1 Why a STA is required

The use of a highly directional high gain antenna operating in the unlicensed 57-64 GHz band is desired as part of prototype to realize a communication link between RF-ID like cheap wireless sensors and the base station, which is both the transmitter and ultimate receiver. The proposed transceiver exceeds the radio emission limits specified in Part 15.255 of the FCC rules and regulations, therefore requiring a STA for experimentation during development of the prototype. However, care will be taken to prevent any humans entering the regions of principal radiation by maintaining the emission levels below those specified in Bulletin 65, for the 3 locations described in detail in Section 4.

2 Purpose of Operation

We have proposed a novel architecture for data extraction from a network of low-power sensors with limited communication and computation capabilities that we term an 'Imaging Sensor Net'. Unlike in conventional multihop sensor to sensor communication, the sensors communicate directly with the collector/base station node using a line of sight channel. Since the origin of the sensed data is critical in many applications, this architecture utilizes a radar-like round trip delay estimation to additionally locate the sensors.

The collector node transmits a RF 'beacon', which is a long aperiodic pseudo-random noise sequence to initiate the communication using a highly directional high gain antenna. The sensors that are illuminated by the beacon electronically reflect the collector node's beacon, modulating the return with low rate data and frequency translation to avoid backscatter or ground return. The collector proceeds to sweep the entire field with overlapping illuminations of sensors. The received signals from these multiple illuminations are then jointly processed using techniques similar to Synthetic Aperture Radar Processing to extract the data, and locations of the corresponding sensors.

The 60GHz millimeter wave band was chosen for this prototype, since there is unlicensed bandwidth available and also at this frequency, multipath effects are at a minimum due to significant attenuation during reflections, which is desired to make the delay estimation algorithm accurate. We consider two possible architectures for the sensors - one in which the sensor reflects the beacon with no gain(similar to RF-ID sensors) at the sensor and the other, where the sensor amplifies the signal before reflection. In the RF-ID like sensors, the collector node must provide enough power in the beacon in order to compensate for the attenuation in both the down and up links, which necessitates large transmit powers at the collector. The transmitter emission characteristics are provides in the next section.

3 Radio Emission Characteristics

We now estimate the transceivers in band and out of band emission for the different deployment sites.

3.1 In-band Emissions

The transceiver Cassegrain transmit antenna used in the collector radio has the following specifications:

Operating Frequencies(Wavelength λ)	=	59 GHz(5.1 mm) to 62 GHz(4.8 mm)
Antenna Input Power(P)	=	200 mW(23 dBm)
Directivity(G) with $3dB$ antenna loss	=	40 dB
EIRP	=	2 kW
Diameter(D)	=	30 cm
Peak to average Power ratio	=	5dB
Main Lobe Width	=	2° azimuth & zenith

FCC Office of Engineering and Technology Bulletion 65(OET-65) provides guidelines and methods for evaluating compliance with FCC's human exposure regulations[1]. Emission limits for operation in the the desired unlicensed 57-64 GHz band are specified in [2].

The power densities are now calculated at $60GHz$ or $5mm$ wavelength. The near field boundary is defined by[1] as

$$R_{nf} = \frac{D^2}{2\lambda} = \frac{(0.3)^2}{4 * 0.005} = 4.5m$$

and the power density in the near field is

$$S_{nf} = \frac{16\eta P}{\pi D^2} = \frac{16 * \eta * 10^{-0.7}}{\pi * 0.3^2} = 1.13\eta \text{ mW/cm}^2$$

where η is the aperture efficiency give by

$$\eta = \frac{G\lambda^2}{\pi^2 D^2} = \frac{10^4 * 0.005^2}{\pi^2 * 0.3^2} = 0.2814.$$

Therefore, in the near field(for distances less than R_{nf}),

$$S_{nf} = 318\,\mu W/cm^2.$$

For distance greater than R_{ff},

$$R_{ff} = \frac{0.6D^2}{\lambda} = \frac{0.6(0.3)^2}{0.005} = 10.8m$$

the power density at a distance R is

$$S_{ff} = \frac{PG}{4\pi R^2} = \frac{30 * 10^4}{4 * \pi * 100^2 * R^2} = 238.732\ W/R^2,$$

for e.g. with R = $1m$, $S_{ff} = 238.732\ W/m^2 = 23.8\ mW/cm^2$. The emission levels for operation of RF devices in 57-64 GHz band are 9 $\mu W/cm^2$ average and 18 $\mu W/cm^2$ peak measure at 3 m from the antenna. The power density for the Cassegrain used is $318\mu W/cm^2$ average and $954\mu W/cm^2$ peak power density (in the near field).

3.2 Out of band emissions

The out-of-band radiations are minimized by a combination of a transmit band-pass filter and the inherent high-pass filter characteristics of millimeter-wave waveguides. The rectangular V-band waveguides(e.g. Aerowave 15-1205) in the transmitter has a cut-off frequency of $40GHz$ below which any out-of-band signals from the transmitter are attenuated very strongly. In the 2" length of waveguide, the loss at 38 GHz exceeds 100 dB. The RF transmit filter(Quinstar

QFB-6103V0) used has an insertion loss of 1dB in the passband of 59-62 *GHz*. The transmit filter has a stopband (< 57 and > 64 *GHz*) with attenuation of atleast 25dB i.e. power transmitted in the stopband is less than 1 *mW* even under the extreme worst-case assumption of 100% of the transmitter output power being out-of-band.

4 Test Sites

We intend to use 3 different test sites all in the vicinity of the Engineering Sciences Building on campus. The 3 locations are desired to test the system for short, medium and long ranges. Figure 1 shows the test sites on an enlarged campus map. In Figures 2, 3 and 4, plan and elevation views of the 3 test sites are shown. The figures also present the power density at the sensor nodes and the maximum power densities on humans standing in the main lobe or on a side-lobe of the antenna. Note also that the peak and average power densities are the same for this system. It can be seen that power densities are below the 1 mW/cm^2 legally permissible limit for human exposure in all 3 sites even for humans on the main lobe of the antenna. We would also like to assure the FCC that we would take care to cordon off the experimental areas or perform experiments during weekends as far as possible to further reduce the exposure to humans in the area. Figures 5,6 and 7 are pictures of the 3 sites looking from the 'eye' marked on figures 2, 3 and 4.

Figure 1: Reference schematic for emission specification for different transmitter locations

References

[1] *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*, FCC Office of Engineering & Technology, Bulletin 65, August 1997

[2] Section 15.255, *Part 15, FCC Rules and Regulations*, FCC Office of Engineering & Technology, February 2006

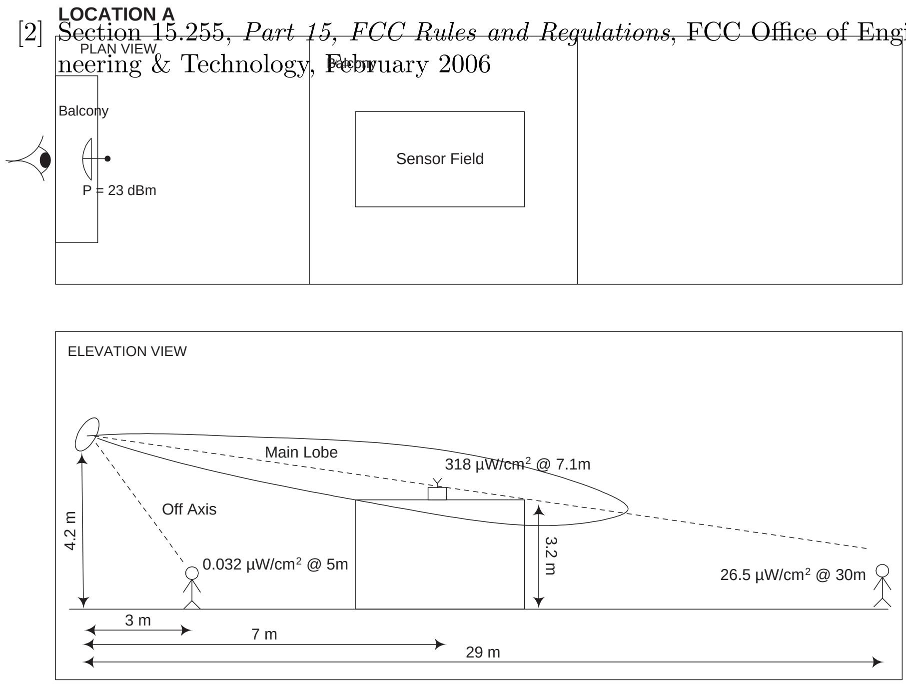

Figure 2: Site A for short range testi

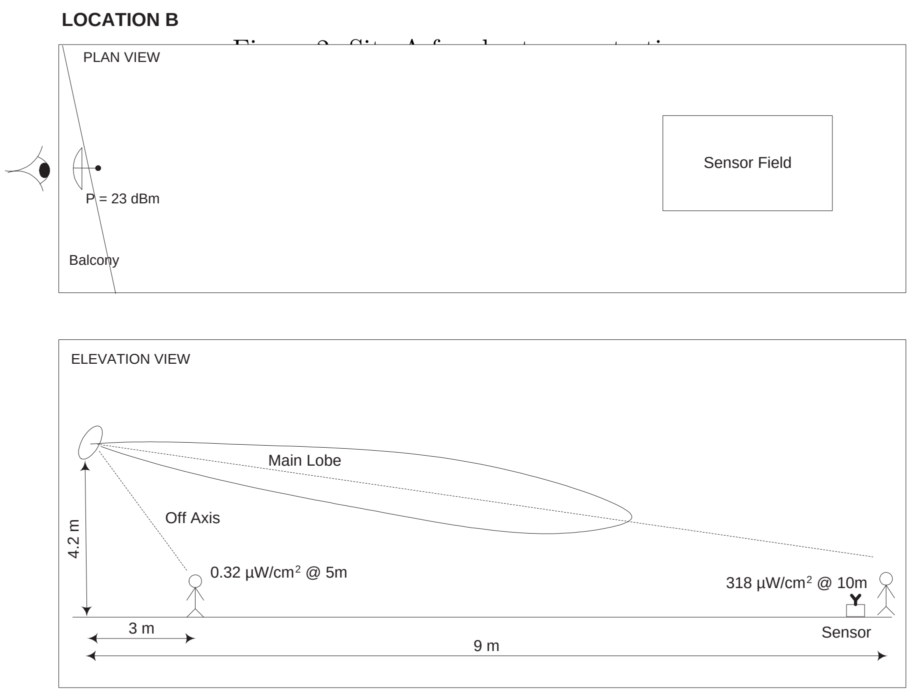

Figure 3: Site B for medium range testing

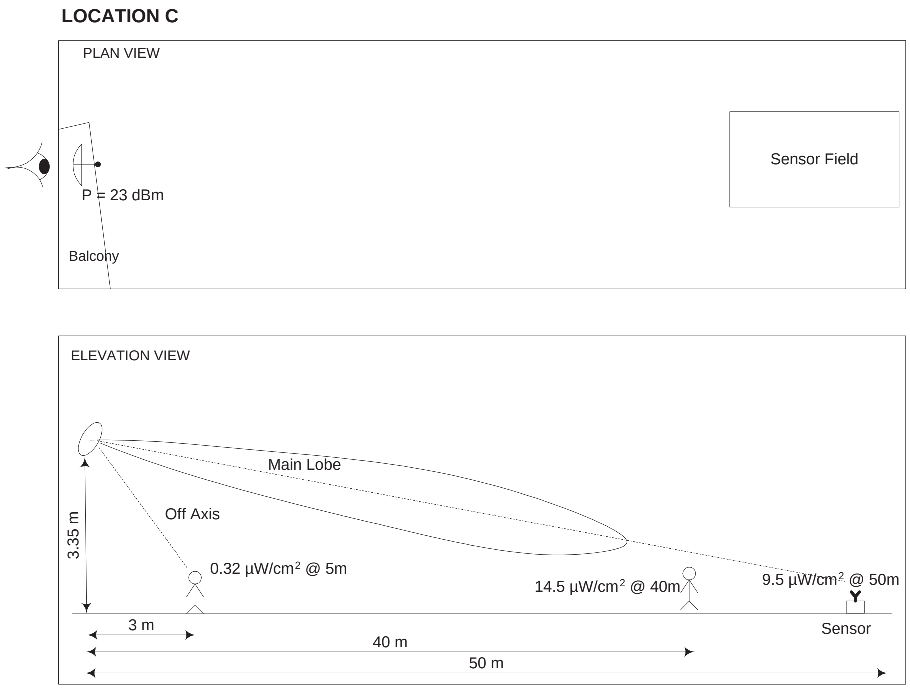

Figure 4: Site C for long range testing

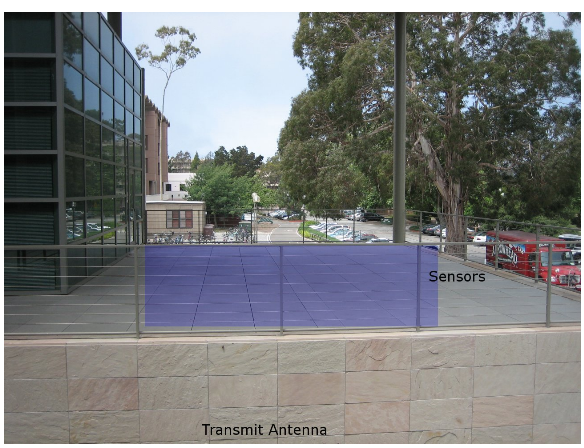

Figure 5: Site A for short range testing (looking from the ‘eye’ in the plan view of site A)

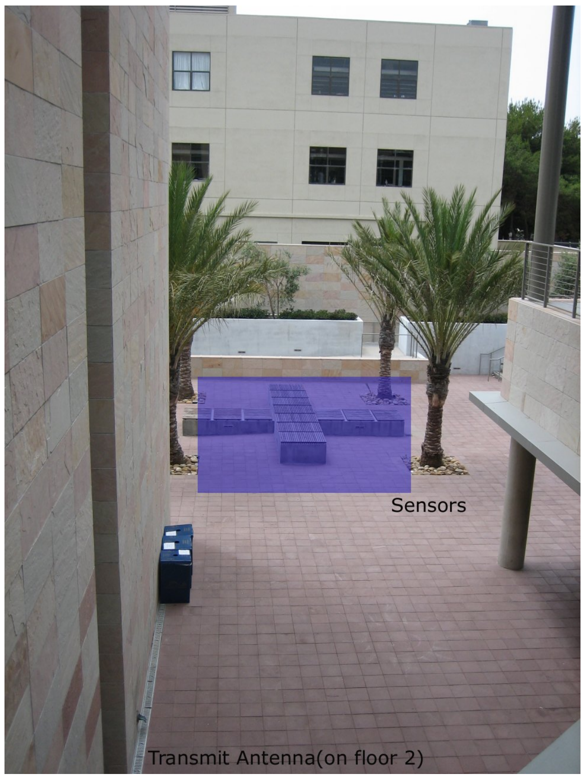

Figure 6: Site B for medium range testing (looking from the ‘eye’ in the plan view of site B)

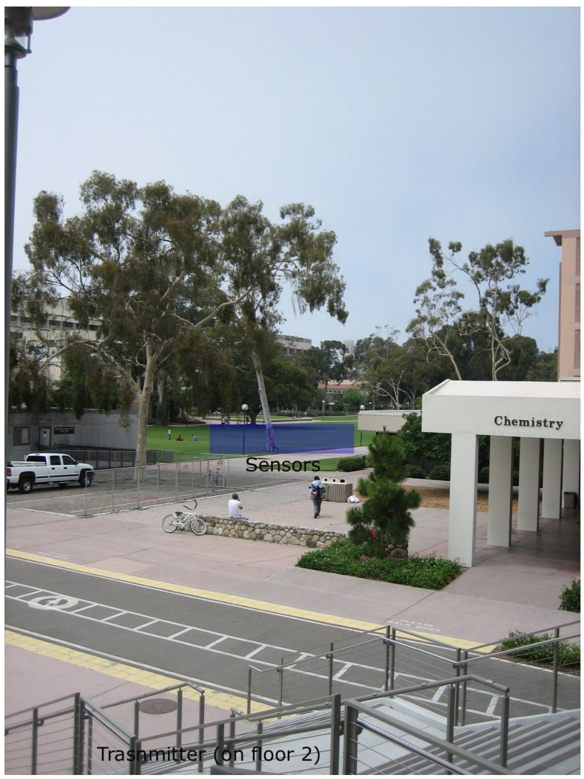

Figure 7: Site C for long range testing (looking from the 'eye' in the plan view of site C)