A Study of Frequency Interference and Indoor Location Sensing with 802.11b and Bluetooth Technologies

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Abstract

Location-aware computing is regarded as a key feature of many future mobile applications. GPS serves well for most outdoor applications; however, its dependence on satellites makes it ineffective in indoor environments. Several technologies such as infrared sensing, radio frequency, ultrasonic and RFIDs have been proposed for indoor location sensing. Each of these methods has its own merits and shortcomings. Recently there has been an increase in the use of commodity wireless technologies like 802.11 or Bluetooth for indoor location positioning. Since BT and WLAN don't get along very well, the paper presents experimental results of interference effect of one technology on the other. These results help in determining which of these two technologies is more suitable for location sensing applications. The paper also presents two techniques of how Bluetooth technology can be used (with and without the use of signal strength information) for location sensing. The paper concludes by suggesting some changes to the Bluetooth architecture to improve its capabilities for location positioning.

1. Introduction

The location of people and objects relative to their environment is a crucial piece of information. Indoor location sensing has already found many applications other than asset tracking and security. The more traditional applications might be as simple as tracking the location of a valuable shipping carton or detecting the theft of a laptop computer, or as complex as helping someone to find his or her way around an unfamiliar building (e.g., museums or art galleries). Hospitals and day care centers have started using positioning technologies to locate personnel or the nearest doctor (or medical equipment) in case of an emergency [8, 9]. Several researchers in the area of ad hoc wireless networks have proposed to improve the efficiency of MANET routing algorithms by using location information of member nodes [14, 22, 26, 32, 35]. GPS (and differential GPS), can help locate people or objects as long as they are outdoors, where the signals from the 24 orbiting GPS satellites may be received. However, there is a need for a similar system that works indoors, where the physics of radio propagation rules out the reception of GPS's weak microwave signals. In order to achieve location tracking in indoor environments, researchers and industry have proposed several systems, which differ with respect to the technology used, accuracy, coverage, frequency of updates and the cost of installation and maintenance [1, 2, 4, 23, 27, 34]. Some of the older technologies use costlier equipment. In other cases, the equipment is difficult to install or the system requires a person to carry or wear a device (tag) that is part of the sensory network. Steggles and Cadman [31] provide a good comparison of various RF-tag-based location sensing technologies.

Last few years have seen an increase in the use of commodity wireless technologies like WLAN [3, 11, 12, 18, 24, 30, 36] and Bluetooth (e.g., Bluetags Corporation and AeroScout, formally known as Bluesoft) for indoor location sensing. It is interesting to note that both these technologies were designed without location sensing in mind. These two technologies are fast becoming ubiquitous in office and home environments; thus requiring no additional infrastructure to be in place for indoor location sensing. The Bluetooth SIG is also working on a new Local Positioning (LP) Profile (version 0.95 as of this writing) [7]. This profile specification defines a mechanism and format for the transfer of position related data over Bluetooth. The profile also supports position determination and location awareness. Bluetooth and 802.11b use the same 2.4GHz unlicensed frequency band; as a result, there has been a lot of concerns about interference between them [10,

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15, 17, 29]. In case of indoor location positioning, it is estimated that on an average, the probability of a WiFi transmission colliding with a simultaneous Bluetooth transmission is around 55% [10]. Therefore, it is an important issue to examine the frequency conflict between two technologies in door environments. This paper presents experimental results of the performance of Bluetooth and 802.11b in presence of interference from the other technology in order to examine which technology is better suited for doing indoor location sensing.

Section 2 briefly describes some of the location sensing systems proposed in the past by various research groups both from academia and industry. The section also gives a quick review of some techniques suggested for avoiding interference between 802.11b and Bluetooth technologies. Section 3 gives a detail description of the experiments (with their results) carried out in our eLANS lab at Michigan State University to examine the interference between the two wireless technologies. Section 4 describes two techniques of how Bluetooth can be used for location sensing. Finally, Section 5 concludes the paper with a wish-list for Bluetooth so that it could be effectively used for location sensing.

2. Related Work

A variety of indoor location sensing systems have been proposed by different research groups and industry. AT&T Olivetti Research Laboratory's Active Badge [34] is the pioneering work on this area based on infrared technology. However, due to the line-of-sight requirement and short-range signal transmission, researchers realized that infrared technology is not a very good solution for this problem. Other projects include Active Bats system by AT&T Research Laboratory using ultrasonic technology [1], the Cricket Indoor Location System at MIT with a combination of ultrasonic and RF technologies [2], TinyOS RF motes by UC Berkeley [20], and the Cooltown project by Hewlett Packard [4]. In recent years, most of the researches have been adopting the radio frequency (RF) technology for this purpose instead (e.g., RADAR project by Microsoft Research [11], SpotON done at University of Washington [19]). Like the RADAR project, Project Aura done at Carnegie Mellon University also tries to utilize the IEEE 802.11 wireless technology for location sensing in addition to its use as a network infrastructure [30]. [18, 24] are two recently proposed techniques that use 802.11 technology for positioning.

Several groups including the IEEE 802.15 work group [5] have addressed the issue of co-existence amongst the two technologies. In general, two classes of coexistence mechanisms have been proposed: collaborative (where the BT and WLAN exchange information) and non-collaborative (where the two technologies operate independently and cannot coordinate their transmissions). MAC EnHanced Temporal Algorithm (MEHTA) [21] is a collaborative technique that uses a central controller that monitors BT and WLAN traffic and coordinates their transmission to avoid interference. TDMA [28] scheme uses a similar approach where BT and WLAN traffic do not overlap in time. Collaborative algorithms have a distinct shortcoming – they cannot eliminate interference in devices that are not collocated. Some non-collaborative mechanisms suggest techniques like Adaptive Frequency Hopping [16, 33], where the BT device is given a limited choice of hop frequencies. These frequencies correspond to the frequencies not used by a nearby WLAN device. However, implementing such a mechanism would require major change in the BT architecture. Chiasserini and Rao [15] suggested an OverLap Avoidance (OLA) scheme which can work with or without collaboration between the devices.

3. Experiments

Various experiments carried out at the eLANS lab to examine how one wireless technology affects another and the interference effect on throughput was measured. Figure 1 shows the layout of the eLANS lab and the positions of various 802.11b devices used in the experiments. After several trial runs, we observed that for most experiments a signal strength log of 2 minutes (120sec) was enough to show any pattern. We therefore carried out all the experiments for three minutes (180sec). We ignored the first and the last 15 secs of the log file (to eliminate startup latencies or ending errors) and examined the rest of the 150sec. All the signal strength plots in this paper are shown for 150 sec (2.5 minutes). The experiments can be divided in to four sets:

- Influence of 802.11b devices on other 802.11b devices,
- The effect of Bluetooth on 802.11b,
- The effect of 802.11b on Bluetooth, and finally,
- The effect of Bluetooth on Bluetooth.

3.1 Influence of 802.11b devices on other 802.11b devices

Case A-1: Single pair of 802.11b devices present in the environment – No Interference

An iPAQ with D-Link card and a laptop with Orinoco card are configured to ping each other over the same channel (Channel 6). The activities of a particular link are monitored and logged by Orinoco client manager software. This setup represents that case where there is no interference. Figure 2 shows SNR values at Laptop (local device) and iPAQ (remote) of this setup when no interference devices are present.

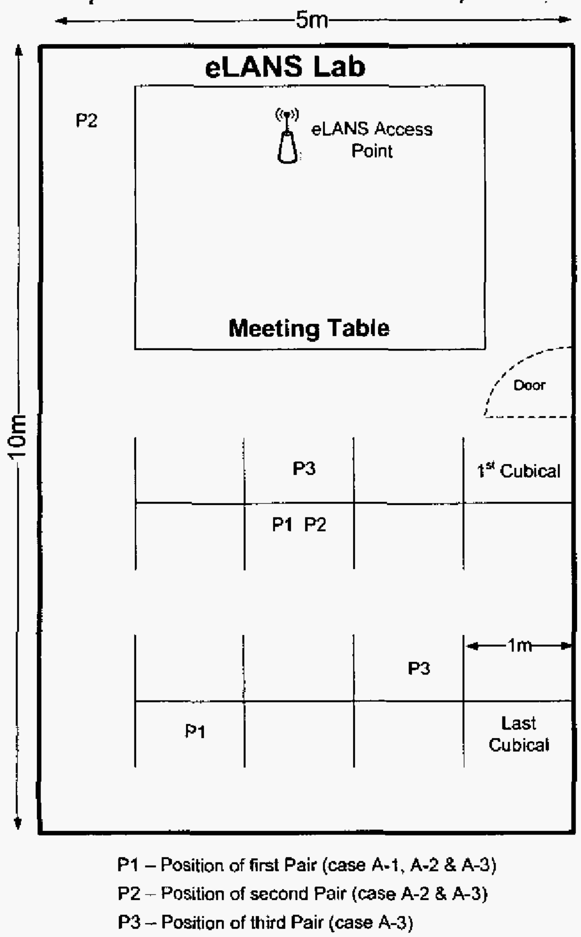


Figure 1: Layout of eLANS lab

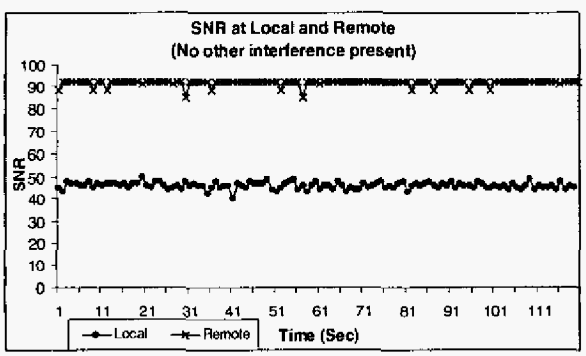


Figure 2: SNR values of case A-1

Case A-2: Single interfering Pair of 802.11b devices in the environment

Another iPAQ with D-Link card and an Orinoco USB client on a PC are added to the setting in Case A-1. They are configured so that they communicate over the same channel as the earlier configuration. This adds another pair of 802.11b devices over the same wireless network. Figure 3 shows the SNR values when another pair of 802.11b devices is present in the same network.

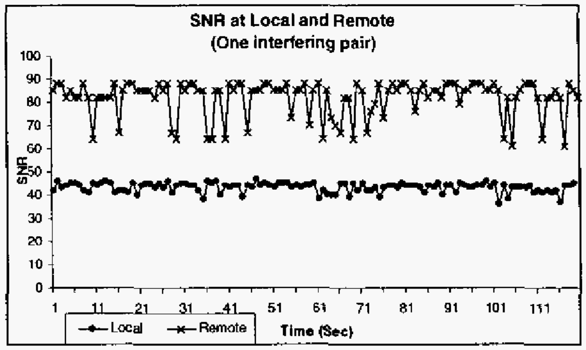


Figure 3: SNR values of case A-2

Case A-3: Two pairs of interfering 802.11b devices are in the environment

This time the experiment is repeated with two interfering pairs. Each of these pairs consists of an iPAQ with D-Link card and an Orinoco USB client connected to. All the devices are configured so that they communicate over the same channel as the earlier configuration. Figure 4 shows the SNR values of when two other interfering pairs of 802.11b devices are present in the same network

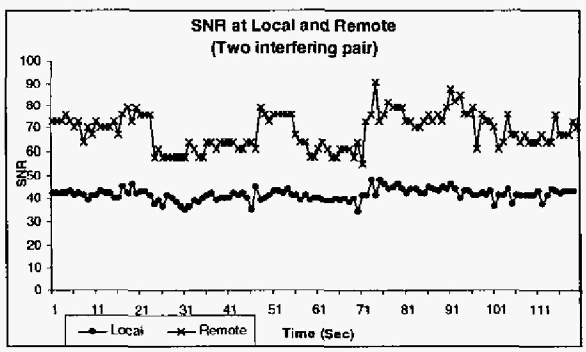


Figure 4: SNR values of case A-3

Observation: When no interference is present, the signal strength stays stable over the entire range. When a single pair is introduced in the same network, there is interference between the two causing the signal to fluctuate. The SNR shows a sharp drop at the point where there is collision between the two pairs. With two pairs, the interference greatly increases. Unlike the case of single pair interference, where there are spikes during time of interference, in case of two pair inference, there are times when the SNR drops and stay flat for a long time.

3.1.1 Effect on throughput

In theory, an 802.11b link should have an effective bandwidth of 11Mbps. But due to processing overhead, signaling information, stray interference, etc, the bandwidth is reduced to a lower value. The interference factor increases when more devices operating over the same channel are added, all other factors remaining the same. The sharp drops in the SNR values in the graph show this. Collisions mean retransmission. Thus it can be said that as the number of devices are increased in the same network, effective bandwidth for a particular link drops.

To test the effect of one 802.11b device on another, we did a performance evaluation using HP's Netperf benchmarking software [6] running on a PIII-750MHz PC running RedHat Linux 7.3. The client system ran on a PII-366MHz Dell Latitude Laptop running RedHat Linux 7.1. Our initial experiments showed lower values of throughput when the laptop was used as the server; possibly due to OS overhead and its slower CPU speed. For all experiments, we used the laptop as our Netperf client device. On both the devices we used the Orinoco Silver card for wireless access.

We started the experiment by sending a 64byte UDP packet from the Netperf server (pc) to the client (laptop). TCP packets are not used for throughput measurement as they try to retransmit lost packets because of connection-oriented property. In subsequent steps, we tested the performance in increments of packet size from 64bytes up to (64x92)5888 bytes. Figure 5 shows the throughput curve. We found that the throughput was high when the UDP packet size was 1472 bytes or its multiples. The reason is because 1472 bytes is close to the maximum payload value for an Ethernet packet size (1518 bytes with headers). Packet sizes higher than 1472 bytes result in fragmentation; while, packets smaller than 1472 bytes are not enough to keep the channel busy causing periods of silence between successive ping packets, thus resulting in lower throughput values. We believe, when the packet size is multiple of 1472 bytes, the fragments are equally divided and result in a local maxima. In the rest of the experiments we used packet size of 1472 bytes.

To test the (interference) effect of other 802.11b pairs, we introduced two pairs of wireless devices (two iPAQs and two PCs) in the same environment. Figure 6 shows the throughput for different scenarios. There were two sets of experiments that were conducted for each pair – one with the interfering pair very close to the test pair and the other with the interfering pair at the distance of 7m with a cubicle partition in the middle. We noticed that the throughput was not affected (by the new pairs) for smaller (ping) packet sizes. However, as the ping packet size between the new pair increased, the effect of interference was more visible (Figure 6). The receiver throughput values are average of three trials.

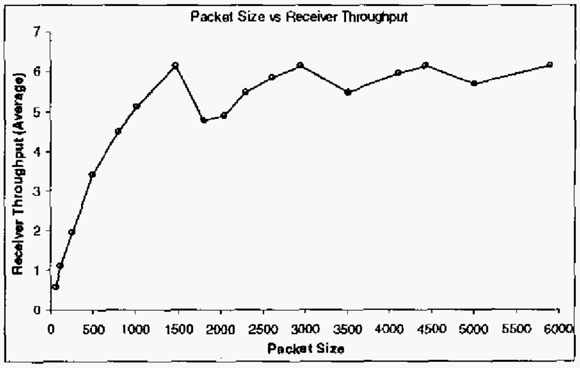


Figure 5: UDP packet size versus throughput

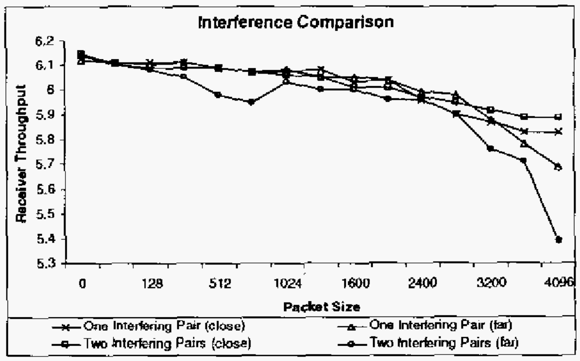
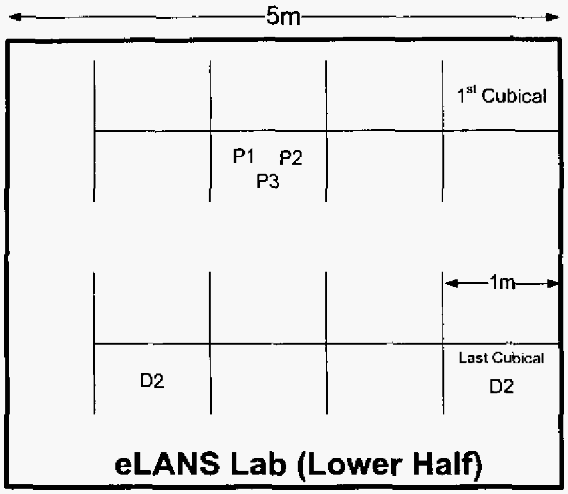


Figure 6: Throughput of 802.11b

3.1.2 Location sensing with 802.11b

The 802.11b standard defines 11 possible channels that may be used. Each channel is defined by its' center frequency. These center frequencies are located at a distance of 5MHz from each other. Since the 20db bandwidth could as wide as 16MHz [10, 15, 17, 29], multiple co-located channels have to be spaced out from each other. Thus, one 802.11b network could operate at any channel, but two co-located networks would have to have enough spacing, say channel 2 and channel 10, giving a minimum of 24 MHz in between them. Similarly, three co-located networks would have to choose from something like channels 1, 6 and 11, to ensure enough spacing. In our experiment, since all three pairs were using the same channel and actively involved in a file transfer operation, there was heavy interference between them. In case of real-time location sensing applications, there would be several 'sensor' 802.11b devices collaborating to detect the location of 'unknown' 802.11b devices. However, in order to avoid interference between the signals from different WiFi sensors, one would have to impose a limit on the number of sensors that can exist in a given area or on the number of WiFi device that can be tracked.



P1 – Position of BT Pair (case B-1(i), B-1(ii) and B-2)
P2 – Position of 802.11b pair (case B-1(i))
P3 – Position of two 802.11b pairs (case B-2)
D2 – Position of 802.11b device (case B-1(ii))

Figure 7: BT and 802.11b positions in various scenarios

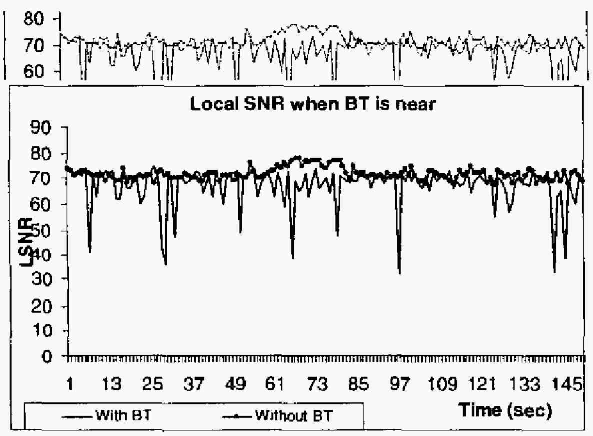


Figure 8: Local SNR values for case B-1(i)

3.2 Effect of Bluetooth on 802.11b devices

Case B-1: Interference with a single pair of Bluetooth device

We examined two scenarios in this case:

(i) Interference from near-by BT devices: In this case, a pair of 802.11b devices were placed in the same cubicle (within 1m) as a pair of (interfering) Bluetooth devices (see Figure 7 the case B-1(i)). The Bluetooth devices were set to exchange a large file between them. The Orinoco Client manager running on the laptop logged the SNR for the two cases. Similar to the earlier set of experiments, the data was logged for 180sec but only the 150sec was considered. Figure 8 shows the SNR with and without any interference from the Bluetooth devices. Sharp negative spikes are observed when Bluetooth is present in the environment clearly indicating that there is interference between the two technologies.

(ii) Interference from far away BT devices: Figure 7 case B-(ii) shows the setup for the far scenario. The laptop running Orinoco client manager (and logging SNR) was placed in the last cubicle. Figure 9 shows the result for this setup. Again, like the earlier case, sharp spikes are observed in presence of Bluetooth. However, the frequency of the spikes is less.

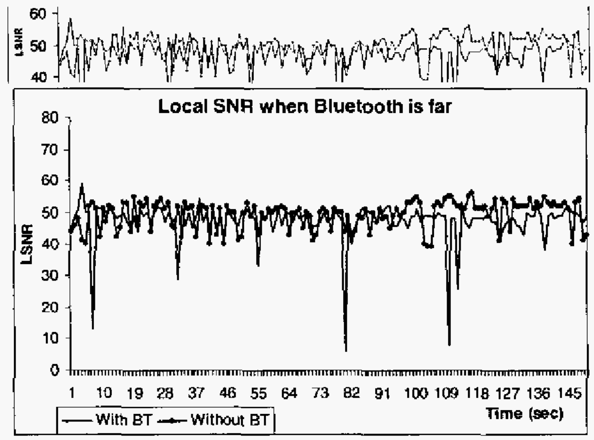


Figure 9: SNR values on the laptop for B-1(ii)

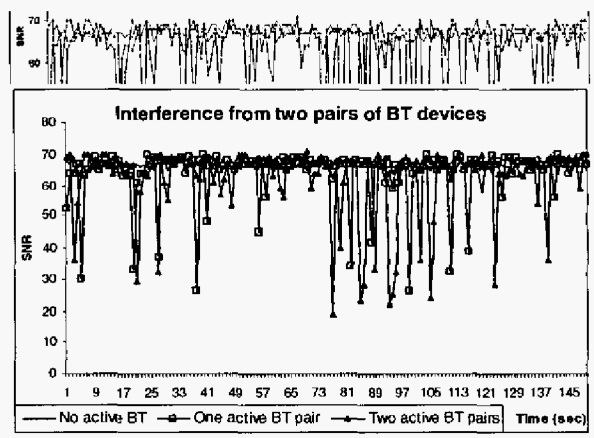


Figure 10: Local SNR values for case B-2

Case B-2: Interference between a pair of 802.11b & two pairs of Bluetooth devices

In this set, all the devices were placed in the same cubicle. Figure 10 shows the result for this setup. In presence of more devices, the frequency of the negative spikes is higher. However, there is little increase in the magnitude of the spikes.

3.3 Effect of 802.11b on Bluetooth

The Bluetooth specification makes it optional for the manufacturers to give signal strength information for a particular link. The Bluetooth products that were used in these experiments didn't give signal strength information and hence Bluetooth performance was measured in terms of file transfer time, which points to the effective bandwidth for a Bluetooth link. Three experiments were carried out. In each case, a file of size 4437KB was transferred between two Bluetooth devices with increasing number of 802.11b pairs. Table 1 shows the result.

Table 1: Effect of 802.11b on Bluetooth

No. of 802.11b Pairs	File transfer time
1	6 min 4 sec
2	6 min 5 sec
3	6 min 7 sec

Observation: It can be seen that there is a marginal decrease in the file transfer time as the number of 802.11b devices are increased. Implying that 802.11b had very little effect on the Bluetooth bandwidth. Currently, there is no Bluetooth API to carryout throughput measurements. In the future, we plan to take a closer look at bandwidth performance for Bluetooth in presence of interference.

Explanation: By their nature, when both Bluetooth and 802.11b devices occasionally operate on the same frequency, packets will be lost and throughput be reduced. In the course of experiments, it was seen that in extreme conditions where a Bluetooth or 802.11b interfere is positioned right beside to a receiver of the opposite technology, throughput is significantly reduced. However, as the interferer is positioned further away, the interference reduced. If the distance between the two is more than 10m, then the throughput is only minimally reduced compared to normal. Bluetooth will cause more interference with 802.11 (or 802.11b/g), than the other way around due to Bluetooth's much faster hop rate [7]. While a WLAN device is transmitting on a particular frequency, a Bluetooth device might hop to this frequency several times. Bluetooth hops about 600 times faster than 802.11 [13, 25] which hops at the rate of 2.5hops per sec. The situation is much worst in case of 802.11b/g which uses DSSS – meaning no change in frequency.

3.3.1 Effect on throughput

Although both technologies drop packets, WiFi packets are bigger compared to Bluetooth packets. As a result more information has to be re-transmitted when 802.11b incurs retransmission. Thus, the effect of interference is more adverse on 802.11b. To study the effect of Bluetooth on the throughput of 802.11b, we collected throughput data using Netperf and carried out t-Test comparisons. Table 2 shows the results. The throughput of 802.11b is affected by the presence of Bluetooth and it reduces as the distance increases. The throughput also depends on the number of devices present in the vicinity.

Table 2: Performance of 802.11b in presence of BT

Condition	Receiver Throughput (10^6 bits/sec)			t-Test Results	
	Low	Mean[1]	High	Paired	p-value
C1: No Bluetooth device present	6.11	6.12	6.15	C1-C2	0.000
C2: One Bluetooth Pair in close vicinity	4.37	5.33	5.91	C2-C3	0.002
C3: One Bluetooth pair in middle cubicle[2]	5.64	5.88	6.11	C3-C4	0.003
C4: One Bluetooth pair in last cubicle[3]	6.10	6.12	6.14	C1-C4	0.096
C5: Two Bluetooth pairs in close vicinity	3.60	3.94	5.08	C1-C5	0.000

3.4 Interference between Bluetooth devices

The currently Bluetooth products available in the market do not support signal strength measurement. Therefore, the average time required for a file transfer was used as a measure to study the effects of Bluetooth on other Bluetooth devices. Table 3 shows the results for a file size of 4437KB. It was observed that there wasn't much difference between the (mean) time it took to complete the file transfer in each case.

Explanation: Since Bluetooth jumps frequencies at 1600 hops per sec, the chances of collision while at a particular frequency are low. Besides a Bluetooth packet is smaller compared to WLAN packets [13, 25] and hence, retransmissions (due to collision) are not expensive. Thus the effective bandwidth is not greatly affected when there is interference between Bluetooth devices only.

Table 3: Effect of Bluetooth on Bluetooth

No. of Bluetooth Pairs	Effective Bandwidth
1	6 min 7 sec
2	6 min 9 sec
3	6 min 11 sec
4	6 min 12 sec

3.4.1 Signal variation in an indoor environment

Along with the interference comparisons, another experiment was conducted to study the signal variation of wireless devices used in an indoor environment like offices, hospitals etc.

A laptop was placed in the 1st cubicle in eLANS (see Figure 1) with Orinoco software to monitor and log the

[1] Interference from Bluetooth is not constant but in the form of spikes. Hence, values in this column are average of 10 trials.
[2] Middle Cubicle is about 7m away from the test pair with a wooden partition in between.
[3] Last Cubicle was about 10m away from the test pair with two wooden partitions in between.

link status of its connection with the access point placed on the far side of the eLANS meeting table. The experiment was started at approx 8.10am and was left running (logging data every 20 sec) for about 3hrs. Some facts about the experiment day – The lab was empty between 8 to 9am. A team meeting started at 9am and went on little over 10am. Between 10 to 10:30am, many eLANS members attended a presentation in another room. 10:30 onwards, the lab was almost full with all its members present in their respective cubicle.

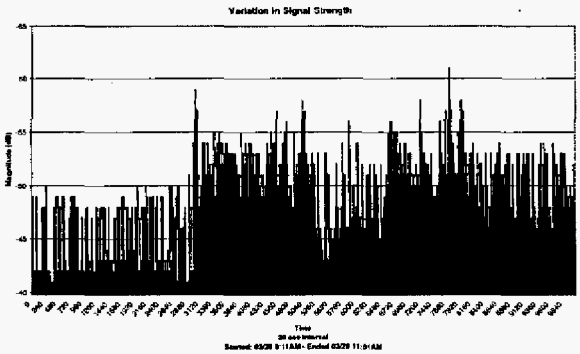


Figure 11: Signal variations in a busy room

Observation: The results of the experiment are shown in Figure 11. Note that the values on y-axis are negative db which means that higher values on the graph correspond to lower signal strength. From the graph, we can see that the signal strength was strong during 8-9am when the lab was empty. We can see that during the team meeting (9-10am), there was a strong degradation in the signal strength. There is little improvement in the signal strength when some of the lab members attended the seminar in another room. However, as the number of people in the lab started increasing, (10.30am onwards), the signal strength slowly degraded.

Explanation: Signal propagation is greatly affected by placement of furniture, movement of people, walls, etc. Signal strength alone cannot be used for estimating distance. Almost all of the RF-based location sensing systems use signal strength in combination with some other techniques for improving their accuracy.

4. Location Sensing with Bluetooth

From the experiments described in the previous section, we can conclude:

- As the number of 802.11b devices operating over the same channel increases, the interference between them increases.
- There is significant interference between Bluetooth and 802.11b devices. The interference is higher when the devices are close to each other. Beyond the range of Bluetooth, it drops down significantly. Also, the effect of Bluetooth is more on 802.11b than the reverse case.
- There is very little interference between two Bluetooth devices place in close vicinity.

In a location-sensing environment, we would need to have several devices of the same type operating on the same network. Hence, it would be important that these devices have very little interference between them. With the above results, it can be seen that Bluetooth can satisfy these requirements and hence can be a good candidate for use in indoor location sensing. Since Bluetooth is becoming a standard feature in most hand-held devices, it would eliminate the need for the user to carry additional sensory devices, as needed by several location-sensing technologies of earlier times. A Bluetooth piconet can have 7 active slaves and up to 200 inactive devices in parked mode. For location sensing applications, it is enough to 'see' another Bluetooth device. Also, it doesn't matter if the other device is a master or a slave. The device should be within the range to be detected. This implies that a Bluetooth sensor would be able to detect up to 200 other Bluetooth devices.

We have already seen in Section 3.4.1 that signal strength varies randomly with time. By using the concept of reference tags, a real-time system can be designed [23]. The signal strength variation in such a system will affects the tracking and the reference tag in the same manner. With the advent of Bluetooth ASIC chips, the price of Bluetooth devices is expected to drop down significantly in the near future and the size of a Bluetooth sensor would be very small. Thus using Bluetooth reference tags would be a feasible idea. We consider two possibilities – location sensing when signal strength information is not made available and location sensing when that information is available. At present all of the Bluetooth devices available in the market don't make signal strength information available. Making it available is optional according to the Bluetooth specification.

4.1.1 Without signal strength information

Similar to RFIDs [31], every Bluetooth device has a 48-bit address. We can use Bluetooth tags as reference tags which can be uniformly spread in the area of interest. The Bluetooth sensors can be placed at 5m each so that they overlap in their range. Since the reference tags are positioned in-between the sensors and the sensor range overlap, each reference tag would be seen by more than one sensor. Figure 12 shows such a setup. We define a table whose rows represent individual tags and the columns represent every reader. We can follow this approach for an unknown device whose location is to be determined. By compare the row of an unknown device with those for known devices, we can predict where the device might be present. Table 4 shows an example.

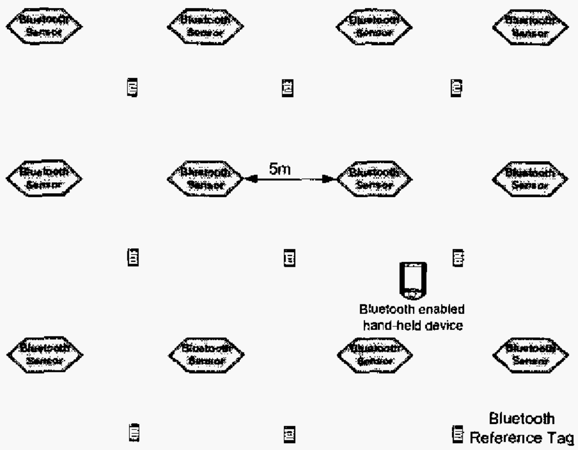


Figure 12: Bluetooth location sensing using the concept of reference tags

Table 4: Locating unknown tag using reference tag

Reader	1	2	3	4
Tag – 1	0	1	1	0
Tag – 2	1	1	1	0
Tag – 3	0	0	1	1
Unknown – 1	0	0	1	1
Unknown – 2	1	0	1	0

We can see from the table that the Unknown-1 device's row information matches with that of Tag 3 which means that they are very close to each other (if not at the same place). The row information for Unknown – 2 closely matches with that for reference tag 2. Hence, it must be located somewhere in the vicinity of Ref Tag 2. The accuracy of this approach depends on how tight the reference tags are placed, the geometric placement of readers and reference tags and the amount of overlap between neighboring readers.

4.1.2 If signal strength information available

If in the future Bluetooth products meant for location sensing could give signal strength information then, a real-time system can be implemented. Referring to Figure 13, we do the following analysis. Assume there are n Bluetooth readers and m reference tags. We define the Range Vector of an unknown tag as:

$$u = (u_1, u_2, \ldots\ldots, u_n)$$

where r_i denotes the signal strength value of the unknown tag perceived on Bluetooth reader i, $i \in (1, n)$. For the reference tags, each one also has its range vector as:

$$r_i = (r_{i,1}, r_{i,2} \ldots\ldots r_{i,n}) \text{ where } i \in (1, m).$$

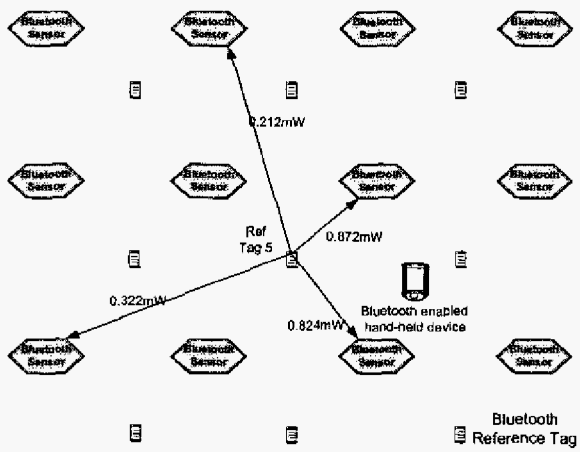


Figure 13: Signal strength of Ref Tag 5 as perceived by Bluetooth readers

Due to the instability of the signals (Section 3.4.1), we cannot obtain the physical distance between the reader and a tag (reference tag or unknown tag) directly from the signal strength. However, with the known coordinates of all the reference tags, we are able to physically locate an unknown tag based on the reference cell of the unknown tag. We can introduce the Euclidian distance in signal strength. For each individual unknown tag, we define:

$$E_i = \sqrt{\sum_{k=1}^{n} (r_{i,k} - u_k)^2}$$

as the Euclidian distance in signal strength between an unknown tag and a reference tag r_i.

To simplify the description of our approach, let us assume there are 4 RF readers and 16 reference tags in the experimental environment. Our approach can be easily extended to an environment that has more than 4 RF readers and 16 reference tags. The signal strength vector of the reference tag and the unknown tag is $s = (s_1, s_2, s_3, s_4)$. When we consider one individual unknown tag, its vectors E_i (for each of the i^{th} reference tag) are given by:

$$E_1 = \sqrt{\sum_{k=1}^{4} (r_{1,k} - u_k)^2} \ldots E_2 = \sqrt{\sum_{k=1}^{4} (r_{2,k} - u_k)^2}$$

$$\ldots\ldots E_{16} = \sqrt{\sum_{k=1}^{4} (r_{16k} - u_k)^2}$$

Let E denotes the location relationship between the reference tags and this unknown one. There are three key issues that we examine through the process of locating the unknown tag. The first issue is the placement of the reference tags. Since the unknown tag is ultimately located in a reference tag cell, the layout of reference tags may significantly affect the location accuracy of an algorithm.

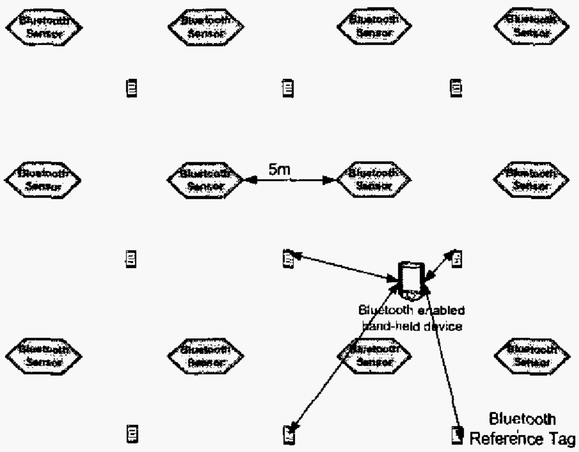


Figure 14: Case of 4-nearest Neighbors

The second issue is to determine the number of reference tags in a reference cell that are used in obtaining the most approximate coordinate of the unknown tags. This may also be termed as selecting 'k' nearest neighbors. Now, for example we may use the coordinate of the reference tag with the smallest E value to the tracking tag as this unknown tag's coordinate (k=1), or we can choose 2 nearest tags (k=2) and the unknown tag's coordinates can be simply determined by the arithmetic means of the coordinates of those two nearest tags as:

$$x_{unknown} = \frac{1}{2}(x_{nearest1} + x_{neraest2})$$

$$y_{unknown} = \frac{1}{2}(y_{nearest1} + y_{neraest2})$$

When we are using k nearest reference tags' coordinate to locate one unknown tag, the following equation could be introduced:

$$(x, y) = \frac{1}{k}\sum_{i=1}^{k}(x_{ri}, y_{ri})$$

However, since the nearest neighbors are not at the same distance from the unknown tag, we need to assign weight so that the nearest tag gets more importance than the one far. This becomes the third issue in this approach. Thus, the unknown's coordinate can be obtained as:

$$(x, y) = \sum_{i=1}^{k} w_i (x_{ri}, y_{ri})$$

Intuitively, this must be done based on the E value of each reference tag in the cell. Instead of giving weight to all k-nearest neighbors the same weights in averaging, w_i is introduced and it is a function of the E of all k-nearest neighbors. Our approach of the weight is depending on the E as:

$$w_j = \frac{\frac{1}{E_i}}{\sum_{i=1}^{k}\frac{1}{E_i}}$$

In this approach, the reference tag with the smallest E value has the largest weight.

5. Conclusion and Future Work

This paper presented experimental results of inference between 802.11b (WiFi) and Bluetooth device. Since BT and WLAN have become common in most indoor environments, it is important to study the interaction between the two technologies if one of them were to be used for location positioning. This paper attempts to do just that. Our results indicate that Bluetooth could be a good candidate for location sensing in an indoor environment. We presented two techniques for location positioning using Bluetooth. Cost of Bluetooth chips is expected to greatly reduce making it possible to have Bluetooth devices that cost less than a dollar. This will make location sensing with Bluetooth very inexpensive. Bluetooth was not designed for location sensing and hence there are certain enhancements that it would have to undergo so that it is best suited for indoor location sensing. Here's a wish-list for Bluetooth location sensing:

a. An important improvement would be to reduce the time taken by a Bluetooth device to detect other Bluetooth devices in its vicinity. In addition, many of the BT products have fixed scan (refresh) rate. For example, in the 3COM USB adapter, the lowest refresh time is 5mins. In order to track moving objects, future BT devices should have a shorter wait period between successive scans.
b. The Bluetooth core specifications do not require that signal strength (RSSI) values be available to higher-level software. If this information is made available, it can greatly aid in accurate location sensing. With signal strength information, the nearest neighbor concept developed in [23] and section 4.1.2 can be applied.
c. The Bluetooth spec specifies 3 power levels at which Bluetooth devices can operate. The minimum power level (1mW in class 1) gives a coverage range of roughly 10m. If future implementations can give a shorter range, then location sensing can be made more accurate. Since Bluetooth devices are expected to be cheaper in the future, we can use

more sensors covering very short area thus improving accuracy.

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