Wireless Sensed Environment for Body Area Networks

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Abstract – In low power wireless body area networks it is envisaged that there will be communication between on-body devices and wireless nodes placed in the environment (sensed environment) to provide a range of applications including health monitoring. However, there remain major challenges to realise this scenario such as decisions on the optimal node location, node orientation, transmit power level, and the number of nodes to cover the area of interest (sensed environment) which if not correct can lead to poor coverage or over-provisioned, oversized networks. In this paper we experiment with a BAN device and nodes deployed in a variety of locations throughout an office environment to represent a sensed environment. Packet loss rates (PLR) were analysed to explore trade-offs between node densities and transmit power levels. We determine that the deployment location, the density, and BAN transmission power level are important factors to be considered in the scenario where a mobile BAN communicates with a sensed environment. We found that deploying the environment nodes at chest height on the surrounding wall yielded the best results in terms of coverage and node density providing an optimal link between the BAN and the sensed environment.

Keywords – Wireless Sensor Networks (WSN), Body Area Networks (BAN), wireless, sensors, sensed environment

I INTRODUCTION

Due to the increasing average age of populations in the world today and the associated rise of healthcare costs, the development of systems for freeing hospital resources is of particular interest in academic and industrial researchers [1]. A proposed solution to this issue is to use on-body devices and wireless nodes placed in the environment such as, the home, workplace, or hospital (wireless sensed environment). This could ease the demands on current medical centres by reducing unnecessary hospital visits through monitoring patients in their homes. The sensed environment functions as an interface from the BAN to other networks. Deployment of the nodes for the sensed environment is a fundamental issue. The numbers, density, and location of nodes will determine signal power, RF coverage, cost, and node lifetime. A sensed environment would be considered to be completely covered if every point in the space is within RF range of an active node in the environment, thus permitting a BAN to remain connected to the outside world while it moves through the environment [2]. Cost and node lifetime are affected by the number of nodes; fewer nodes deployed will require higher transmit powers which in turn will affect battery lifetime. Fewer nodes will also be less effective in busy offices cluttered with furniture and equipment. Using lower transmit powers will help extend battery lifetimes, but will require a higher density of node deployment. To explore this trade-off this paper investigates the optimal deployment of nodes in the sensed environment with the objective of minimizing cost while maximizing RF coverage and node lifetime. Throughout the paper, PLR is used as a metric for wireless communication performance.

Previous studies into node deployment [3, 4] have targeted static deployments where variability of the wireless link quality over time is small and slow. In contrast this work considers a BAN device where the wireless link quality can change considerably and rapidly due to variation in the subject’s position and orientation within the room. The location and density of the environment nodes for the sensed environment is an important factor especially in providing uninterrupted communication to a mobile BAN node which includes the body as another possible obstruction (body shadowing). This paper reports our work to discover the optimal deployment locations for the environment nodes to provide ideal coverage and connectivity for a BAN device at a range of transmission power levels in an office environment.

II METHODOLOGY

Our testbed consisted of two Tmote Sky nodes [5] and numerous WiSAR nodes (18 to 24) which are based on Tmote Sky nodes, hereinafter referred to as environment nodes. One Tmote Sky node was setup as a basestation node connected to a PC to collect and store all measurements relayed from the environment nodes. The other Tmote Sky node is set up as an on-body transmitter and attached to a 79kg/1.7m male test subject.

The on-body transmitter runs an application on the TinyOS [6] operating system that broadcasts a packet every 500ms at several different power levels at a centre frequency of 2.395GHz, which is outside the main 2.4GHz ISM band minimising interference during the experiments. In order to allow all environment nodes to transmit successfully to the basestation, a simple form of TDMA was deployed to allow each environment node adequate time to forward their frame to the basestation. This is achieved by giving each environment node a specified time slot in which to retransmit their packet. This removes the chance of collision from neighbouring nodes if they are using standard IEEE 802.15.4 MAC CSMA. The frames transmitted from the BAN node contain a monotonic increasing sequence number. For the duration of the experiment the environment nodes, running a TinyOS application also stay in receive mode until they receive a broadcast frame correctly. The transmitted sequence number and the measured received signal strength are recorded and then transmitted to the central basestation along with the environment node ID. When frames are lost, their corresponding sequence numbers are not present in the stored data and the packet is recorded as being lost in the data analysis.

In a similar set up to Fabio et al [7] we place a transmitter on the chest of the subject while the environment nodes were deployed at various locations. The Inverted – F Antenna (IFA) of the Tmote Sky node attached to the test subject was fixed 2cm from the body due to the battery pack needed for the experiments. The subject performed typical stationary and dynamic activities in the office area, shown in Fig. 1, for specified durations listed in Table 1; the subject sat at each desk of the office for a period of 50secs before moving to the next desk and then walking around the office twice in opposite directions. Every effort was made to repeat the routine identically at the power levels 0, -3, -7, -10, -15, and -25 dBm of the BAN node at each of the environment nodes locations. This sequence was repeated three times for each power level for validation and averaging purposes. The measurements were recorded after office hours when there was nobody in the office to minimise the effects of other bodies on the experiment.

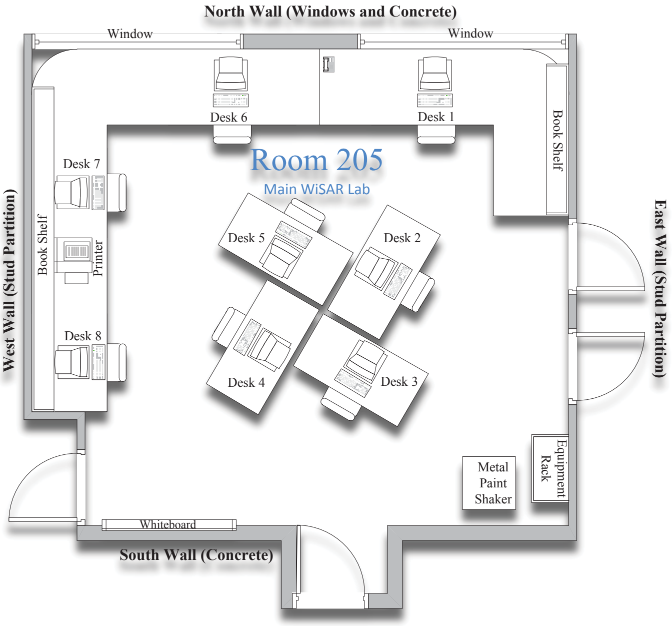

Fig. 1: Layout of the Main WiSAR Lab, Room 205

The test consisted of investigating which location for sensed environment nodes yielded the best Quality of Service (QoS) in terms of packet loss. The areas tested were:

1. Ceiling area deployed 24 environment nodes in a 6x4 grid, one metre apart
2. Floor area was deployed in a similar fashion to ceiling with 24 environment nodes in a 6x4 grid, approximately one metre apart
3. Wall-High area had 24 environment nodes deployed approximately one metre apart high on each wall (2.55 metres above the ground) as not to be intrusive on people or furniture within the office
4. Wall-Mid area had 18 environment nodes deployed at the chest height of the subject in the same manner as the wall-high nodes; one metre apart, with the exception of where furniture or doorways made it impractical to deploy a node and as such was not used.

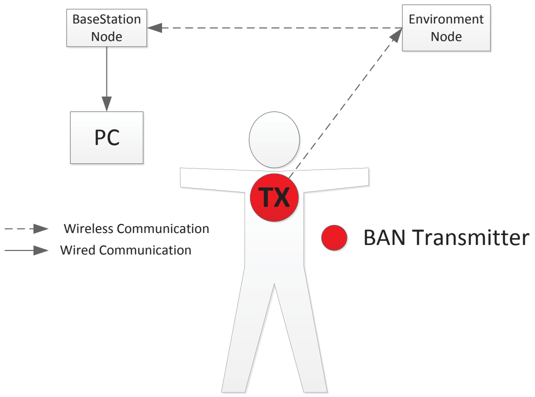

Fig. 2: Experiment Set-up Showing Packet Transmission Path

Experimental Routine		
	Seconds	Total (s)
Set up	5	00:05
Sit at desk1	50	00:55
Move to desk2	10	01:05
Sit at desk2	50	01:55
Move to desk3	10	02:05
Sit at desk3	50	02:55
Move to desk4	10	03:05
Sit at desk4	50	03:55
Move to desk5	10	04:05
Sit at desk5	50	04:55
Move to desk6	10	05:05
Sit at desk6	50	05:55
Move to desk7	10	06:05
Sit at desk7	50	06:55
Move to desk8	10	07:05
Sit at desk8	50	07:55
Stand up	5	08:00
Walk Around Room in Defined Line	30	08:30

Table 1: Experiment Routine

III RESULTS

Matlab was used to extract the packet loss figures from the test data. Packet losses and poor link quality occur due to many reasons such as interference from other wireless systems, multipath, fading, shadowing (object and body), antenna type and orientation and changes in a subject's position and orientation within a sensed environment. For each of the deployment scenarios the PLR for each environment node was determined for a corresponding transmitter power level by analysing each packet received by each of the environment nodes. This data was used to determine the optimal deployment of nodes in the sensed environment with the objective of minimizing cost while maximizing RF coverage and node lifetime. Although the office used in this experiment is unique the results will provide a platform to develop optimal node deployment techniques for mobile BAN communications in a typical office environment.

Before each deployment an experiment was carried out to determine if there was any packet loss between the environment nodes and the basestation node at any of the tested deployment locations. This ensured that was no packet loss between the environment nodes and the basestation node.

The following results are presented in two sections; one analysing the PLR results and the other the density of nodes.

a) Packet Loss Rate

Ceiling

Using MATLAB the PLR of each node in the ceiling deployment is presented in Fig. 4. As with all the experiments, the procedure is repeated three times at each power level for validation purposes. A packet is not considered to be received unless it has been received correctly by each environment node at all three repetitions of the experiment. Fig. 4 shows which environment node placements of this particular deployment perform best in terms of the PLR calculated at six different transmitter power levels of the CC2420 transceiver. It can be seen that there is a relationship between the transmitter power level and the PLR. As the transmitter power level decreases the PLR rate increases, most notable is -25dBm. This power level has a significantly worse PLR rate at each of the environment node positions which shows that -25dBm, as a power level, provides very poor throughput even at such a low traffic intensity (1 frame every 500ms) which will only increase as throughput increases.

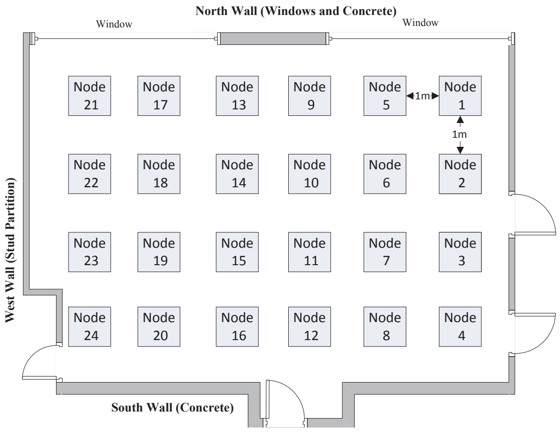

Fig. 3: Ceiling deployment layout

From Fig. 4 it can clearly be seen that node location 4, 10, and 21 are among the best performing locations in terms of PLR rates. Other locations perform well also i.e. nodes 13-18, however this yields no information as to the optimal location or density of environment nodes but merely highlights the better areas of the ceiling for deployment. In order to derive this information each frame was examined to determine in which nodes it was successfully received..

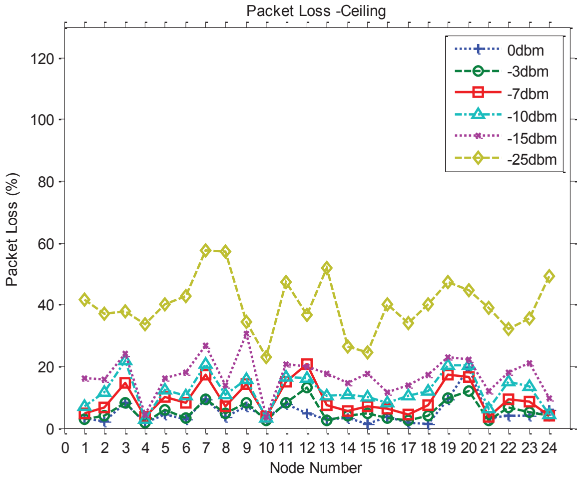

Fig. 4: Average PLR of all Trials at Ceiling for each Node

Floor

At this location, nodes were deployed in a squared grid like formation one metre apart. Their orientation was such that the tip of the IFA antenna (x-axis) was pointing directly towards the ceiling, perpendicular to the floor to use the slight directional pattern of the antenna to our advantage (see Fig. 5).

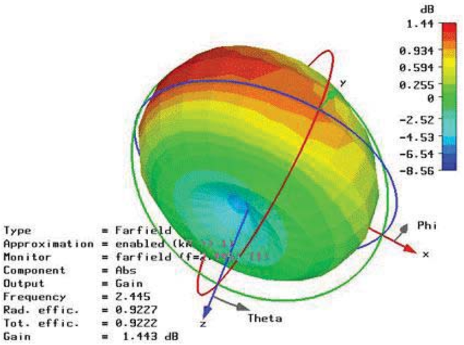

Fig. 5: Radiation Pattern of Inverted F Antenna [8]

This location was more difficult to deploy as some nodes were under desks and furniture. This showed the disadvantage of this location as it would be more difficult to design a WSN to receive BAN communications with furniture obstructing nodes and thus affecting quality of the network.

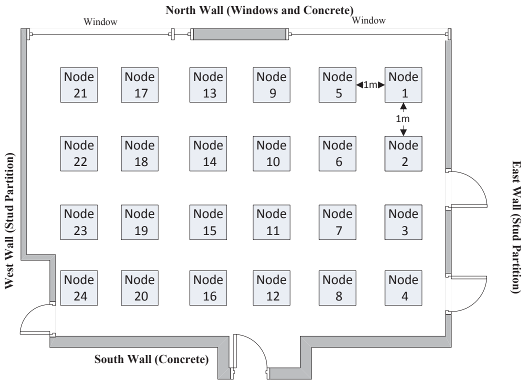

Fig. 6: Floor deployment layout

Fig. 7 shows the PLR figures for the floor location. Node 20 malfunctioned during the experiment and as such its readings are ignored in the results. At this location it can clearly be seen that this area yields the worst results of any of the deployment areas with vastly greater PLR rates at every power level tested.

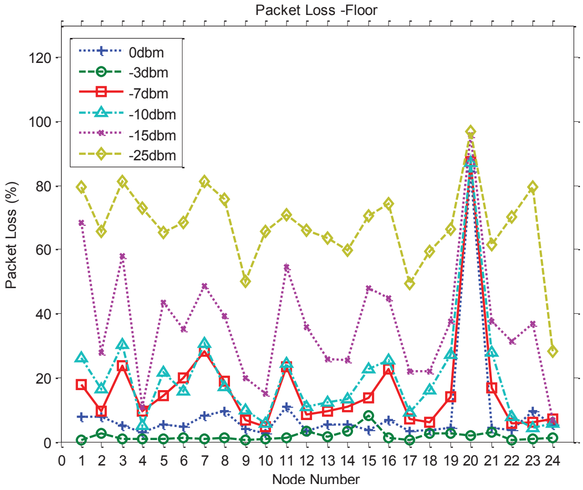

Fig. 7: Average PLR of all Trials at Floor for each Node

Wall-High

At this location the nodes were placed around the room on the walls as shown in Fig. 8. The environment nodes where deployed so that the tip of the IFA antenna (x-axis) was pointing inwards on room to use the slight directional pattern of the antenna to our advantage. Fig. 9 shows the PLR figures of all node locations of the experiment at each tested power level (0dBm to -25dBm). It can be seen that there are two node locations which yields consistently higher PLR rates (7 & 20) compared to the other nodes. Reasons for this are unclear. Possible explanations may be that node 7 is located above a metal equipment rack and perhaps the radiation pattern of the node is affected, or multipath fading particular to this position is responsible for the higher packet losses. Also it is unclear as to the effects causing node 20 to have above average PLR rates as it is positioned in the corner of the office similar to nodes 1, 8, and 13 which do not have the same packet losses in comparison to nodes 7 and 20. This could also be due to multipath fading unique to this node placement and relative orientation of the office.

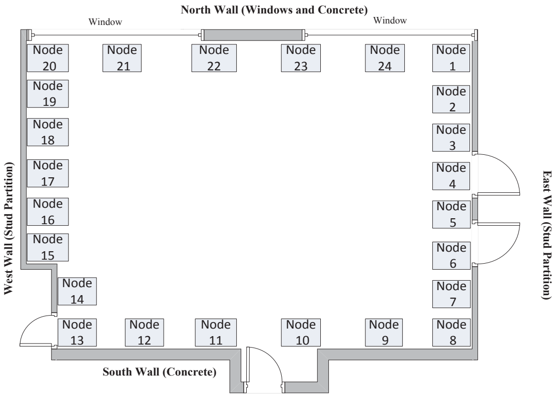

Fig. 8: Wall-High deployment layout

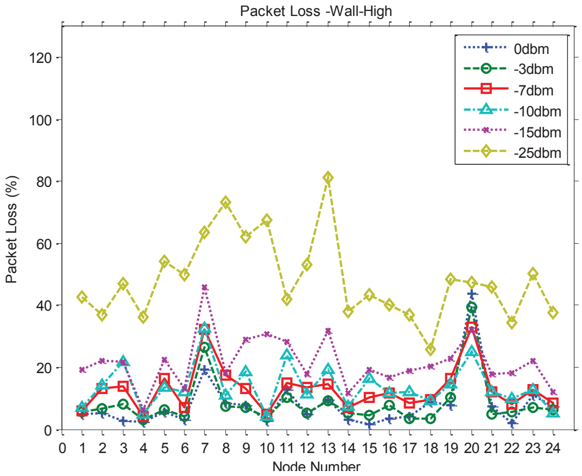

Fig. 9: Average PLR of all Trials at Wall-High for each Node

Wall-Mid

The deployment at this location was similar to the wall-high deployment as shown in Fig. 10. The nodes were placed around the walls of the office at the chest height of the test subject, with the IFA antenna perpendicular to the wall to use the slight directional pattern of the antenna to our advantage (see Fig. 5). However, there are several obstructions such as access to other rooms and equipment racks which hinder the number of nodes that can be deployed, resulting in fewer of nodes being used.

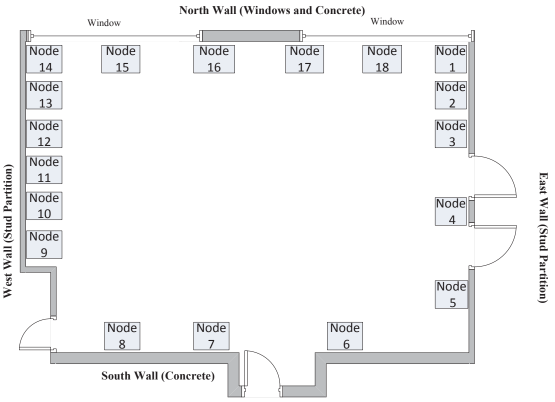

Fig. 10: Wall-Mid deployment layout

Fig. 11 shows the PLR figures for this placement of environment nodes. It is noticeable that the PLR rates improved considerably for all nodes at this location, especially at node 4 and node 10 where PLR rates are less than 5% at all power levels except the lower power levels of -15dBm and -25dBm. Reasons again for this are unclear but perhaps it is due to the central location of the nodes on the walls with a relatively clear line-of-sight to the BAN. Most notably the worst nodes here are node 6, node 11, and node 18. Reasons for these nodes having poorer PLR rates compared to other nodes at this deployment could be simply caused by location. Node 6 is located very close to a metallic paint shaker which could hinder the communications ability of this node. Similarly node 11 is located very close to a printer. This demonstrates the variability in performance that can be caused by the location and movement of furniture and office /lab equipment. Node 18's poor performance is difficult to understand as it is located at a very similar area to node 15 which reports a significantly lesser PLR rate. However this could be caused by multipath fading.

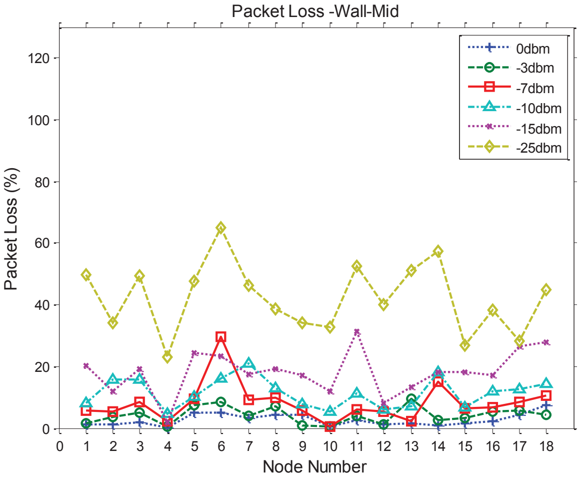

Fig. 11: Average PLR of all Trials at Wall-Mid for each Node

a) *Density*

The communication range of nodes is limited, especially at the lower power levels and depending on the number of nodes in the area (density) – it is likely that some environment nodes will not "see" the BAN node. This can only be avoided by significantly over-provisioning the network by introducing redundancy. Either the radio range or the node density must be increased to ensure good over-all connectivity among the environment nodes towards the access point. Fig. 12 shows the minimum density of nodes required at all the deployments to provide maximum RF coverage at each power level tested. It shows that a transmit power level of 0dBm requires the least density of nodes for maximum coverage and -25dBm requires the greatest density of nodes. It is unclear as to why the lower transmit power levels of -10dBm and -15dBm require fewer nodes than the higher transmission power levels of -7dBm and -3dBm at the ceiling location, however multipath could be responsible for this.

The floor deployment shows an increase in the density of nodes required at all power levels especially at -15dBm and -25dBm. This demonstrates that this deployment location requires many more nodes than the previous tested locations at each power level, thus it can be determined that this deployment area performs the worst of those examined in this work.

At the wall high deployment the average density required increases as power level decreases. Density is clearly affected by the power level at this deployment area, with the number of nodes required to provide optimal coverage increasing as the power level decreases. In comparison to the ceiling nodes these nodes' PLR rates decrease at a greater rate as the power level decreases, which in turn leads to a greater increase in the density of nodes required. This demonstrates that this deployment area is not an optimal placement for the environment nodes in comparison to the ceiling placement due to the higher density. However this does tell us that more nodes would be required if we were unable to place nodes on the ceiling.

With the reduction in PLR rates across all nodes at every power level at the wall mid location, inevitably the density of optimal node(s) will be reduced. The number of optimal nodes required for this scenario is vastly reduced in comparison to the previously examined locations, as can be seen in Fig. 12. There is little increase in the average density required in the power range 0dBm to -10dBm. The range from -10dBm to -15dBm only requires an extra two optimal nodes to provide maximum coverage to the BAN, whereas the decrease in power level from -15dBm to -25dBm causes a respective jump in the density requirement of optimal nodes from three to seven at this deployment, in order to provide seamless uninterruptable communications to the BAN.

Density at this location is the best out of all the deployment scenarios with vast decreases in densities of optimal nodes required to provide maximum possible coverage to the BAN.

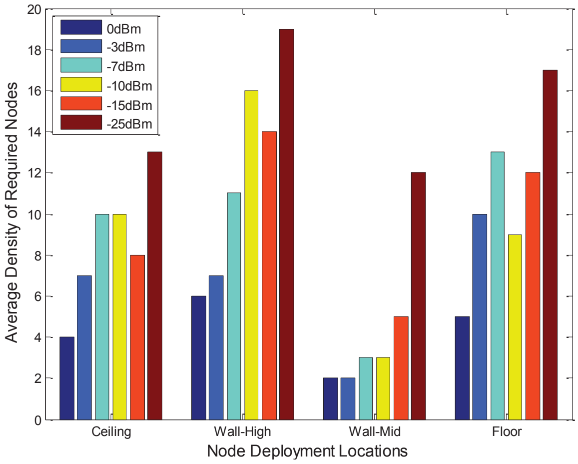

Fig. 12: Density of nodes required at each node deployment.

IV CONCLUSION

In this paper an experiment was devised to determine the optimal deployment for nodes in a sensed environment which have to provide a reliable communication link to a mobile BAN. From these experiments the deployment area that provided the best performance was the wall-mid deployment. Of the deployment areas tested it required the least number of nodes to provide maximum RF coverage in the sensed environment in comparison to the other areas tested. This paper confirms the fundamental importance of node deployment in order to provide complete RF coverage of a defined area i.e. the sensed environment. Literature shows us that this is a fundamental issue in static networks where all nodes are in fixed positions. The introduction of a mobile user only increases the need for precise deployment, not only the positions in which nodes are deployed but also the density in which they are deployed. Density of deployment is directly related to the cost of deployment and therefore optimum placement and density of nodes for a sensed environment needs to be carefully considered. This work shows the differences in the number of nodes required at each different deployment and showed the influence transmission power level can have on deployment density. As well as having an influence on the density of nodes required to provide optimal RF coverage, transmission power level affects the lifetime of a network and hence maintenance costs i.e. changing of batteries etc. therefore, it will be important to find a balance between hardware cost and maintenance cost when designing a sensed environment.

Future work would include investigating the influence of the number of people in a sensed environment to discover how more people moving in the space affect performance. Also it is reported in literature that using relay devices, or a more cooperative approach, can improve energy consumption [9]. One such possible benefit of the sensed environment would be to use it as a BAN relay option. This could provide temporary alternative routes to bypass an on-body wireless link which has been temporarily attenuated due to the harsh propagation conditions naturally occurring in and around the human body such as shadowing.

V ACKNOWLWDGEMENT

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VI REFERENCES

[1] A. Sani, “Modelling and Characterisation of Antennas and Propagation for Body-Centric Wireless Communication,” Ph.D. dissertation, Queen Mary, University of London, April 2010.

[2] K. Xu, Q. Wang, H. Hassanein, and G. Takahara, “Optimal Wireless Sensor Networks (WSNs) Deployment: Minimum Cost with Lifetime Constraint,” in *Wireless And Mobile Computing, Networking And Communications, 2005. (WiMob’2005), IEEE International Conference on*, vol. 3, aug. 2005, pp. 454 – 461 Vol. 3.

[3] N. M. Boers, I. Nikolaidis, and P. Gburzynski, “Patterns in the RSSI Traces from an Indoor Urban Environment,” in *Proc. 15th IEEE Int Computer Aided Modeling, Analysis and Design of Communication Links and Networks (CAMAD) Workshop*, 2010, pp. 61–65.

[4] M. T. Kouakou, S. Yamamoto, K. Yasumoto, M. Ito, “Cost-efficient Deployment for Full-coverage and Connectivity in Indoor 3D WSNs,” in *Information Processing Society of Japan Dicomo*, 2010, pp. 1975 – 1982.

[5] Moteiv Corporation, “*Ultra Low Power IEEE 802.15.4 Complaint Wireless Sensor Module*,” [online] Available at: <http://sentilla.com/files/pdf/eol/tmote-sky-datasheet.pdf> [Accessed 24th Apr 2011].

[6] P. Levis, S. Madden, J. Polastre, R. Szewczyk, A. Woo, D. Gay, J. Hill, M. Welsh, E. Brewer, and D. Culler, “Tinyos: An operating system for sensor networks,” in *in Ambient Intelligence*. Springer Verlag, 2004.

[7] Fabio Di Franco, Christos Tachtatzis, Ben Graham, David Tracey, Nick F. Timmons and Jim Morrison, “On-Body to On-Body Channel Characterization,” in *IEEE Sensors*, Limerick, 2011.

[8] Silicon Laboratories, “*Designing with an Inverted-F PCB Antenna*,” [online] Available at: <http://www.silabs.com/Support%20Documents/TechnicalDocs/AN697-DesigningwithaPCBAntenna.pdf>. [Accessed 25 June 2012].

[9] E. Reusens, W. Joseph, B. Latre, B. Braem, G. Vermeeren, E. Tanghe, L. Martens, I. Moerman, and C. Blondia, “Characterization of On-Body Communication Channel and Energy Efficient Topology Design for Wireless Body Area Networks,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 13, no. 6, pp. 933–945, 2009.