 1.3km with a maximum transmission power of +8 dBm [21]. This in turn increases the available Point-to-Point (P2P) range which can become beneficial for emergency response situations especially when a large area is required to be covered which may require responders to spread out. The distance between users can then be further increased bridging the connection between team members within the communication range via Mesh Networking.

Mesh Networking enables the devices within the network to interact with one another without the requirement of any dedicated access points or wired connections to be established as opposed to Wi-Fi-based systems. This is achieved via an ad-hoc topology connection comprised of 4 states of which are Master, Slave, Standby and Parked. The Master state manages the transmission of Data while the Slave manages data reception. When connecting devices to the network a device can have the state of standby were it waits to join the Piconet at a later point while retaining its MAC address. Otherwise, the device can operate with the Parked state in which the derive waits to adhere to the Piconet later and releases its MAC address. By utilising these states, it allows the network to expand its overall range and transmission data capacity, while leveraging neighbouring networks as illustrated in Fig. 1 below which depicts two Piconets establishing a Mesh Network.

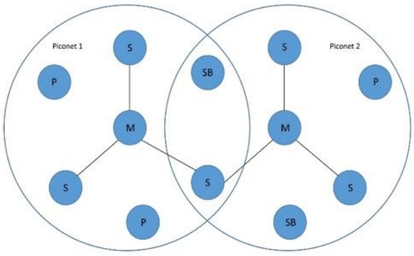


**Fig.1** Bluetooth Ad-hoc Piconet Topology illustration

Mesh networking increases coverage and data capacity by adding collection points. Nodes with Master and Slave states can establish a Many-to-Many topology and create a bridging node that collects, transmits, and relays data from neighbouring devices. The self-healing characteristics is achieved by re-routing signals and providing an alternative transmission route in case of node dysfunction or signal degradation due to attenuation factors. This ensues the most optimal route with minimal interference, achieve by re-routing signals via alternative neighbouring nodes to avoid factors such as debris.

BLE 5.0 enables packet transmission sizes of 255 octets, 8 times larger than BLE 4.0, and transfer speeds of 2 Mbps [22] with reduced latency to <3ms [23]. These improvements enable a more accurate real-time monitoring system with increased data collection and transmission of sensor readings, thus providing detailed evaluation of the user/environment for higher assessment and evaluation in small/large-scale operations.

In addition to these benefits, it's also possible to ascertain an estimated distance between nodes via Received Signal Strength Indicator (RSSI) location tracking algorithms [24]. Therefore, these measurements can be used for search and rescue missions and tracking of emergency responders who possess a BLE device. This feature can be further enhanced with UAV node by forming a grid system, establishing a frame of reference, and predicting user routes to aid in reducing response time. This study aims to investigate the effects on Air-to-Ground propagation when using Bluetooth based UAV Nodes. The following section explores the experimental setup used to collect the results presented in this paper.

## 4. Experimental Setup

The experimental test setup consisted of using two BLE 5.0 nodes. Node A operate as a Peripheral Device which was attached as a payload to a UAV. This node operated as a transmitter, sending a message which would then be received by a Central Device Node B. Upon receipt Node B would calculate the corresponding RSSI of the signal transmission as a means of evaluating the signal performance between the two devices.

The BLE devices used for this experiment featured the Nordic nRF52832 which communicates with a 2.4 GHz radio in a manner which offers up to +4dBm output power operating with an ARM Cortex M4F CPU running at 64MHz [25]. This enables the testing scenarios to be conducted with the Standard Transmission Power profile of 0dBm and Enhanced Transmission Power profile of +4dBm to assess any performance difference between these two power profiles.

The UAV used during the experiment was the DJI Phantom 4 which offers a small lightweight platform with several added features which would be best suited for real-world deployment when flown at low altitudes among users within the vicinity. The first feature is the object avoidance software and anti-collision sensors which reduces the UAV colliding/crash landing into objects. This is achieved via the gimbal and object detection software in addition to avoidance sensors located at the front and bottom of the UAV. In addition to these, the UAV also enables for high accuracy altitude tracking with a tolerance of +/- 0.5 metres.

The UAV also features manual control via remote control in addition to a TapFly mode. TapFly enables the user to highlight a person or object within view and the UAV will then engage an autopilot function to remain within the proximity of the user. In addition to this, the UAV also has a return to landing function either on command or when the battery levels reach a specific threshold (depending on the distance from home base). This enables the UAV to stay within the launch vicinity while also reducing the chance of getting lost. Furthermore, this UAV offers a 28-minute flight time per charge with approximate charge time of 1 hour 10 minutes' enabling prolonged use throughout the day [26].

Throughout the experiment, node A was attached to the UAV and set to various heights to assess any performance impact on the signal quality regarding height. This was done as the UAV would need to alter its current altitude when deployed in a real-world scenario. Three heights were used 5, 10 and 15 meters, while in turn ensuring the relative transmission distance between both devices remained a total distance of 15.24 meters. This was done to remove any potential impact generated via free space loss. This, therefore, enabled a more accurate evaluation into the impact generated by height in relation to Air-to-Ground propagation. Additionally, this also enabled insight into insight into the impact generated by elevation angle as this would change in relation to height.

Due to the average height for men being 5 ft. 7.5 inches and women being 5 ft. 3 inches [27] a deployment height of 4 ft. was chosen as a means of mimicking a user's average chest height. This was done to simulate real deployment as the users' wearable devices would ideally be placed here as a means of obtaining the user's bio sign data such as cardiac and respiratory data via electrocardiogram (ECG) sensors.

In addition to height and elevation angle, the experiment consisted of two different Transmission Power profiles for Node A. The first profile was set to a Standard Transmission Power of 0dBm to establish a baseline RSSI for each elevation. The second profile consisted of an Enhanced Transmission Power of +4dBm. This enhances both the communication range and robustness of the transmitted signal as it has more power to expend. However, this in turn can have an impact on both power consumption and RSSI measurements. This becomes a primary concern as it means the operation time of the devices is reduced, but it can also impact the performance of RSSI based algorithms. Therefore, by implementing two different power profiles for each height configuration it enables the possibility to investigate any performance differences regarding RSSI which may occur between these two power profiles.

For each scenario, 100 data points were collected for each Height and Power profile as a means of achieving a more accurate average RSSI reading under each condition. This was done as the RSSI measurement is likely to fluctuate due to small changes to the surrounding environment and therefore wouldn't provide a constant reading at any given time. This was done as the RSSI measurement is likely to fluctuate due to small changes to the surrounding environment and therefore wouldn't provide a constant reading at any given time. These changes to the surrounding environment can be related to various factors such as the levels of Particular Matter i.e., pollen/dust, Temperature, Wind Speed. or Humid etc. Therefore, by establishing an average value across multiple data points it becomes possible to ascertain more realistic approximation of the overall RSSI of the signal.

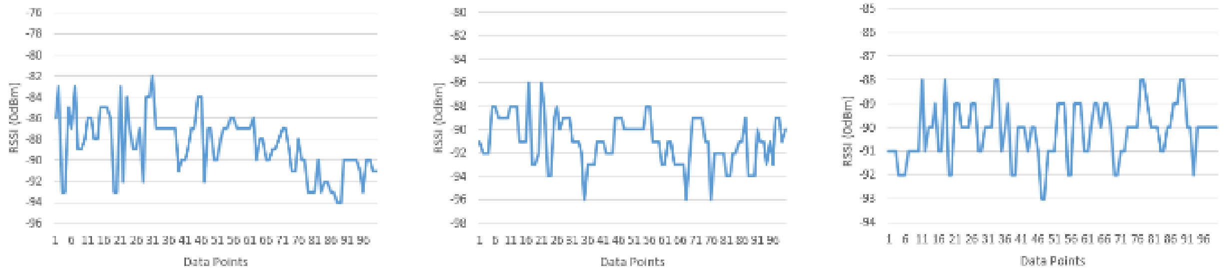
This experiment itself was conducted in a large open space area free of environmental attenuation factors such as material penetration loss, reflections/scattering etc. This was done as a means of reducing any potential environment attenuation factors by providing a clear LoS. This in turn provides a clear indication of the impact generated by isolating the effects that Air-to-Ground signal propagation and Transmission power profile have on the communication performance of the transmitted

## 5. Experimental Findings

### 5.1 Experimental Results

Throughout this experiment, it was shown that there was a relatively small impact on performance between the varying heights as shown in Fig. 4 for Standard Transmission power profile and Fig. 5 for the Enhanced Power profile.

For the Standard Transmission Power profile, the best result was shown to be collected at the height of 5 metres with an average RSSI of -88.57 dBm being achieved. At the height of 10 Metres, the performance of signal was shown to result in an RSSI reading of -90.94 dBm resulting in an increased loss of 2.37 dBm. Additionally, once the UAV reached the height of 15 Metres it can be seen that the average RSSI recorded was shown to be -90.19 dBm. This illustrates a difference of 0.75 dBm when compared to that of the 10-metre height resulting in improved performance. However, when compared to the 5-metre height a performance loss of 1.62 dBm occurred.



Standard Transmission Power at Height 5 Meters

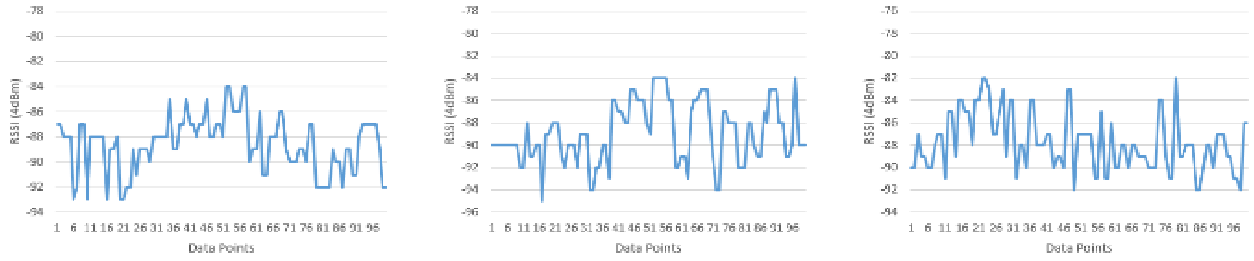
Standard Transmission Power at Height 10 Meters

Standard Transmission Power at Height 15 Meters

Fig.4 RSSI Performance with Standard Transmission Power profile

When using the Enhanced Transmission Power profile of +4dBm it can be seen that when operating a height of 15 metres the signal performed best resulting with an average RSSI reading of -87.73 dBm. When operating at the height of 10 metres, this produced an average RSSI of -88.91 dBm. This resulted in a reduction of 1.18 dBm

When operating at the height of 5 metres, this produced an average RSSI of 88.61 dBm. This resulted in a performance loss of 0.88 dBm when compared to the 5-metre height configuration. Additionally, when compared with the 10-metre configuration to the 5-metre configuration this resulted in an average loss of 0.3 dBm occurring.



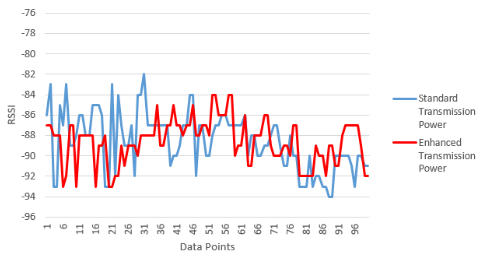
Enhanced Transmission Power at Height 5 Meters

Enhanced Transmission Power at Height 10 Meters

Enhanced Transmission Power at Height 15 Meters

Fig.5 RSSI Performance with Enhanced Transmission Power profile

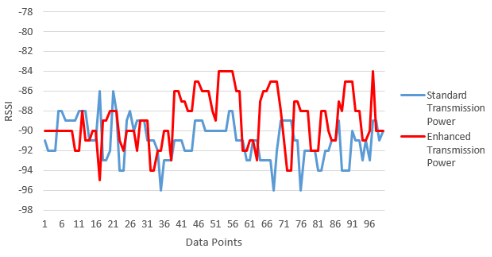
When comparing the two power profiles for each UAV height it can be seen in Fig. 6 that the Standard Transmission Power profile provided an increased performance over that of the Enhanced Transmission Power profile resulting in an average difference of 0.04 dBm when operating at a height of 5 Metres as seen in Fig. 6.



Transmission Height 5 Metres

Fig. 6 Standard Vs Enhanced Transmission Power profile at Height of 5 Metres

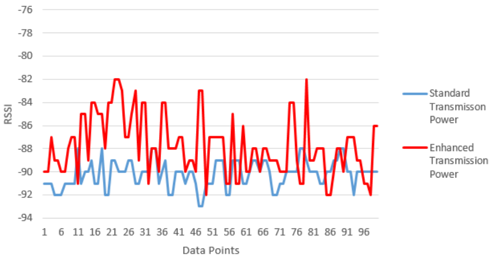
However, when operating with the Enhanced Transmission Power profile at the height of 10 Metres it can be seen in Fig. 7 that the Enhanced Transmission Power profile performs better resulting in an average improvement of 2.75 dBm over that of the Standard Transmission Power profile.



Transmission Height 10 Metres

Fig. 7 Standard Vs Enhanced Transmission Power profile at Height of 10 Metres

Similarly, when comparing the operational performance at the height of 15 Metres it can also be seen that the system's performance operated best when using the Enhanced Power profile as seen in Fig. 8. This resulted in an average RSSI improvement of 2.46 dBm over that of the Standard Transmission Power profile.



Transmission Height 15 Metres

Fig. 8 Standard Vs Enhanced Transmission Power profile at Height of 15 Metres

5.2 Discussion of Results

Overall, throughout this experiment, it can be seen that the performance difference which occurs when transmitting at different heights was shown to have a minimal impact on the performance of the system. However, despite this, the performance at 5 metres was shown to be the best when using the Standard Transmission Power profile. This is most likely due to this test scenario having the small elevation angle which in turn resulted in a clearer LoS between both the Transmitting Node and the Receiver Node antennas.

When operating with the Enhanced Transmission Power profile the systems was shown to perform best at the operational height of 15 metres. The reasoning for this is most likely due to the increased robust nature of the increased signal power provided by the Enhanced Power Transmission profile which in turn allowed for compensation with the decreased performance caused by the increased elevation angle between the Transmitting and Receiving Nodes. The reason in which this height performed a better average RSSI than that of the 5-metre height is most likely due to the increased robustness of the transmitted signal against free-space loss.

When comparing the difference between the three Enhanced Transmission Power profile it can be observed that when operating at a higher height of 15 metres an improved average RSSI was obtained when compared to that of the 5-metre height. This is primarily because as the UAV comes closer to the ground, the number of reflected signals received increases. While this wasn't seen in the Standard Transmission Power profile is primarily due to the increased robustness provided by the Enhanced Transmission Power profile. This in turn enabled the signal to have more energy to expel thus enabling any signals which would have previously been lost to be received. This in turn resulted in the more successful reading of lower quality signals which in turn reduced the average performance across the 100 data points collected. Furthermore, the 15 metre height also resulted in a higher elevation angle between the nodes which in turn resulted in reduced ground reflections obtained by Node B.

In terms of performance difference between the height configurations of 10 and 15 metres, it can be seen that the height of 15 metres performed best with both the Standard and Enhanced Transmission Power profile. Once again this is most likely due to the lower height of the 10-metre which would have provided more reflections when providing the signal with increased power as oppose to the 15 metre height scenario.

## 6. Conclusion and Future Works

Bluetooth 5.0 is an appropriate technology for remote health tracking UAV for emergency response applications. This point is further reinforced due to the improvements made through the latest iteration BLE 5.0 with introduces an increase in transmission range, speed, and data capacity while also producing a reduction in latency over previous BLE versions. In addition to this, Mesh Networks enable devices to achieve self-healing, as well as enabling communication without the dependency of a central access point being required. This becomes beneficial for emergency response of natural disasters in the event damage occurs to one or more nodes within the network.

This in turn results in a reduced impact in overall system performance, as opposed to total communication loss. Furthermore, BLE 5.0 supports backwards compatibility, enabling this technology to be integrated into existing systems for improved efficiency and performance. These enhancements can be further expanded via UAV based nodes.

UAV based nodes enable he system to alter the devices current positioning for achieving the most optimum signal between devices. Additionally, UAVs are also capable of establishing enhanced connection coverage and performance by establishing communication links across various altitudes. This becomes primarily beneficial for establishing full building coverage as it allows communication links across multiple floors to be achieved.

Throughout this testing, there was little performance impact on the RSSI measurement of the signal when operating at different height elevations, which resulted in a maximum average performance difference of 2.37 dBm when operating with the Standard Transmission Power profile. When operating with the Enhanced Transmission Power profile the maximum average performance difference was 1.18 dBm.

However, it should be noted that while there was a noticeable performance increase when using the Enhanced Transmission Power profile, this comes with the caveat of increased power consumption, thus reducing the operational time between charges/battery replacement as opposed to that of the Standard Transmission Power profile. Therefore, due to the small impact difference between these two power profiles the Enhanced Transmission Power profile should only be implemented when required to counter depletion factors which would otherwise make the communication unreliable or non-existent.

Future work, however, will involve assessing the impact on signal quality when the UAV is moving instead of holding its altitude position. This in turn will help identify any impact generated when the UAV is required to alter its position during deployment. Additionally, the assessment of the impact generated when conducting Indoor-to-Outdoor communication when using an outside UAV bridging node for communicating across different floor levels will also be investigated.

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