# Atlantis: Location Based Services with Bluetooth

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## 1 Abstract

In an effort to offer context aware, location based services using the Bluetooth platform specification, a centralized framework has been developed that allows location approximation via sensor data from a ubiquitous Bluetooth sensor network consisting of numerous base stations. Distance from a certain base station of known position is extrapolated; a localization algorithm is applied to determine the relative position; and a service is offered if the position qualifies.

## 2 Introduction

In recent years, the wireless phenomenon has swept the computing industry. Beginning with portable computers, wireless internet and wireless devices, computer users now expect a greater amount of freedom with respect to their gadgets. The result of this shift in demand is the creation of several different standards for wireless communication. WiFi, RFid and Bluetooth represent some of the more dominant technologies. But with any standard, to be truly universal also requires it to be universally affordable. In this arena, Bluetooth technology has the upper hand because it is easier and cheaper to produce. The physical nature of the instrument allows it to be embedded in very small devices. The combination of affordability, portability and a catchy name suggest a bright future for Bluetooth despite its low bandwidth compared with other protocols.

If in the near future, a radio frequency technology such as Bluetooth becomes as prevalent as devices such as cellular phones, software developers can capitalize on its popularity to provide ubiquitous and intelligent services including but not limited to marketing, occupational queues and automation of common tasks.

One particular area of interest is the possibility of providing context aware applications such as a location based service. Currently, this type of service is limited to indiscriminate devices such as motion detector enabled doors or laser triggered alarm systems. The prospect of intelligent location based services that can identify their clients is enticing. These services may not require the pinpoint precision of the Global Positioning System (GPS). Thus end users will be hesitant to carry cumbersome and expensive GPS devices when they can multitask by using a Bluetooth enabled PDA, which they must carry anyway. Current known attempts at implementing a position aware computing service using Bluetooth appear to be limited to highly controlled, unobstructed environments. They also seem to only take into account the types of devices with low range that do not implement the Bluetooth protocol's well defined method of power consumption control. As such devices are becoming more and more widespread, a general localization service must account for this power conservation behavior. The motivation and objective of this project is to devise a centralized framework for predicting location and offering location based services for Bluetooth enabled devices.

## 3 Bluetooth

Bluetooth technology is an open platform specification for a radio frequency communication protocol for wireless devices. It was developed in an effort to promote collaboration between the various segments of the computing industry by the Bluetooth Special Interest Group, whose members include Agere, Ericsson, IBM, Intel, Microsoft, Motorola, Nokia and Toshiba. The technology's namesake is the 10th century Danish King, Harald Bluetooth who consolidated the warring factions of Norway, Sweden and Denmark [1].

Bluetooth utilizes the 2400 - 2483.5 MHz frequency range, which is primarily unregulated in most countries. Well defined frequency hopping capabilities exist for countries in which use of this range is limited. Currently, there are three classes of Bluetooth devices, differentiated by their maximum power output and thus approximate range. Class 1 devices operate at a maximum output of 100 mW with a range of about 33 m, Class 2 operates at 2.5 mW and approximately 10 m, and Class 3 operates at 1 mW and a range of about 3 m [2].

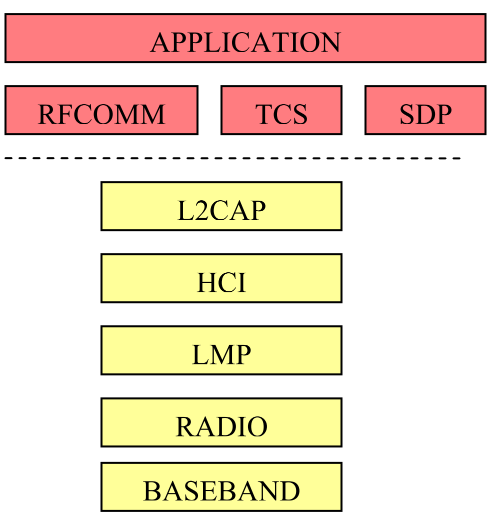


Figure 1. Bluetooth Stack

Link negotiation and communication is accomplished via five distinct layers, Baseband, Radio, Link Manager Protocol, Host Controller Interface, and the Logical Link Control and Adaptation Protocol, which together form the Bluetooth system stack [3].

All Class 1 devices are required to implement a power conservation protocol, which allows them to dynamically adjust their output power levels to achieve optimal reception without wasting energy. The Link Manager Protocol layer within the Bluetooth stack is responsible for performing this function.

The networking protocol allows for two roles, descriptively referred to as master and slave. Official specifications delineate that a device may have a maximum of seven slave devices connected in its piconet. [3]

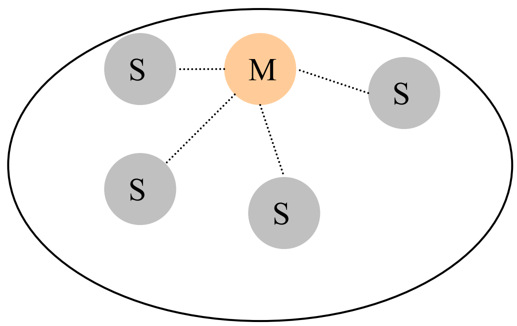


Figure 2. Piconet

## 4 Localization

Atlantis takes advantage of the Link Manager Protocol (LMP) power conservation scheme to predict the distance between two Bluetooth dongles. For any Bluetooth device, there exists an optimal receiving power range termed the Golden Received Power Range (GRPR). This range is device specific. The lower limit is predefined as 6dB above the actual sensitivity of the receiver (and not more than -56 dBm). The upper limit is 20 dB over the lower limit with an expected error of 6dB.

To understand the process, consider a data transfer between two devices, A and B. If device A senses that the signal from device B is outside the range of its GRPR, device A will submit a request to device B to increase or decrease its power output level until the optimal received signal strength is restored.

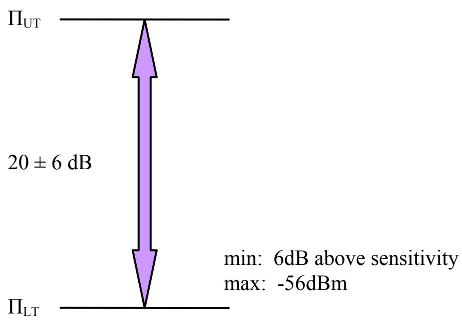


Figure 3. Golden Received Power Range

The Host Controller Interface layer in the Bluetooth stack reveals three methods that reflect the conditions of the received signal.

The function Read_RSSI returns the value of the Received Signal Strength Indicator (RSSI). A positive RSSI value is defined as the number of decibels the received signal is above the upper threshold of the GRPR, while a negative is defined as the number of decibels the received signal is below the lower threshold. If the RSSI value equals 0, then the signal is within the optimum GRPR range [4].

* Section omitted pending US Patent application.

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If valid data is available, applying the heuristic described above to the sensor readings from each station gives a triple of the station's x coordinate, y coordinate and distance from the device of interest. With respect to each individual station $s_i$, the probable location of the tracked device can be described as

$$r_i^2 = (x - x_i)^2 + (y - y_i)^2 \qquad (9)$$

If at least 3 distinct versions of equation (9) are available, Atlantis is able to perform a triangulation algorithm to determine the expected 2-dimensional position of the device. The estimated position is taken to be the area in the Venn diagram formed by the circles where all three variables are true. This is done by taking the equations in pairs and calculating the two nodes of intersection of the two circles. Atlantis maintains sequences of the x and y coordinates of the nodes. Upon completion, we take the average of the median values of each sequence to be approximations of the location in order to guarantee that the predicted coordinate is inside the area of interest. In the figure, it can be seen that in any angular orientation, the median values of the x or y coordinates of the nodes of intersection are always within the range of the x or y values of the region of intersect. In this particular case, for x, we take nodes 4 and 6. For y, we take nodes 3 (or 4) and 6.

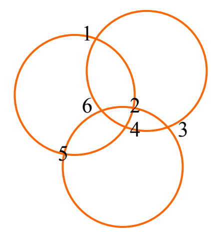


Figure 4. Nodes of Intersect

Occasionally, there will be sets of data obtained that define circles that do not intersect. In this scenario, the radius of each of the circles is incremented by a predefined factor until an intersection occurs or the algorithm determines that no intersection is possible. The latter case may occur if the radii are increased to higher than the dimensions of the area of interest in cases like concentric circles.

To minimize error introduced by imperfect data, computing the nodes of intersect requires substitution of each of the distinct equation (9)'s into each other. For n stations, it can be proven that this process requires n! time. This running time is justified because it is reasonable to assume that the number of stations is small and bounded. In addition, if the stations are positioned intelligently to maximize coverage area, only a fraction of the total base stations are expected to return usable values. Other stations will be outside the range of contact of the device. This method of approximation is justified because we do not guarantee high precision.

An alternative is to use least squares approximation to estimate the position of the device. However, a simpler algorithm is desirable because it can be employed in many remote devices that boast limited computational power. Moreover, the precision dictated by this type of service is not expected to be high regardless of the algorithm used.

## 5 Implementation

This localization scheme uses a centralized server to manage the ubiquitous network of Bluetooth base stations. This project was developed as a specific application of the general Atlantis Sensor and Actuator Management Framework. The Atlantis Framework was selected because it provided a convenient point of integration for the data collection module and the service actuation module [5].

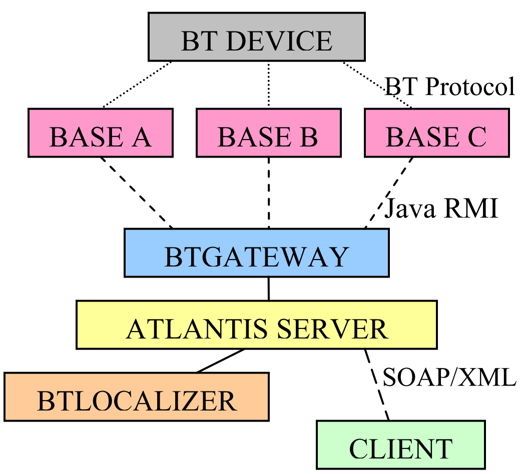


Figure 5. Localization Framework

The sensor network is comprised of several stationary computers termed base stations, each fitted with an identical Bluetooth dongle. At each base station, a light weight Java program that interfaces with the Host Controller Interface layer of the Bluetooth stack runs as a Java Remote Method Invocation (RMI) server awaiting incoming queries from the centralized server. The base station node supports queries that scan the bandwidth, connect, disconnect, switch roles, and retrieve the RSSI, TPL and LQ values from a device of interest. Methods Read_RSSI, Read_TransmitPowerLevel , and Read_LinkQuality were not supported by JBlueZ, the Java interface to the official Linux Bluetooth Stack, BlueZ. These methods were revealed by decompiling the JBlueZ libraries and augmenting them with the methods mentioned via Java Native Interface (JNI). During the course of this process, many issues with permissions had to be resolved. In particular, accessing the Host Controller Interface methods required super-user privileges, which we could not obtain on the public network. This problem was solved by creation of a special user group.

Localization data collection is mediated by a Sensor Gateway (BTGateway) developed for the Atlantis Server. The BTGateway allows Atlantis to encapsulate the entire Bluetooth network into one component. The server submits a request for signal sensor data to the BTGateway, which spawns a thread for each base station node and queries its assigned node for values of TPL and RSSI. This is done by first requesting a connection. Initially the base station occupies the master role because it requested the connection. In order to support multiple base stations simultaneously connecting to the device of interest, the base station immediately requests a role reversal. Upon completion of the connection phase, the device of interest will act as a master device hosting its own piconet of base station devices. The base station then proceeds to collect several readings of TPL and RSSI and then closes the connection.

In the scenario where more than 7 base stations are within the range of the tracked device, the 7 stations reporting the smallest 1-dimensional distance are allowed to connect since the distance estimation heuristic's accuracy depreciates with increasing distance.

Instantaneous radio interference can affect the accuracy of data obtained. To minimize such disturbances, incoming data is arranged in epochs for the purpose of normalizing the interference. Cataloguing the data in this manner introduces the likelihood of queuing of obsolete historical data. If this is the case, the BTLocalizer may reduce the lag between calculated coordinates and actual position by purging the data catalogue of the oldest epochs. In this way, the location coordinates are taken as a Markov process. In applications where historical data is relevant, this feature may be disabled.

The BTGateway is responsible for collecting this data on the server side. Through the internal mechanism of the Atlantis Server, the data is shuttled to the Localization component, called BTLocalizer. When all base stations have either returned readings or failed to execute the request of a given epoch, the Localizer runs the algorithm described above to approximate coordinates of the device.

The coordinate data is again given to the server, which determines whether or not it falls within a predefined monitored zone. If it does, a service is offered to the device being tracked. In this scenario, a surveillance photo is taken and transferred to the device.

# 6 Experimental Setup

The Bluetooth sensor network used in this project is comprised of six Cambridge Silicon Radio Class 1 Bluetooth dongles placed at the positions indicated in the map. The LMP Version is 1.1 and LMP Subversion is 0x20d.

The terrain used is one floor of a building consisting of primarily of offices. In the map, the dots indicate the location of the base stations.

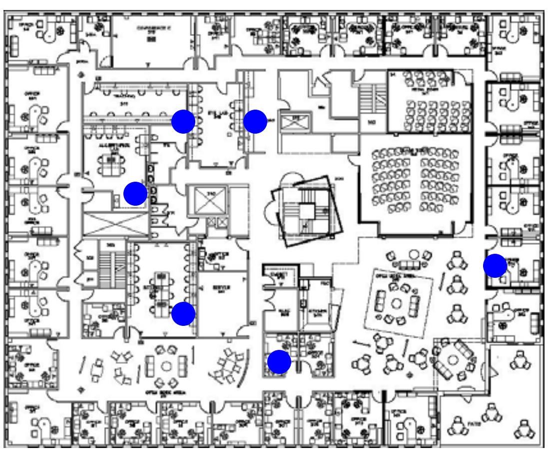

Figure 6. Experimental Setup

To demonstrate the ability to track heterogeneous devices, two different mobile dongles were used. The first is the same model as the base station devices. The second is a dongle of unspecified class with power control capabilities distributed by vendor 3Com. The LMP Version is 1.1, LMP Subversion 0x73.

Each base station node runs on a Debian version 2.4 kernel with standard BlueZ Bluetooth protocol stack.

Calibration measurements and tests were performed with a Windows laptop hosting a dongle. The Bluetooth stack used was the standard Windows stack.

# 7 Data Analysis

Experiments and calibration consistently produced data with precision of about 5 meters in one dimension with an unobstructed path. This data was verified in additional 1-dimensional experiments with obstructions native to the terrain. The collected data matches the predicted values within the expected experimental error.

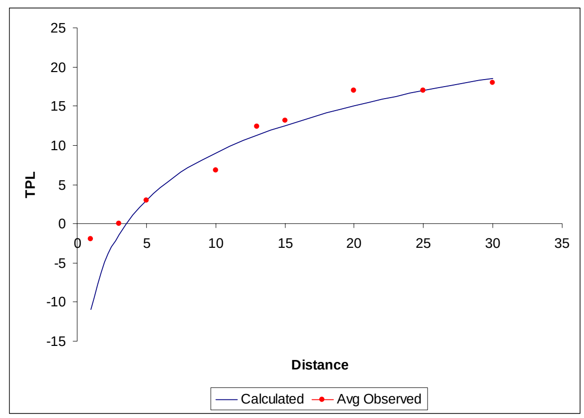


Figure 7. Distance Estimation

The precision of the measurements are limited by the LMP layer. Observations show that the low end devices used only has the ability to vary the output power by factors of 3 dBm. This property decreases the precision of the received readings by effectively creating a step function for the predicted distances. As shown in the graph, at intervals of approximately 5 meters, the prediction algorithm is fairly accurate. At distances in between, the TPL output value may take either the lower or higher value, translating into a mean margin of error of about 5 meters.

In addition, the obstructions within the terrain, especially metallic surfaces form a reflective shield which corrupts the signal strength. Another problem with an uncontrolled terrain is the existence of spurious transmissions from other devices. This causes momentary fluctuations in the TPL and RSSI and results in error in the approximations of distance. Any error may be amplified by the localization algorithm which could potentially use three or more inaccurate readings in determining the position. Regardless, observed error is consistent and therefore suggests that data can be calibrated further using a signal processing algorithm.

Accuracy increases as the tracked device enters the center of the convex hull defined by the base station coordinates. It also increases with increasing base station density, and decreasing distance to the base stations, suggesting that there is more irregular signal attenuation as the device becomes more distant.

The system is generally able to position the device within approximately a seven meter radius of the actual location, which is adequate for the intended purpose of location based services such as advertisements and announcements.

# 8 Conclusion and Future Work

Atlantis successfully demonstrates the use of Bluetooth technology in context aware applications. Location based services with Atlantis can be augmented in future projects by creating a more comprehensive network of base stations. Currently the network uses low end devices with inferior power control capabilities resulting in spurious errors during localization.

Further refinement of the prediction heuristic can lead to more precise readings for obstructed paths. Employment of sophisticated artificial intelligence may be helpful in taking into account the type and extent of obstruction around a base station that may impede signal propagation.

Inevitably, Bluetooth will become more refined and the specifications will become better defined for applications such as location based services or it will be replaced by a different platform that allows this.

Applications of location based services using Bluetooth technology may become an important entity in commerce in the future. This includes enabling customers to make purchases or be targeted for marketing based on their relative locations. For example, a customer may place an order in a drive through without the necessity of speaking into the traditional stationary microphone. Another example is a customer walking through a shopping mall and receiving advertisements tailored to his or her personal preferences as he or she approaches a certain store.

This technology is also applicable in other industries. A restaurant worker may be notified of requests for beverage refills or messages indicating that an order is ready. Location based services can increase worker productivity by saving time on communication.

Another field of application of interest is medicine. Current "paperless chart" systems primarily utilize stationary computers because current mobile computers are difficult to carry for long periods of time due to their weight. In addition, a physician is likely to waste time searching for a patient chart or data. With this model, a doctor can replace a heavy notebook pc with a lightweight pocket pc or comparable device. As a doctor approaches a patient's bed in a hospital or enters an exam room all pertinent data will be automatically loaded into his or her device. Such a system could expedite the adoption of standardized medical computing formats which will improve the quality of patient care.

# 9 Acknowledgements

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