

# Analysis of the Effect of Human Presence on a Wireless Sensor Network

**Ben Graham, Christos Tachtatzis, Fabio Di Franco, Marek Bykowski  
David C. Tracey, Nick F. Timmons and Jim Morrison**

WiSAR Lab, Letterkenny Institute of Technology, Letterkenny, Co. Donegal, Ireland  
{ben, christos, fabio, marek, david, nick, jim}@wisar.org

## Abstract

Wireless Sensor Networks (WSNs) are gaining an increasing industry wide adoption. However there remain major challenges such as network dimensioning and node placement especially in Built Environment Networks (BENs). Decisions on the node placement, orientation, and the number of nodes to cover the area of interest are usually ad-hoc, which leads either to poor coverage or over-provisioned, over sized networks. Ray tracing tools are traditionally employed to predict RF signal propagation however such tools are primarily intended for outdoor environments and do not accurately predict RF performance in buildings. RF signal propagation varies greatly indoors due to building materials and infrastructure, obstacles, node placement, antenna orientation and human presence. Because of the complexity of signal prediction these factors are usually ignored or given little weight when such networks are analyzed. The contributions of the paper are multi-fold. The results show the effects of the building size and layout, building materials, human presence and mobility on the signal propagation of a BEN. Additionally, they show that antenna radiation pattern is a key factor in the RF propagation performance, and appropriate device orientation and placement can improve the network reliability. Further, the RSS facility in RF transceivers can be exploited to detect the presence and motion of humans in the environment. The results presented are obtained and analyzed from a real BEN deployment and illustrate that such parameters must be considered when planning and deploying BENs.

## 1 Introduction

Developments in wireless technology and sensors have resulted in a range of new applications for Wireless Sensor Networks (WSNs). One such type of WSNs is the Built Environment Networks (BENs) which can be deployed in a wide variety of applications such as environmental monitoring, surveillance and healthcare applications. WSNs are characterized by having a large number of devices (motes) with sensing capabilities, limited processing capability and wireless connectivity to other devices. The wireless capability allows the sensors to be deployed close to the phenomenon being observed while their limited memory and processing capabilities result in low cost; this allows the deployment of a large number of such devices. The motes used in WSNs usually contain a micro-controller, RF chip, sensors and often use low level operating systems such as TinyOS [1] or Contiki [2].

When deploying a wireless network within a building, it is vital to have an understanding of how the transmitted signals are affected through obstacles and with distance. The channel between transmitter and receiver may be a line of sight (LOS), but more likely the presence of objects such as office furniture, lab equipment and people will create obstructions and provide multiple paths (multipath) for the waves to reach the receiver. Diffraction, reflection and scattering are main causes of multipath and fading. Multipath and fading are the dominant effects on the channel as the transmitted signal propagates through the media to the receiver [3]. The ideal antenna radiation pattern for a mote is symmetric in all directions and would result in constant radio range and performance in a spherical radius of the mote [3]. In reality this uniform transmission pattern does not exist and failure to understand a mote antenna transmission pattern and how it can be affected by the environment can result in network reliability issues and/or inappropriate placement of motes. There are numerous papers that investigate the relationship between signal attenuation and building materials [4][5][6] and software packages that simulate the radio frequency (RF) attenuation within buildings using ray

tracing techniques [7]. Little attention has, however, been given to the effects that antenna pattern irregularity and human presence can have on the signal strength and reliability of even a small scale network when it has been deployed.

This paper provides measurements of Received Signal Strength (RSS) from within various locations of a typical office environment during a twenty four hour period and an understanding of how signal attenuation is affected by building materials, antenna selection, orientation and both human presence and movement.

The paper is divided into five sections. Section 2 and 3 describe the experimental setup and software used. The results of the experiments are provided and discussed in Section 4. Lastly Section 5 concludes by highlighting the main outcomes of the paper.

## 2 Experimental Setup

The experiment consisted of a large number of motes deployed within an office environment for a 24 hour period. The purpose of the experiment is to measure the RSS from a large number of locations within the office. This is achieved by having multiple motes within the lab transmitting data back to a basestation. Measurements of RSS were taken using the CC2420 Received Signal Strength Indicator (RSSI) and used to build a map of the signal attenuation from the centralized basestation. The CC2420 datasheet states that the RF chip has a very linear RSSI measurement with a dynamic range of about 100dB [8]. To verify this linearity stated in the datasheet a calibration test was carried out; the results confirmed the linearity was within the  $\pm 6$ dB error allowed over the majority of the dynamic range. However non-linear behaviour was highlighted at transmission powers below -85 dBm.

The use of a twenty-four hour test period means that measurements are taken when the office is occupied during the day and unoccupied at night so that the changes in RSS due to human presence can be detected. The use of a large number of motes ensures that an accurate map of RSS can be obtained.

### 2.1 Location and hardware

The experiment was carried out within the WiSAR Lab which is located in the CoLab building at the Letterkenny Institute of Technology. The lab is located on the second floor and consists of four rooms with a total ground area of 95m<sup>2</sup>. The four rooms consist of two general offices these being Room 204 and Room 205A, one large lab Room 205 and a machine room/store 205B. During the twenty four hour experiment all four rooms will have had people in them at some point, for the duration of the daytime working hours (09.00-17.30). More specifically room 204 has three occupants, room 205 had two and both 205A and 205B had none.

For the duration of all experiments, the basestation was located in the centre of room 205 and attached to the ceiling. This is the most central location for a basestation and has a line of sight, or a fairly unobstructed line, to most of the locations under test. The basestation was fitted with a 1/4 wave monopole vertically oriented stub antenna. Each room has a suspended ceiling at a height of 2.7 metres, with each ceiling consisting of equally sized tiles, which made an excellent grid that aided with the placement of the motes (Fig 1). All internal walls within the lab are stud partition and all external walls of the lab are concrete.



Fig 1 – Motes attached to ceiling

The experiment was performed at a total of seventy locations within the lab, divided into seventeen locations in Room204, thirty-three in Room 205, eight in Room 205A, ten in Room 205B and two additional locations in the hall. Fig 2 shows a map of the mote locations within the lab, the grey circles represent the occupied workstations, the white circle represents the basestation while the orange square in the middle of room 205 represents unoccupied workstations. All walls are represented by the black line. Due to the large number of locations to be measured, the experiment was sub-divided into five separate areas of fourteen motes at any one time. With this in mind the room layout does change slightly for each experiment because of the different placement of the motes. It is not known if these small differences have an affect on the experiment results but it must be acknowledged that they exist.

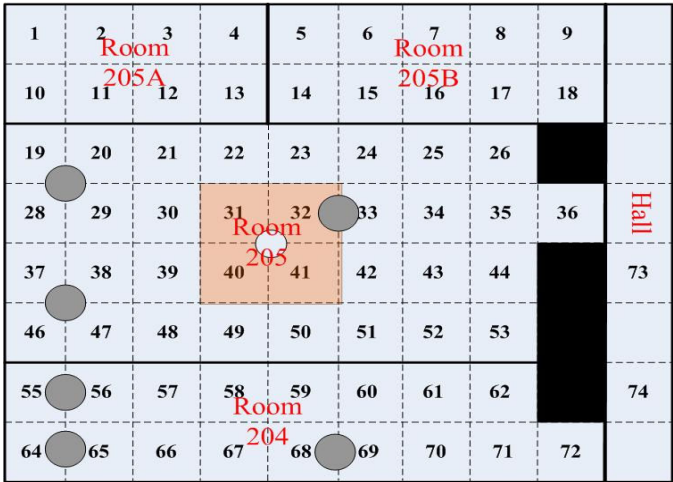


Fig 2 – Layout of mote locations within the lab

The WiSAR mote [9] was used for the transmitters in the experiments. It is based on the commonly available IEEE802.15.4 compliant Tmote Sky [10] which uses the MSP430F1611 microcontroller and the CC2420 radio transceiver from Texas Instruments. This is a suitable test device for a BEN as it provides the data-rate and low power requirements of BEN applications. As the WiSAR mote has no USB Circuitry [11], a Tmote Sky was used as the basestation so that its USB connection could be used to connect to a database server to collect the results.

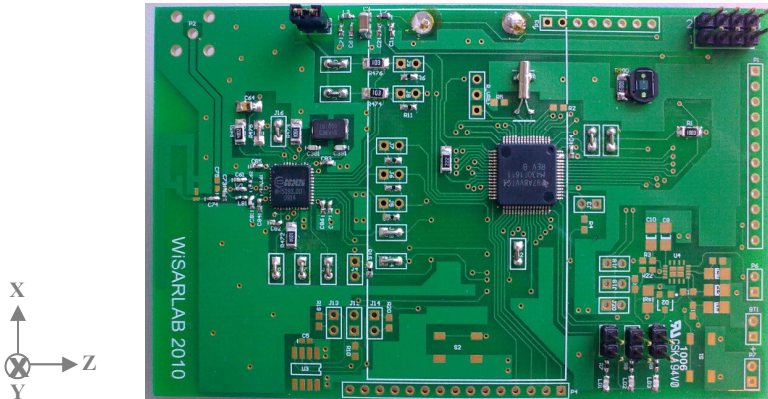
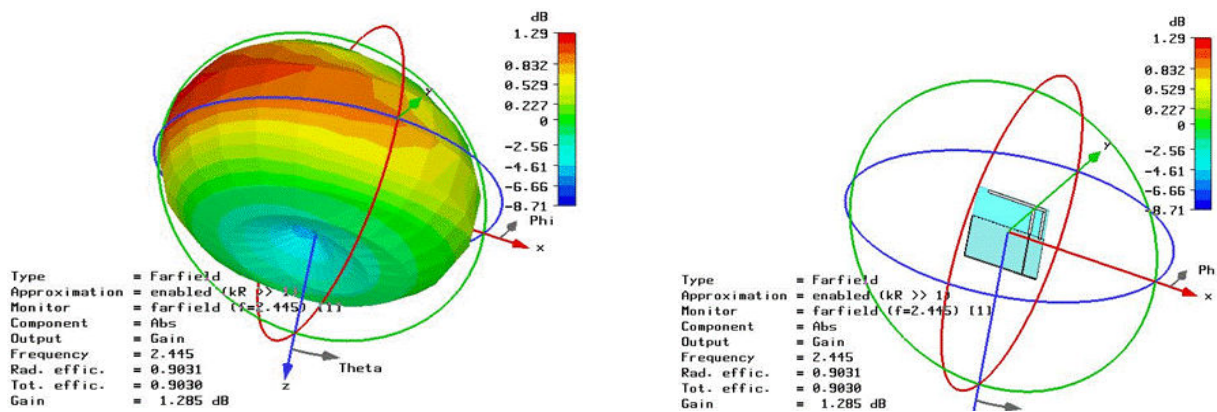


Fig 3 – WiSAR Mote

The Tmote sky and the WiSAR Mote incorporate an inverted-F PCB Antenna. The inverted-F PCB antenna is one of the most commonly used antennas at 2.4GHz mainly due to its minimal cost and radiation pattern which is effective for omnidirectional applications. The inverted-F PCB antenna is often stated as been omni-directional, but in fact its radiation pattern is directional and this means that the transmitter mote’s orientation will have an affect on the RSS at the basestation. Fig 5 shows a 3D simulation of the radiation pattern for an inverted F antenna [12]. The strongest direction of radiation is on the X and Y axis in the direction of the antenna tip.



**Fig 4 – Radiation Pattern of inverted F antenna [12]**

All motes were attached to the ceiling in an identical position with the antenna pointing towards the floor. This is not an ideal antenna direction, but was the most suitable in terms of mounting. With the motes positioned in this manner, the strongest RF signal will be transmitted towards the ground on the X axis and slightly towards the front of each mote. This setup was selected to highlight how incorrectly aligned antennas can affect the network where the multipath is most dominant between all locations and the basestation.

Finally, an RF sweep of the lab with a spectrum analyzer, showed that Wireless Local Area Network (WLAN) were operating on channels 1,6 and 11 at frequencies 2412MHz, 2437MHz and 2462MHz respectively. In order to reduce the effects of interference, the experiments were performed at 2425MHz, which was found to be unoccupied by other devices.

### 3 Software

Software was developed for both the basestation and transmitter devices for this experiment. All software was developed to run on a TinyOS platform [1]. TinyOS is an open source operating system designed for wireless embedded sensor networks.

The transmitter uses a typical timer based sensor program, which wakes the microcontroller from low power mode (LPM3) every 10 seconds, performs a temperature, humidity, light and battery measurement, increments a sequence number, then transmits this along with its node id before returning to sleep (LPM3). The total transmitted packet payload length was 18 bytes.

The basestation program receives incoming packets from the radio, calculates the RSS from the incoming packet, before forwarding the received packet including the added RSS information to a database. This data is stored in a database server, connected to the basestation by USB, and all packets entered into the database are time stamped. The data in the database can then be used in two ways; it can be extracted manually for analysis, or it can be viewed as a historical plot via the WiSAR Lab webpage [13].

### 4 Results

The following results are presented in three sections; those at night when the office was empty, those during the day when people are present and an Antenna orientation section which investigates the effect of the antenna radiation pattern. The median and standard deviation are presented here for both the day and night set of results. The median was obtained rather than the mean as the median is unaffected by any outlying results. The standard deviation was also obtained for both night and day to indicate the signal fluctuation at each measured location. The RSS median of the night results were recorded without any human presence and show the effects of distance, mote orientation, and building materials on the signal strength. The daytime results allow the analysis of human presence on the WSN. The mote's orientation is shown at the bottom of each plot, with the X-axis perpendicular to the floor.

#### 4.1 Night-time (Empty Office) Results

All night time measurements were taken when the office was empty between the hours of 22.00 and 08.00. Due to the number of node locations to be measured, experiments had to be carried out over 5 consecutive nights. During this time the room layout remained constant in order to minimize any effects that may have arisen due to changes in multipath caused by changes in office layout, but as mentioned earlier small changes did occur due to the different placement of motes during the separate tests.

Fig 5 shows the median of the RSS during the night for all locations and these are the reference RSS values when the environment is constant. The RSS values range from -35 to -85 dBm, and generally nodes closest to the basestation showing the higher values and nodes further from the basestation showing lower values with the following exceptions. At this point it should be remembered that all transmitter motes are placed in a non ideal orientation.

- In Fig 5 node location 20 shows the median RSS to be -45 dBm while the nodes closer to the basestation are less. One possible explanation may be that node 20 is located directly above an equipment rack. As the node's strongest transmission path is in the direction of the floor, a reflection may be occurring from the rack to the basestation, unlike the nearby locations where the most of the RF is reaching the floor.
- In the same way location 32 has a significantly lower RSS value than location 40 which is at a similar distance from the basestation, again this may be due to the fact that location 40 is transmitting directly down to a desk area and location 32 is just on the edge of this desk area.
- As mentioned earlier the directional radiation nature of the inverted F antenna is strongest on the X axis towards the floor and slightly to the front of the mote on the Z axis. This Z axis radiation can be observed by the fact that motes located in Room205A and Room205B present a stronger RSS than the motes in Room 204, even though the motes are at a similar distance from the basestation.

Greater attenuation was observed at nodes 8, 9, 17, 18 and this can be explained by the presence of several metal enclosures in their vicinity. These locations were all measuring RSS values less than -85dBm, which is outside the linear range of the CC2420's RSSI measurements.

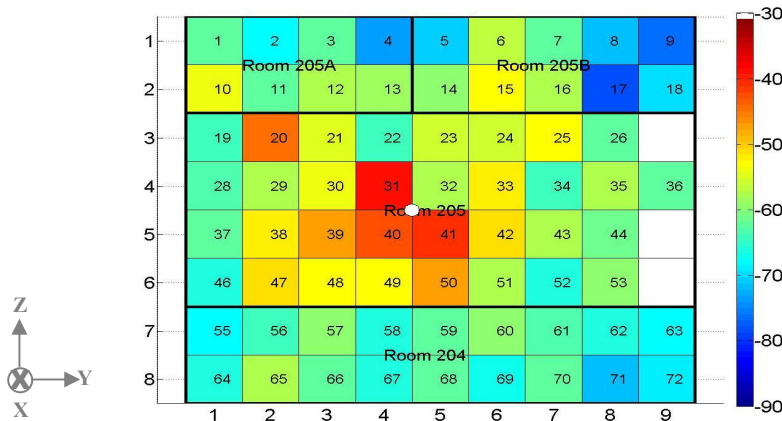


Fig 5 – Median RSSI values at night

Fig 6 shows the standard deviation of the RSS values over the night period. The majority of the motes as expected show very little variance as the environment remains constant and the multipath is unchanged. But two motes at locations 10 and 32 showed higher fluctuations of 5 and 6dBm respectively (even after swapping the motes to eliminate the possibility of faulty hardware).

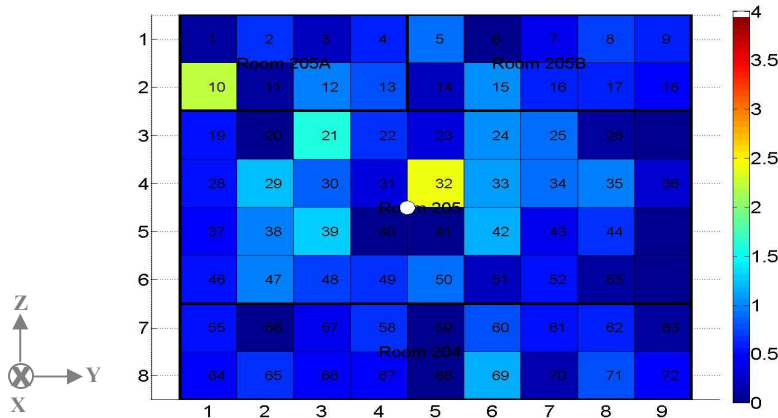


Fig 6 – RSSI variance at night

## 4.2 Day Time Results

All day-time measurements were taken during working hours and as with the night measurements the experiments had to be carried out over 5 consecutive working days. During this time, the office layout was kept as constant as possible. The number of humans present and their movement patterns during the 5 day tests would have varied slightly as can be expected in any real deployment. The lab had 5 occupied workstations for the majority of the daytime experiments located under motes 56, 65, 69 between motes 19 and 28 and between 37 and 46. Fig 7 shows the median of the RSS for all locations during the daytime hours.

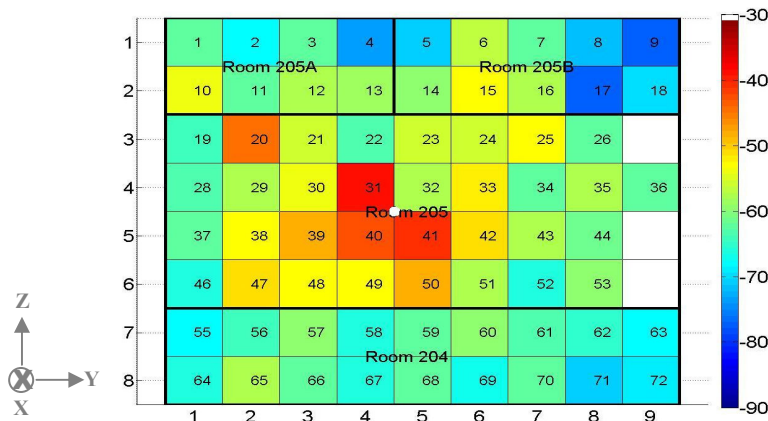
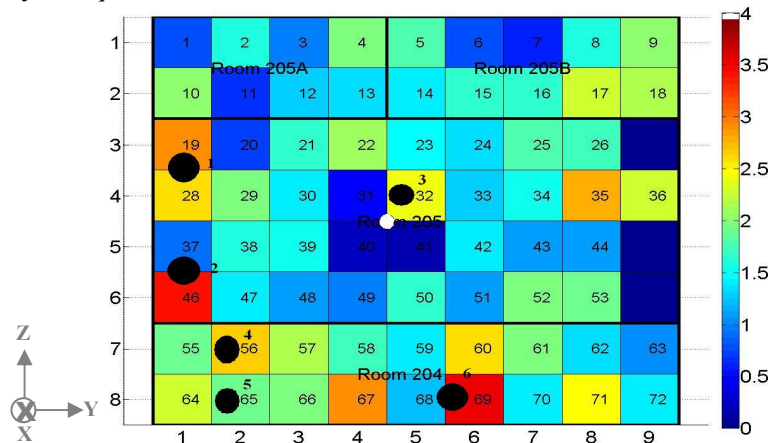


Fig 7 – Median RSS values of the day

The median RSS results from during the day are almost identical to the night time results and on first sight, suggests that human presence has no effect on RSS, but this is not the case as was seen when viewing the RSS time series. For this reason, it is necessary that the fluctuations in the measurements are considered.

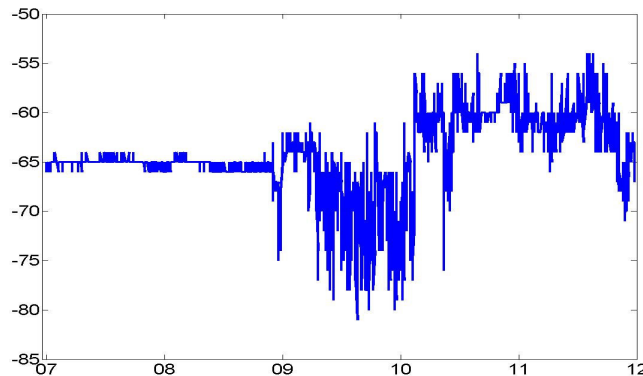
Fig 8 shows the standard deviation of the RSS over the full twenty four hour period and more importantly highlights several locations that show high levels of fluctuations which were not present during the night. The black circles represent the location of occupied workstations. The highest variations were at locations 46 and 69 with a RSS ranging from -55 to -80 dBm and -62 to -80 dBm respectively during the 24 hour period. Both of these motes were located in close proximity to an occupied workstation, showing that human presence is having a major effect on RSS. Similarly, motes 19, 28, 32, 56 and 60 presented larger than normal fluctuations as all of these motes were in close proximity to an occupied workstation. Motes 22, 36 and 71 were located above the doorway to room 205A, 205 and 204 respectively and all showed a larger than normal fluctuation, due to people frequently passing under these locations as they enter and exit the lab. Mote 67 in room 204 also

showed higher than normal fluctuation but in comparison to the other nodes it was not in close proximity to any occupied workstations.



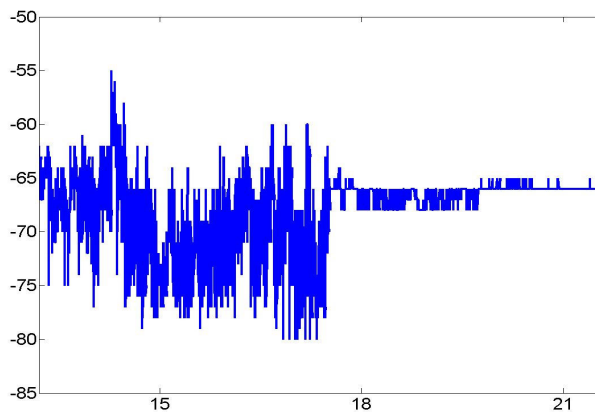
**Fig 8 – RSS variance over the 24 hour period**

As an example of the RSS fluctuations experienced by a node above an occupied workstation, Fig 9 shows the time series of the RSS for node 46 from 07.00-12.00. From 07.00-08.45 the RSS is constant at approximately -65 dBm as no humans were present in the lab. At 08.45 when someone enters room 205 and moves to workstation 1 causes the RSS to drop. At 09.00 another person enters and sits at workstation 2 increasing the RSS. For the rest of the working day the RSS fluctuates widely while people move within the room affecting the signal strength. This plot shows the major effect on RSS of just two people in the lab and the resulting RSS fluctuations.



**Fig 9 – Node 46 RSS for 07.00-12.00 hrs**

Fig 10 plots RSS for the same node 46 from 12.00-22.00 and it is easy to observe that the fluctuation almost disappears from 17.30, when the room becomes empty.



**Fig 10 – Node 46 RSS for 12.00-22.00 hrs**

### 4.3 Antenna Orientation Results

The final test was to confirm the effect of the antenna radiation pattern, by repeating the experiment on selected locations. This time the motes were positioned in such a manner that their antenna z-axes were perpendicular to the floor. With this test it was confirmed that when the antenna tip pointed towards the basestation, the RSS values were higher compared to previous setup. Additionally, the effect of human presence and movement was less, because the strongest path of radiation was in the horizontal direction unlike the previous setup that was directed downwards to the occupants.

Fig 11 shows a plot of RSS from node 46 with the new mote orientation. This location was selected because it suffered the highest fluctuation in the previous experiments. Like before, during the night and when the office was empty the RSS was constant. However, the observed median was -58 dBm instead of -65 dBm. During the day, when the office was occupied fluctuations still occurred (in the range of -53 dBm to -65 dBm) but were not as severe as in the pervious setup (-55 dBm to -80 dBm)..

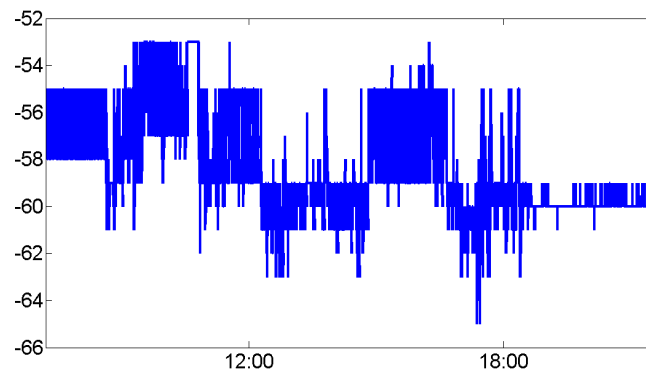


Fig 11 – Node 46 RSS for 07.00-12.00 hrs

## 5 Conclusion

This paper has provided an insight into the deployment of a real WSN in a typical office environment. The results presented in this paper show the effects of the mote placement and radiation patterns. For example, a one metre move in the placement of a mote can vary the RSS by up to 20dBm. The placement of motes close to large metal objects such as filing cabinets or equipment racks can have unpredictable effects on the signal propagation. Therefore, before deploying motes within a network it is important to both understand the radiation pattern of the motes and the office layout. This information should then be used when positioning motes to ensure that their orientation effectively utilises any directional feature.

In addition, human presence within close proximity of motes greatly affects the transmission performance, both in a positive and negative manner. The results highlighted this fact by the large fluctuations of RSS over twenty four hours for motes close to occupied workstations. These fluctuations occur as the movement of a human body causes the multipath signal to change and results in unpredictable RSS, which can often result in dropped packets. The effect of human presence in the experiments carried out was heightened by the fact that the motes located above the workstations were transmitting directly down on the occupants and their movement was directly affecting the multipath. The final test confirmed this by positioning the motes with the strongest transmission directed away from human presence, resulting in reduced fluctuations.

In summary, the findings demonstrate that the effects of both antenna orientation and human presence must be considered when designing new network protocols and deployment layouts. The results also show the potential application of using WSNs deployed in a building to detect human presence and movement. It is recommended that software simulation tools, such as those employing ray tracing techniques, should include the effect of human presence on propagation and incorporate necessary models for this when network planning. Future work is planned on implementing these results in new software models to enhance simulation tools. Longer term tests are also planned that will investigate the relationship between human presence and movement, RSS and the effects on packet error rate in this office deployment.

## Acknowledgment

This work was carried out under the auspices of Enterprise Ireland Applied Research Enhancement (ARE).

## References

- [1] P. Levis, S. Madden, J. Polastre, R. Szewczyk, K. Whitehouse, A. Woo, D. Gay, J. Hill, M. Welsh, E. Brewer, and D. Culler (2005) *TinyOS: An Operating System for Sensor Networks in Ambient Intelligence*, W. Weber, J. M. Rabaey, and E. Aarts, Eds. Berlin/Heidelberg: Springer-Verlag, 2005, ch. 7, pp. 115-148
- [2] Adam Dunkels, Björn Grönvall, Thiemo Voigt (2004) *Contiki - a Lightweight and Flexible Operating System for Tiny Networked Sensors*.
- [3] Weilian Su, Mohamad Alzagal (2008) *Channel propagation characteristics of wireless MICAz sensor nodes*. Ad Hoc Networks (Elsevier) Journal 1183-1193 Monterey, CA 93943, United States.
- [4] W.S Jang, W.M Healy (2009). *Wireless sensor network performance metrics for building applications* Energy and Buildings (Elsevier) Journal (2010) 862-868 Gaithersburg, MD.
- [5] Robert Wilson (2002). *Propagation Losses Through Common Building Materials 2.4GHz vs 5 GHz* University of Southern California.
- [6] T.Masri, S.P Chew, CP.Wong, K.Lias (2005). *A Study of Signal Penetration Into Building Materials* University Malaysia Sarawak.
- [7] H.Kim, H.Lee (2009). *Accelerated Three Dimensional Ray Tracing Techniques using Ray Frustums for Wireless Propagation Models*. Sogang University, Seoul, Korea Progress in Electromagnetics Research
- [8] Texas Instruments “2.4GHz IEEE 802.15.4/Zigbee-ready RF Transceiver” <http://focus.ti.com/lit/ds/symlink/cc2420.pdf>
- [9] WiSAR Lab “WiSAR Lab Development Mote” <http://www.wisar.org/>
- [10] Moteiv Corporation “Ultra low power IEEE 802.15.4 complaint wireless sensor module” <http://sentilla.com/files/pdf/eol/tmote-sky-datasheet.pdf>
- [11] F.D.Franco, C.Tachtatzis, B.Graham, M.Bykowski, D.C.Tracey, N.F.Timmons, J.Morrison (2010). *Current Characterisation for Ultra Low Power Wireless Body Area Networks* 8th IEEE Workshop on Intelligent Solutions in Embedded Systems(WISES 2010) Heraklion, Crete, Greece, July 2010.
- [12] Ember Corporation “Designing with an inverted-F PCB antenna” [http://www.ember.com/pdf/120-5052-000\\_Designing\\_with\\_a\\_PCB\\_Antenna.pdf](http://www.ember.com/pdf/120-5052-000_Designing_with_a_PCB_Antenna.pdf)
- [13] WiSAR Lab “WiSAR Lab Office Testbed” <http://monitor.wisar.ie/>