A Comparative Study of Wi-Fi and Bluetooth for Signal Strength-Based Localisation

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Abstract With the growing need for indoor localisation solutions, this paper investigates the practical applications of wireless networking technologies based on the empirical study. By comparing between the two most widely used wireless technologies, aims to identify which technology, between Wi-fi and Bluetooth, is more capable in RSS-based localisation. Field experiments were conducted in order to collect the data to model the propagation of the two technologies. This study demonstrates that, through comparing the derived models to empirical data, Bluetooth has the potential to improve indoor localisation methods due to its more accurate model.

1 Introduction

GPS is one of the best localisation techniques created to discover a position outdoors; however, GPS has major difficulties for indoor localisation. With extensive time being spent as research into indoor localisation, a significant increase in accuracy has been achieved. Nonetheless, one of the biggest hurdles in indoor localisation systems is the reliability and accuracy of deriving the distance from a signal between two nodes.

Local positions can be calculated through various methods that can be categorised into received signal strength (RSS), angle of arrival (AOA) and propagation

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of time. Time of arrival (TOA) uses the round-trip time (RTT) to calculate the distance of a transmitter from a receiver. This requires clocks with a very high degree of accuracy and precision as a difference of 1.0 μs results in a difference of 300 m [1]. Time difference of arrival (TDOA) is similar to TOA but calculates the difference between the arrival times of a transmitted signal. This requires only the synchronisation between the receivers. In an AOA approach, a receiver can calculate its position through measuring the direction of the incoming signals of transmitters with known position. This allows for the device to use triangulation but requires an antenna array [2].

These localisation techniques have been used with various devices including light detection and ranging (LiDAR), GPS, and radar. However, wireless technologies such as Wi-fi and Bluetooth are becoming more prevalent in everyday use, and increasing in numbers rapidly [3]. Unfortunately, these technologies are often unable to rely on the parameters required for the localisation methods stated above [4]. With the widespread adoption of wireless technologies, such as Wi-fi (IEEE 802.11) and Bluetooth (IEEE 802.15), these technologies provide a unique solution where the many available nodes may be utilised where traditional global positioning systems (GPSs) are unavailable or impractical. This paper extends the research by Sullivan et al. [5] to investigate the differences and similarities between Wi-fi and Bluetooth and their practical applications for localisation through RSS.

2 The Wireless Technologies for This Research

As both Wi-fi and Bluetooth are low cost and have been adopted by many household devices, this study will compare which of these two technologies is more effective for indoor localisation. Both technologies are standardised by the IEEE with Wi-fi under the 802.11 set of protocols and Bluetooth under the 802.15 set of protocols [6]. While the two operate within the 2.4 Ghz band, the differentiating factor between the two is the broadcasting power and the power consumption. WizFi210 and Mini Beacon were chosen as transmission nodes for this investigation.

2.1 WizFi210

At full transmission power, the Wi-fi shield transmits at +8 dBm. Due to the active nature of Wi-fi, it is expected that it would use more power than the Mini Beacon. Furthermore, increased output power will enable the Wi-fi connection to have improved signal quality for data transfer. The specifications are outlined below in Table 1.

Table 1 WizFi210 specifications [7]

Specifications	Description
Radio protocol	IEEE 802.11b/g/n
RF frequency	2.4 Ghz (2.497 Ghz)
Power consumption	Standby: 34.0 µA, Receive: 125.0 mA, Transmit: 135.0 mA
RF output power	8dBm ± 1dBm
Power source	3.3v
Dimensions (excluding antenna)	59 x 54 mm
Range indoors	20 m
Range outdoors	>20 m
Supported data rates	11, 5.5, 2, 1 Mbps

Table 2 Mini Beacon specifications [8]

Specifications	Description
Radio protocol	IEEE 802.15b/g/n
RF frequency	2.4 Ghz (2.400–2.483 Ghz)
Power consumption	50 µA
RF output power	0 dBm ± 1dBm
Power source	2.0–3.6 v
Dimensions (excluding antenna)	36 × 16 mm
Range outdoors	50–90 m

2.2 Mini Beacon

As opposed to Wi-fi, Bluetooth low-energy (BLE) beacons are designed to broadcast a transmission at regular intervals. This technology can be used for limited data transfer; however, for this research, this will be used for investigating signal propagation. This specific BLE beacon is unable to respond to ping requests and is only able to broadcast. The specifications for the Mini Beacon are outlined below in Table 2.

3 Path Loss Model

As a signal propagates through space, it experiences a loss in signal strength. Path loss (*PL*) is a measure of the average attenuation of this loss in signal strength. This is defined as in Eq. 1 [9].

$$PL(\mathrm{dB}) = 10\log\frac{P_t}{P_r} \tag{1}$$

where P_t and P_r are the transmitted power and received power, respectively. In free space, Pr can be expressed using the Friis free-space equation [10]:

$$P_r = (d)\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{2}$$

where G_t and G_r are the transmission gain and received gain by their respective antennas. L is the system losses that are not associated with the propagation such as losses at the antenna. An L value of 1 indicates that there are no losses by the system. λ is the wavelength of the carrier in metres.

As this model cannot account for a d (distance) value of 0, many propagation models use a reference point (d_0) for a close-in distance [11], usually at 1 m. The general path loss model uses γ to reflect the noise exponent of a signal propagation. This model is defined as in Eq. 3 and is used to model the propagation in this investigation.

$$PL(d) = PL(d_0) + 10\gamma\log\left(\frac{d}{d_0}\right) + X_\sigma \tag{3}$$

Free space is represented using a γ value of 2 where as a high noise environment could have a value of 4. X_σ denotes the random variable with a standard deviation of σ. This is used to model shadowing but will be given a value of 0 for this investigation.

4 Data Analysis

In order to ensure clean data, the experiment was set up with an Arduino unit with the WizFi210 module in order to have a Wi-fi node running with the least possible system noise. The Mini Beacon was deployed as is. These signals were read by a notebook computer with an Edimax USB 802.11n Wi-fi adapter and an Orico Bluetooth adapter. Both of these adapters were attached to 3 m USB 2.0 leads in order to minimise the noise generated by the notebook computer itself. The experiment itself was conducted outdoors on flat terrain with no obstructions to line of sight between the transmitter and receiver. This environment was chosen to minimise environmental noise as there were no other electronic devices or above ground cables. Readings for both devices were collected over 2 days in mid-October with no precipitation and a stable temperature of 24° Centigrade for both days. The receiver and transmitter modules were raised 1 m from ground level with the transmitter being placed 0.5 m away from the receiver and moved away by

0.5 m increments for each reading. To ensure that the two transmitting devices would not interfere with each other's signals, the WizFi210 and Mini Beacon were deployed and tested separately.

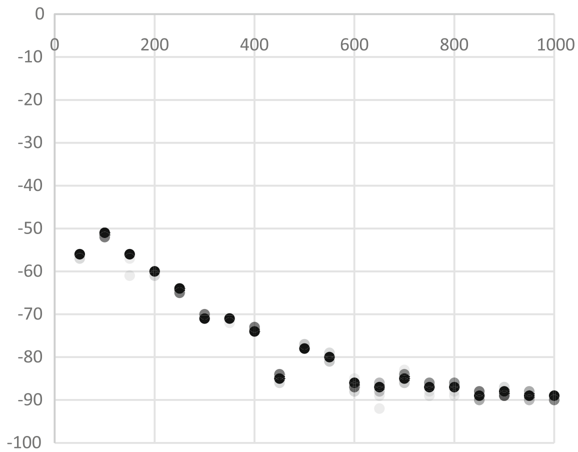
4.1 WizFi210 Analysis

Figure 1 plots all the readings from the Wi-fi device with the darker dots indicating more occurrences of a specific RSSI at a given distance. What should be noted is manner in which the Wi-fi readings loosely follow a logarithmic curve despite the small spread in data readings. This suggests that there is a consistent and significant amount of noise in the signal itself.

Using the median RSSI from each set of readings (i.e. every 50 cm), the γ value for each distance was calculated from the average noise exponent across all distances. This figure, calculated to 4.1854, confirms the previous hypothesis of high noise. The model in Fig. 2 can be derived from using the median noise exponent and the median RSSI at 1 m. Furthermore, the graph also illustrates the confidence interval (CI) for all the readings which indicates the reliability of the data produced. The narrow CI range indicates that the readings are closely clustered, as stated previously.

The high noise exponent is likely to be attributed to the system noise of the hardware itself.

Fig. 1 Wi-fi readings



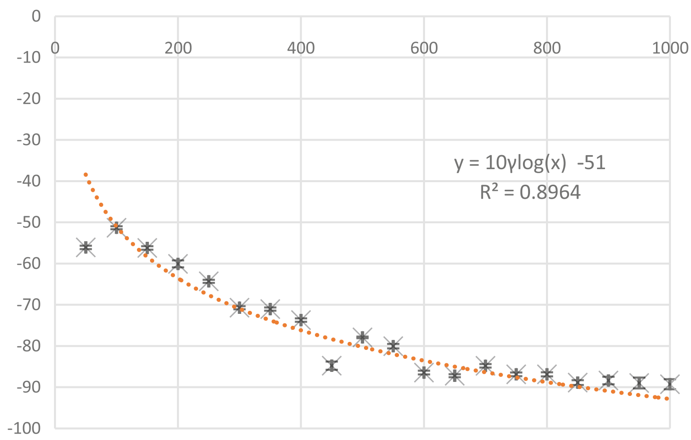


Fig. 2 Dispersion graph of Wi-fi

4.2 Mini Beacon Analysis

Figure 3 illustrates the data collected from the Bluetooth tests. While the data suggest a number of outliers, there is a relatively high concentration around a logarithmic trend.

With an average value of 2.56825, the test can be seen to have very little noise affecting its reading. Using this γ value, the relationship can be modelled as shown in Fig. 4.

Fig. 3 Bluetooth readings

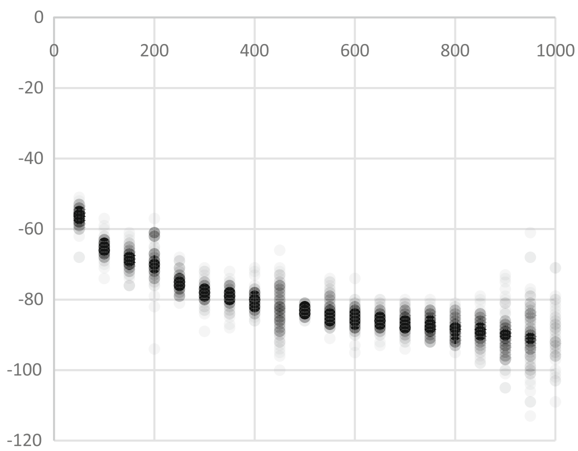
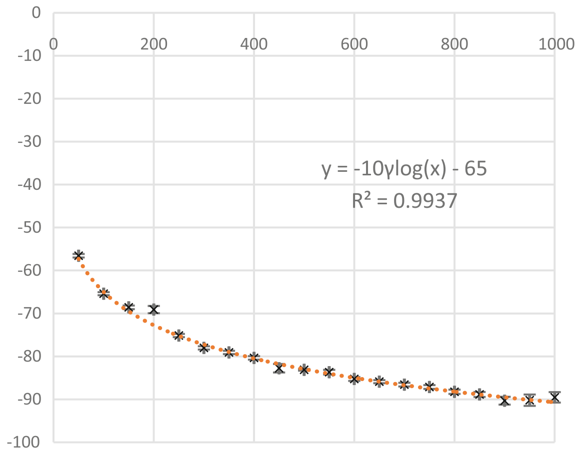


Fig. 4 Dispersion graph of Bluetooth



4.3 *Path Loss*

Both the Wi-fi and the Bluetooth devices follow the path loss model but with varying degrees of noise. It can be seen that from the median noise exponents are contained within Table 3, the Wi-fi device experiences a greater amount of noise to the Bluetooth device.

The noise exponent of the model allows for any estimations to take into considerations the noise from the system itself and its surrounding environment. It does not take into consideration the spread of the data itself which is defined as X_σ Eq. 3. This can be seen by comparing the actual distances to the estimated distances produced by the two models. This is done by using the median RSSI reading at each distance for the two models. Table 4 illustrates the accuracy of the two models. It can be seen that the estimations for Mini Beacon was almost consistently more accurate with an average of 4.61 % error as opposed to the 20.16 % for the WizFi210. It should also be noted that both are accurate to within 100 cm for readings up to 800 cm. The variance in the RSSI readings further than this point may result in a higher degree of error.

Table 3 Noise exponent for Wi-fi and Bluetooth

Device	Noise exponent
Wi-fi	4.1854
Bluetooth	2.5682

Table 4 RSSI to distance error rates for Wi-fi and Bluetooth

Actual distance (cm)	Wi-fi error	Bluetooth error
50	+81.66 cm (163.33 %)	–5.38 cm (10.75 %)
100	0 cm (0 %)	0 cm (0 %)
150	–18.34 cm (12.22 %)	–6.86 cm (4.58 %)
200	–35.93 cm (17.96 %)	–43.44 cm (21.72 %)
250	–45.54 cm (18.22 %)	–4.89 cm (1.95 %)
300	+0.5 cm (0.17 %)	+20.76 cm (6.92 %)
350	–49.5 cm (14.14 %)	+0.85 cm (0.24 %)
400	–45.57 cm (11.39 %)	–16.24 cm (4.06 %)
450	+199.15 cm (44.26 %)	+52.19 cm (11.6 %)
500	–58.33 cm (11.67 %)	+2.19 cm (0.44 %)
550	–56.96 cm (10.36 %)	–0.71 cm (0.13 %)
600	+85.87 cm (14.31 %)	+0.81 cm (0.14 %)
650	+74.66 cm (11.49 %)	+7.17 cm (1.1 %)
700	–50.85 cm (7.26 %)	+18.81 cm (2.69 %)
750	–25.34 cm (3.38 %)	–31.19 cm (4.16 %)
800	–75.34 cm (9.42 %)	–13.77 cm (1.72 %)
850	–41.06 cm (4.83 %)	+9.98 cm (1.17 %)
900	–134.36 cm (14.93 %)	+40.64 cm (4.52 %)
950	–141.06 cm (14.85 %)	+78.87 cm (8.3 %)
1000	–191.06 cm (19.11 %)	–59.36 cm (5.94 %)
Average	–26.37 cm (20.16 %)	+2.52 cm (4.61 %)

5 Conclusion

This study investigated the practical usability of both Wi-fi and Bluetooth for localisation purposes. While Wi-fi is capable of higher rates of data transmission, results indicate that Bluetooth is a more reliable source for local positioning by an average of 15.55 %. While the two operate with many similar technologies and on the same 2.4 Ghz bandwidth, the lower error rates for the Bluetooth beacons, along with its smaller hardware footprint, suggest that the hardware of the device itself contributes significantly to a signal's noise. When considering these factors and its low power consumption, Bluetooth is a more practical solution for localisation.

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