Indoor Positioning

Lab Report for Wireless Communication and Mobile Internet

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I. Introduction

In this semester, I participated in Professor Tian's indoor positioning group. In this group, I learned some basic knowledge of indoor positioning and use it to check the possibility of using CC2541 for indoor positioning.

II. Positioning Technologies

There are several positioning methods in practice[1], but only some of them can be used in indoor posioning:

(a) GNSS(Global Navigation Satellite System)

GNSS is widely used in outdoor positioning system, but it is difficult for its signals to penetrate buildings. In this way, GNSS is not suitable for indoor positioning.

(b) Cellular Network

Cellular sources are too sparsely distributed to provide accurate positioning information. So cellular network is also not suitable for indoor positioning.

(c) Wi-Fi System & Bluetooth System & RFID

These 3 technologies can provide accurate posioning information to satisfy the requirement of indoor positioning, for the system can be distribued in the building.

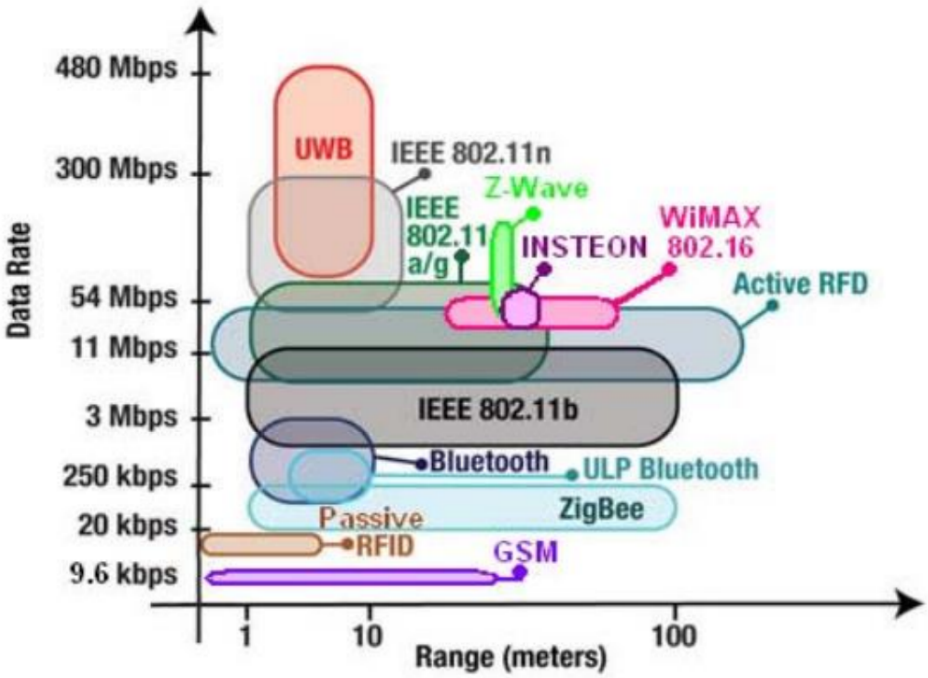

图 1: The Comparison of Transmission Range

III. Positioning Methods

(a) Fingerprinting

This method requires several beacons in the room. The key point of this method is a value called RSSI(Received Signal Strength Indicator) which is strongly coupled with the distance between the mobile device(held by the user) and the beacons in the room. An example of RSSI-distance relationship is shown in Fig. 2. This relationship is dependent on the environment in the speciefic room yet keeps unchanged in this speciefic room for a long time. Thus, the RSSI values contain the information of distance between the mobile device and beacons.

Distance (m)	**RSSI (dBm)**	**Distance (m)**	**RSSI (dBm)**
0.0	0	3.6	-26.5
0.3	-4.5	3.9	-27.4
0.6	-10	4.2	-28.4
0.9	-15	4.5	-28
1.2	-20	4.8	-28
1.5	-20.5	5.1	-27
1.8	-26.5	5.4	-29
2.1	-26.5	5.7	-28
2.4	-27	6.0	-28.5
2.7	-28	6.3	-29.5
3.0	-28.5	6.6	-30.5
3.3	-27.5	6.9	Disconnected

图 2: An Example of the RSSI-Distance Relationship[2]

Then we will use the RSSI values to get the position of the mobile device, i.e. the position of the user. In the room(indicated by the black rectangle), there are several beacons(indicated by the black circle). The mobile device is indicated by the red triangle. Blue lines are constructed to indicate the distance between the mobile device and beacons. Put the device in different positions in the room and the distances between the device and each beacon will also be different, thus, the RSSI values between the device and each beacon will be different. That means, a set of RSSI values can be used to indicate the location of mobile device in the room and this value set is named as fingerprint. Based on the above discussion, the fingerprinting method works as follows. The previous work is like that: for each interested position, measure the fingerprint of this position and add a fingerprint-position pair to the database. In actual work stage, the mobile device measure the fingerprint of current position and search in the database for the corresponding position information. Show in Fig. 3.

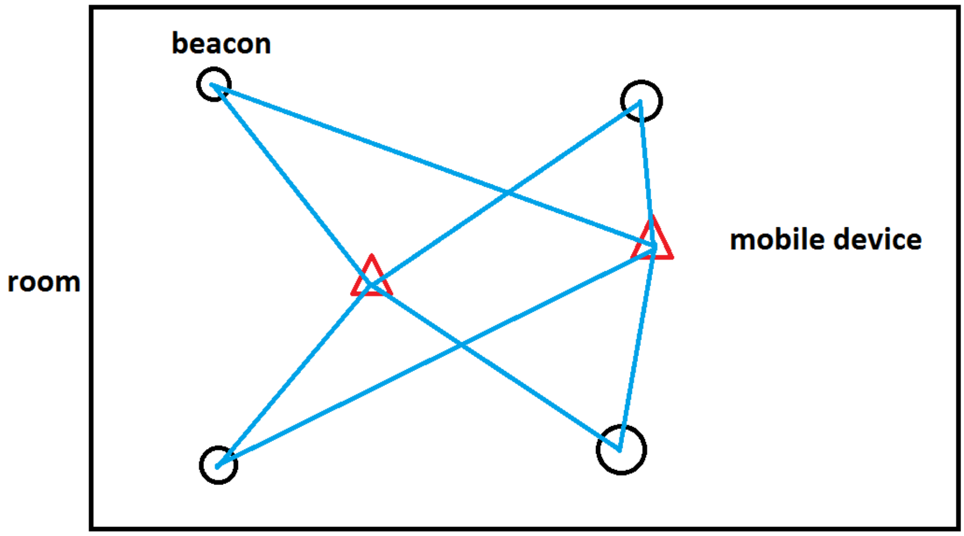

图 3: The Model of Fingerprinting

The advantage of this method is that actual distance measurement is not required. The disadvantage is that the positioning is dependent on the environment(the RSSI-distance relationship).

(b) **Angle of Arrival(AOA)**

In this method, the distance between 2 devices is calculated directly. For the signal with speciefic frequency, the phase of the received signal indicated the distance,

$$2d = \frac{\Phi}{2\pi}\lambda$$

So

$$2d = \frac{\Phi}{4\pi}\lambda$$

It is obvious that for a speciefic phase there are more than one possible distancce, so this method can only deal with distance within on wavelength if there is no addition extension. The extension of more than one wavelength is LCM(Least Common Multiple) method[3]. In this method, multiple frequencies are required. For a set of frequncies f_1, f_2,...,f_n, send the signals in turns and get the received signals' phases ϕ_1, ϕ_2,...,ϕ_i,...,ϕ_n, $\phi_i \in [0, 2\pi)$. For the actual phase Φ_1, Φ_2,...,Φ_n, the difference between ϕ_i and Φ_i will be multiple 2π. That means, the difference of the actual distance and the distance calculated by the above formula will be multiple wavelengths. Calculate for the least possible distance D such that

$$\forall i, \exists n_i, 2D = (\frac{\phi_i}{2\pi} + 2n_i)\lambda$$

.

As the distance is acknowledged by the measurement of phase, the position will be get if the angle between device and beacon is known. To get this value, multiple antennas are required. Fig. 4 shows the AOA model using RFID for an example. In this graph,

$$\theta = arcsin(\frac{d2 - d1}{a})$$

.

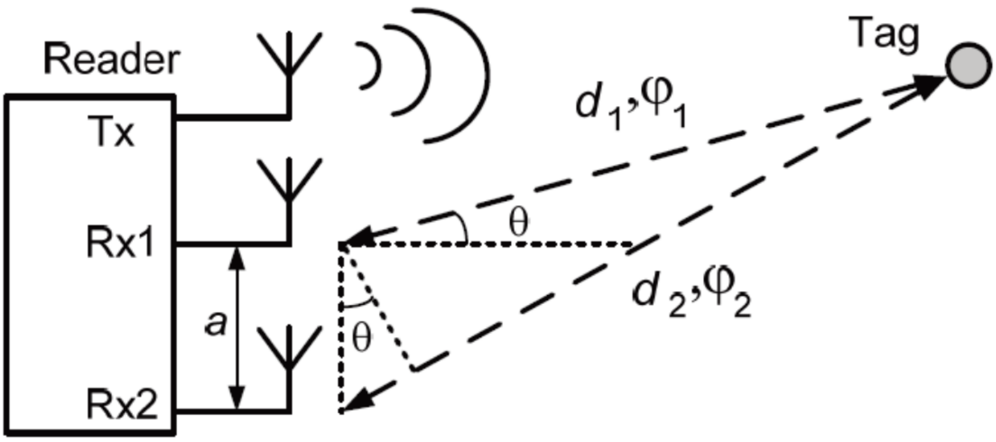

图 4: The Model of AOA

(c) **Time of Flight(TOF)**
The method is similar with AOA. AOA measures phase to get the distance while TOF measures travelling time to get the distance. The advantage is that there will be no multiple solutions; the disadvantage is that accurate time measurement is quite difficult. To make time measurement more accurate, LCM method can also be used. Shown in Fig. 5.

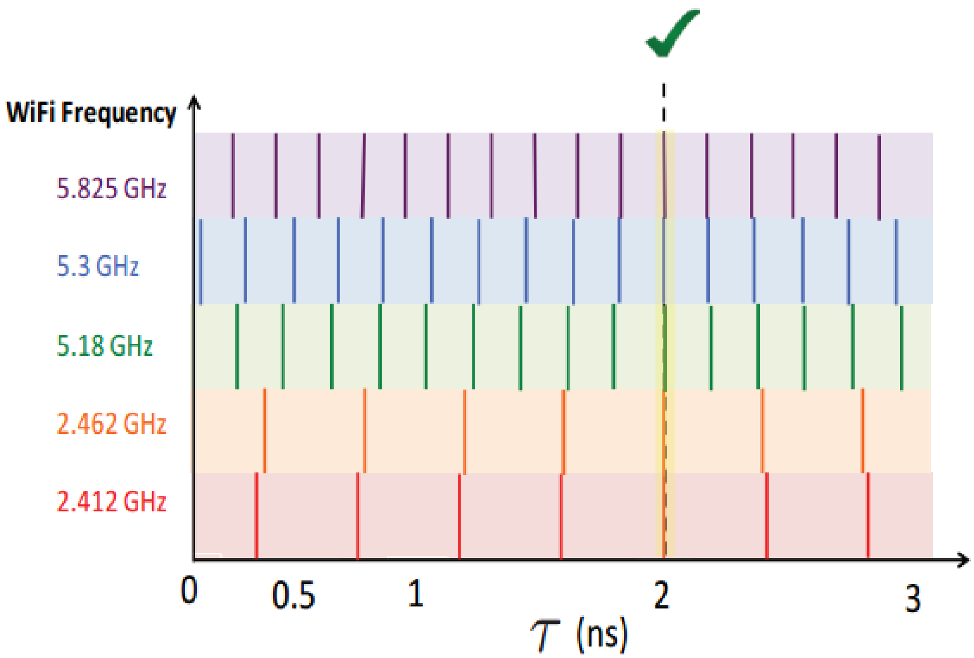

图 5: The LCM[3] Method

IV. Current Work

The current work is to find whether the CC2541 development board can be used in indoor positioning. CC2541 is a low energy and proprietary system-on-chip developed by TI. Shown in Fig. 6.

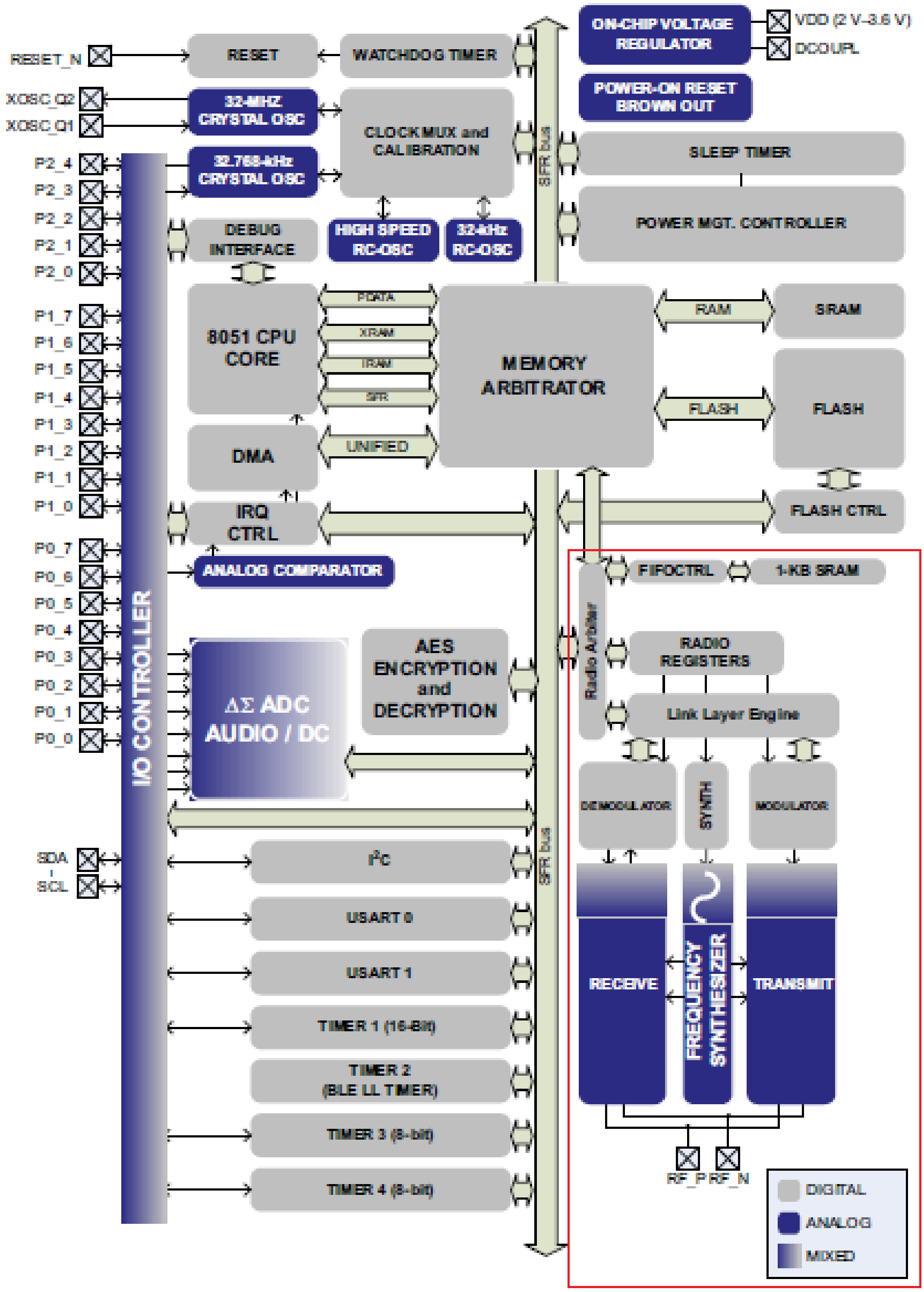

图 6: CC2541

What we are interested in is the BLE(Bluetooth Low Energy, the new protocol included in Bluetooth 4.0) Radio Module on this chip. Shown in Fig. 7.

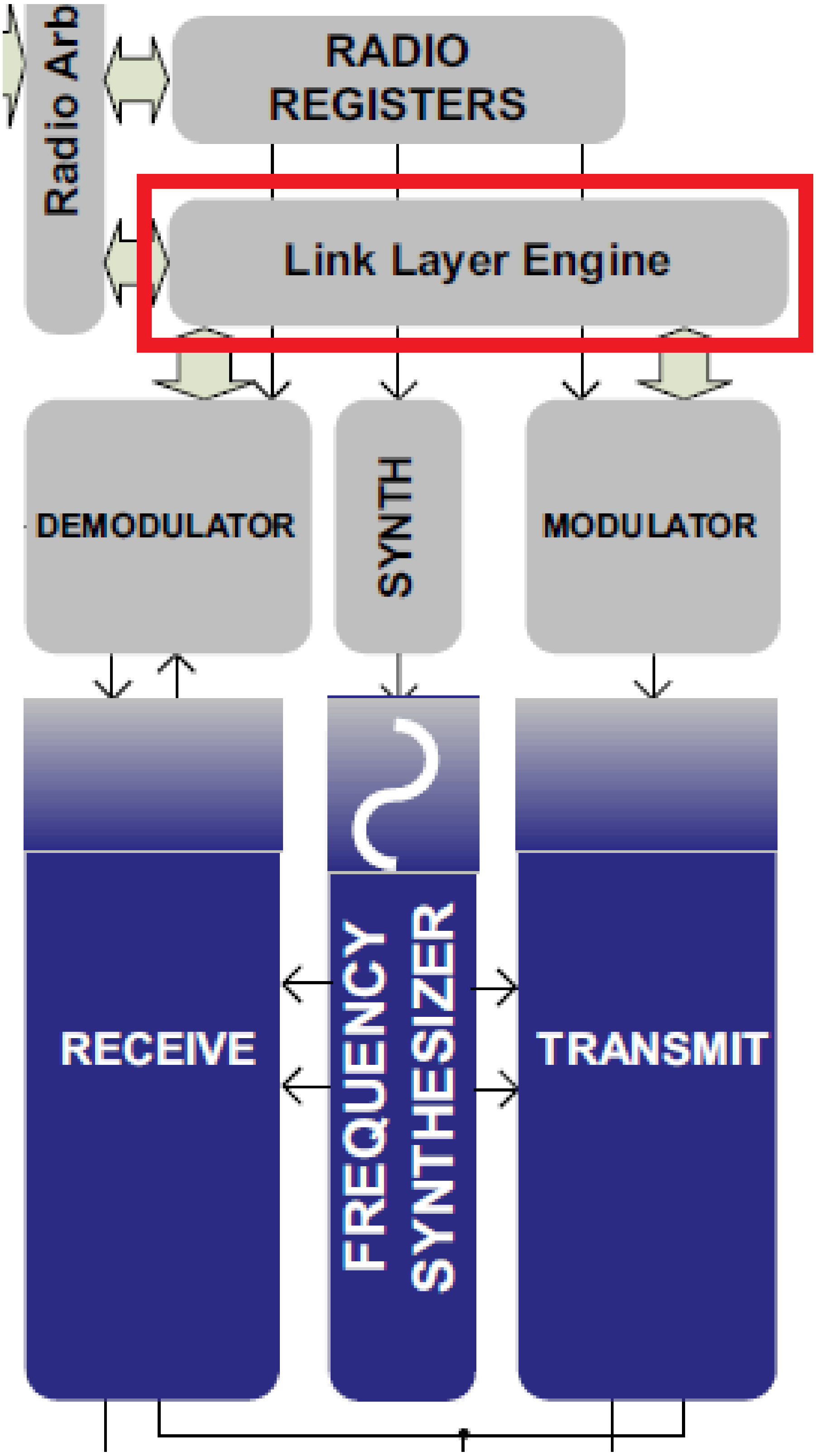

图 7: The BLE Radio Module of CC2541

To get the position using the above methods, RSSI(fingerprinting), phase(AOA) or time of flight(TOF) are required from the interface of this development board. Time measurement is unrealistic as the sampling time of CC2541 is 25ns while the multi-path arrival time is less than 10ns. So the possible method is fingerprinting and AOA.

(a) Finding the RSSI Value
The RSSI value is easy to find. It is provided as an 8-bit digital, 2s-complement signed

number on a logarithmic scale with 1-dB steps. It is measured by averaging the received power over eight symbol periods (128μs).

```
/*********************************************************************
 * @fn      simpleBLECentralRssiCB
 *
 * @brief   RSSI callback.
 *
 * @param   connHandle - connection handle
 * @param   rssi - RSSI
 *
 * @return  none
 */
static void simpleBLECentralRssiCB( uint16 connHandle, int8 rssi )
{
    LCD_WRITE_STRING_VALUE( "RSSI -dB:", (uint8) (-rssi), 10, HAL_LCD_LINE_1 );
}
```

图 8: The RSSI Interface Provided by Development Tools(Software Level)

From the User Guide, it can be found that this value can not be more accurate for the value is stored in a register in the above form.

RSSI (0x6198) – RSSI Status Register

Bit No.	Name	Reset	R/W	Description
7:0	RSSI_VAL[7:0]	0x80	R	RSSI estimate on a logarithmic scale, signed number in 2s complement Unit is 1 dB. The offset to use in order to convert the register value into the real RSSI value can be found in the data sheet of the device (Appendix C). The RSSI value is averaged over 8 symbol periods. The RSSI_VALID status bit should be checked before reading RSSI_VAL the first time. The reset value of –128 also indicates that the RSSI value is invalid.

图 9: The RSSI Interface Provided by the CC2541(Hardware Level)

(b) Finding the Phase
Contrast to RSSI, the phase still can not be found after searching for all the references.

- CC253x4x明细手册datasheet.pdf
- cc2541.pdf
- CC2541简明手册.pdf
- SIG-蓝牙-Core_V4.0.pdf
- swra114d.pdf
- swru271g.pdf
- TI官方BLE教程.pdf
- UserGuide.pdf
- 低功耗蓝牙cc254x开发指南（英文版）.pdf

图 10: The Reference User Guides

Possible Reason: The hardware has encapsulated to at least the link layer as shown in Fig. 7(the link layer engine in graph means that at least the link layer is implemented in hardware) while The phase measurement is ar the physical layer and it is unneccessary for the company to provide such an interface.

V. Future Work

LE Piconet: The Piconet is an adhoc network which links a wireless user group of devices(10m-100m) using Bluetooth technology protocols.
Aim: Build a distribution positioning system

VI. References

[1] Ramsey Faragher and Robert Harle "Location Fingerprinting With Bluetooth Low Energy Beacons," IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 33, NO. 11, NOVEMBER 2015

[2] Fazli Subhan; Halabi Hasbullah; Azat Rozyyev and Sheikh Tahir Bakhsh "Indoor Positioning in Bluetooth Networks using Fingerprinting and Lateration approach,"

[3] Deepak Vasisht, MIT CSAIL; Swarun Kumar, Carnegie Mellon University; Dina Katabi, MIT CSAIL "Decimeter-Level Localization with a Single WiFi Access Point," 13th USENIX Symposium on Networked Systems Design and Implementation (NSDI ́16)