WIRELESS SENSOR NETWORK: WATER DISTRIBUTION MONITORING SYSTEM

Min Lin
Computer Laboratory
Cambridge University
Cambridge, UK
Email: ml406@cam.ac.uk

Yan Wu
Computer Laboratory
Cambridge University
Cambridge, UK
Email: yw264@cam.ac.uk

Ian Wassell
Computer Laboratory
Cambridge University
Cambridge, UK
Email: ijw24@cam.ac.uk

Abstract — Historically, wireless sensor networks have mainly addressed military applications. However, in recent years, many civilian applications, such as managing inventory, monitoring product quality and monitoring disaster zones have emerged. Various technical issues, such as power consumption, radio propagation models, routing protocols, sensors etc need to be considered for different applications. In this paper, we propose a particular application for wireless sensor networks, specifically a water distribution network monitoring system. We propose a possible communication model for the water distribution monitoring network, and describe our channel measurement approach for the determination of an appropriate path-loss model. The accuracy of the proposed measurement approach has been confirmed using the flat earth two-ray model [1].

Keywords – leakgage detection, sensor network, channel modeling, underground, path-loss model, signal strength, fast fading

I. INTRODUCTION

The motivation of this project is to monitor the local water distribution network such that leakage from water pipes can be detected. Leakage detection is becoming critical owing to increasing drought problems in the UK. Recent news from the BBC [2] reported that south east England was experiencing its driest record period. On the other hand, 10,500 liters of water is lost through Thames Water's leaky pipes every second [3, 4]. A report done by the Office of Water Services (OFWAT), water leakage for water and sewerage companies has increased by 13.3% from 1999 to 2004 [5]. As a result, water leakage control is becoming a critical issue to the water companies.

Conventionally, leaks are detected by using acoustic equipment which picks up the sound or vibration induced by water as it escapes from pipes under pressure. Acoustic equipment includes listening devices such as listening rods, aqua phones (or sonoscopes), and geophones (or ground microphones). These are used to listen for leak sounds at contact points with the pipe such as fire hydrants and valves. Acoustic equipment also includes leak noise correlators. These are modern computer-based instruments that are simple to setup in the field and work by measuring leak signals (sound or vibration) at two points that bracket a suspected leak. The position of the leak is then determined automatically based on the time shift between the leak signals calculated using the cross-correlation method. Although modern technology improves the efficiency of the measurement, a significant amount of man-power is still required to locate a leakage point in a large water distribution network. As a result, eliminating leakage would be virtually impossible and enormously expensive with current leakage detection methods. For instance, Seven Trent Water (STW) uses a sensor to measure the water flow in a trunk main feeding a local region (1000-1500 houses). The flow data is sent back to the network control centre via GPRS every 15 minutes. The flows measured in the early hours are of primary interest since the flow due to users should be at its lowest, hence any high values are probably due to leakage. If a leak is suspected, engineers will then be sent into the area to locate the leakage point(s) perhaps using the correlation-based method mentioned previously, and to fix the leaks. However, finding the leakage point is a tedious and time consuming using current methods. Therefore, a more effective water monitoring system is needed in order to reduce water leakage efficiently. We thus propose the deployment of a wireless sensor network (WSN) in the local region and monitoring water flow, pressure and vibration at a large number of locations. However, there are many issues that need to be taken into consideration, such as the radio propagation channel, power and memory constraints, efficient routing protocols, etc.

In this paper, we focus on the physical layer of our sensor network, i.e., radio propagation and the determination of appropriate path loss models. In section II, we will describe the communication scenario for this application. One of our main concerns is underground to above ground radio propagation. To this end, we conducted a measurement campaign to determine the feasibility of the proposed implementation. In section III, we describe our physical measurement campaign. Discussion of our measurement results will be presented in section IV. We then conclude our paper in section V, where we also propose some future work.

II. PROPAGATION CHANNEL MODEL

In this section, we first analyse our application scenario and then propose a possible communication scenario for the WSN.

A. Communication model for the sensor network

In the UK, fire hydrants are generally located underground, consequently, we are faced with the challenge of underground to above ground radio propagation. In [6, 7], a concept of a wireless underground sensor network (WUSN) was introduced, however, this concept is based on an assumption that the underground environment is soil. Their main application is for agriculture. Therefore, it is not directly applicable to our case. Our transmitter (i.e., the sensor node) will typically be placed in a fire hydrant (FH) chamber which is made of concrete and cast iron. Other possible locations include the boundary box situated at the boundary of the customers premises. Figure 1 shows a view of a typical UK fire hydrant.

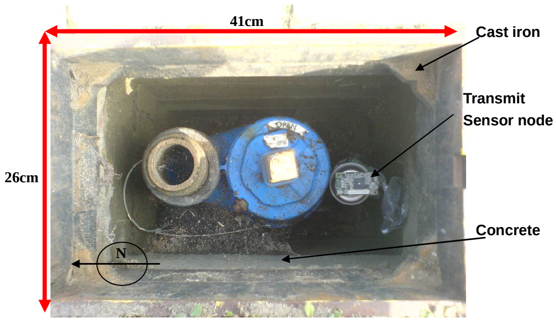

Fig.1 Structure of Fire Hydrant

The sensor node placement shown in Fig.1 is just an example and the exact position of the sensor node may vary depending upon the design of the sensor package. The FH lid and rim are in general made of cast or ductile iron. Radio propagation will be affected by the presence of the cast iron and also by the concrete and surrounding soil components. Consequently, it is anticipated that communication with sensor nodes located in the FH chamber will not be possible without the use of relay nodes on the surface. Therefore, we propose to have relay nodes above the ground within communication range of each below ground (FH) node as shown in Fig.2. Therefore, the underground sensor node will only communicate to a nearby relay node, which will then route the data towards the host node through a network comprising other relay nodes. The host node will then transmit the data to the control centre for further processing. Clearly, the most challenging aspect of this sensor network is to transmit the sensor data from below to above ground, particularly with the existing metal lid on the FH.

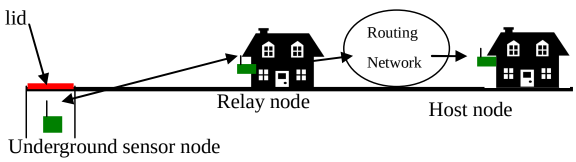

Fig. 2 Below to above ground propagation channel

Although various propagation models for WSN deployment have been studied in [8, 9], both transmitter and receiver nodes are above the ground. Propagation from below to above ground has received little attention to date and as far as we are aware, no path loss model exists for this scenario. Therefore, it is a great practical and theoretical interest that one be determined.

III. Channel Measurement

A. Motivations for the underground to above ground channel measurements

The motivations for the propagation measurements are to enable a suitable channel model to be determined. This model will allow the operating range between an underground node and an above ground node to be determined for arbitrary sensor node parameters, e.g., transmit power and receive sensitivity. As we will implement the sensor network in various scenarios, where parameters such as relay node height and distance between the FH and relay node may vary, it is therefore convenient to have an accurate channel model when deploying the WSN.

B. Measurement concerns

In addition to the overall reduction in received signal power owing to spatial spreading, the variability of the received signal can be attributed to two different fading effects namely fast fading due to multi-path propagation and slow fading caused by shadowing effects. Consequently, if the fast fading is successfully removed by averaging, then only the spatial environment loss and variation due to slow fading remains. For macro cellular scenarios, it has been found that the variations in the local mean are very closely to lognormal [10, 11]. The standard technique for removing the fast fading effect from the slower variations due to path loss and shadowing was initially proposed by Clark [12]. This involved the application of a sliding window technique to determine the local mean of the signal at any particular point. This technique is explained and used in [10-14]. Even though, a larger window will be more effective in averaging out the fast fading, estimation of the local statistics can be affected owing to significant variation of the local mean signal level. Conventionally, the window is chosen to be between $4\lambda - 10\lambda$ [13], but that is for measurements performed in micro cells. However, owing to the smaller distances involved in our application, our averaging window has been chosen to be shorter (in terms of the number of wavelengths) in order to achieve adequate spatial resolution. We propose to average over a spatial area of 1m^2 as shown in Fig.3. That is, the receive antenna (RX point) will be moved around the area while samples of received power are being captured. A wooden rig to support the antenna is used to make this measurement. It has a wheeled base which permits movement in the x-y plane and an antenna carrier, which can be raised or lowered to permit measurement at different antenna heights.

Fig.4 shows our measurement set up. A transmitter having dipole antenna is placed in the fire hydrant (FH) chamber. Two frequency bands have been used, specifically 868MHz and 2.4GHz. The signal strength at different points is measured using a portable spectrum analyzer (SA) (Anritsu MS2721A) with a dipole antenna which is connected to the SA with a 10m low-loss co-axial cable. The height of the receive antenna is varied between 2m and 4m in increments of 1m.

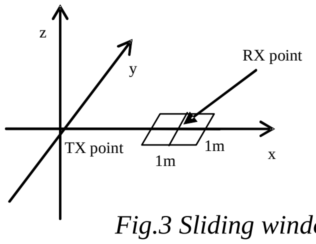

Fig.3 Sliding window

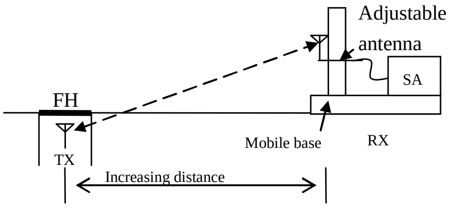

Fig.4 Field Measurement setup (2D)

As shown in Fig.1, the internal structure of the FH is not symmetrical about the east/west axis. Therefore, to determine if there is an effect on the path loss (PL) owing to the internal structure of the FH, we performed measurements in both north and south directions. A *C* program was written to sample the signal strength from the SA and 100 samples were collected for each measurement position. These values are logged for post-processing and analysis purposes. We have validated the accuracy of this measurement by comparing measurements gathered in a flat-earth scenario with those predicted by the well known analytical solution for this case [1].

IV. Measurement Reulsts and Analysis

The path loss results are presented with the FH lid on and off. The path loss, (*PL*) is defined as (1).

$$PL_{(dB)} = P_{TX\,(dBm)} + G_{TX\,(dB)} + G_{RX\,(dB)} - P_{RX\,(dBm)} \quad (1)$$

where, $P_{TX(dBm)}$ is the transmit power, $P_{RX(dBm)}$ is the receive power, $G_{TX(dB)}$ and $G_{RX(dB)}$ are antenna gain at transmit and receive antenna respectively. The results will also enable us to estimate the maximum operating range for any particular type of sensor node, e.g., Jennic's IEEE802.15.4/ZigBee Module Family.

A. Frequency

In Fig.5, we can clearly see that the path loss (*PL*) performance at 2.4GHz is better than 868MHz. One of the possible reasons is because the wavelength at 2.4GHz is much shorter than at 868MHz. This may allow the 2.4GHz signal to propagate from gaps present on the FH lid and around the rim. Fig.6 shows that when the lid is off, the difference between 2.4GHz and 868MHz are much reduced compare to when the lid is on. This shows that the lid has more effect on 868MHz, possibly owing to less radiation from the lid when it is in position. Owing to limited space in this paper, we will only present the directional results at 2.4GHz. We make this choice, since 868MHz has poorer performance than 2.4GHz and is consequently of less interest.

B. Direction

From Fig.7, it seems that at 2.4GHz, *PL* in north and south direction are quite similar at antenna heights of 2m and 4m. However, at 3m antenna height, the performance in the north direction is better. A similar phenomenon was also observed when the lid is off as shown in Fig.8. The reason for this is not certain at present and further investigation is needed.

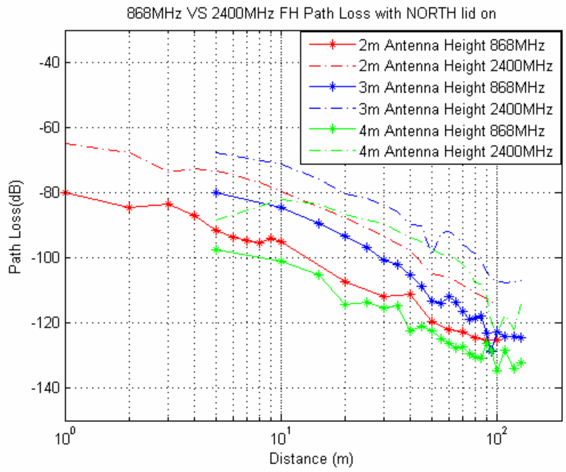

Fig.5 868MHz vs 2400MHz lid on

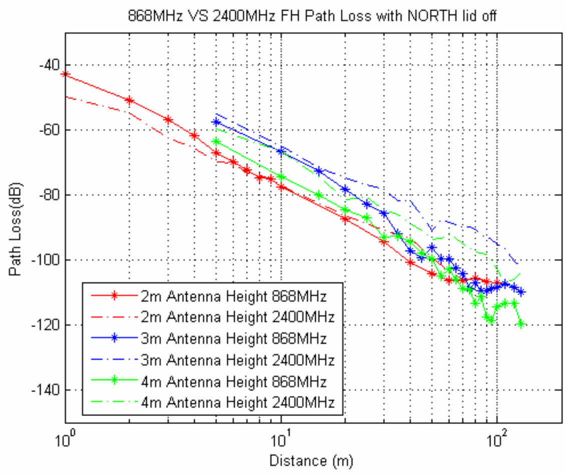

Fig.6 868MHz vs 2400MHz lid off

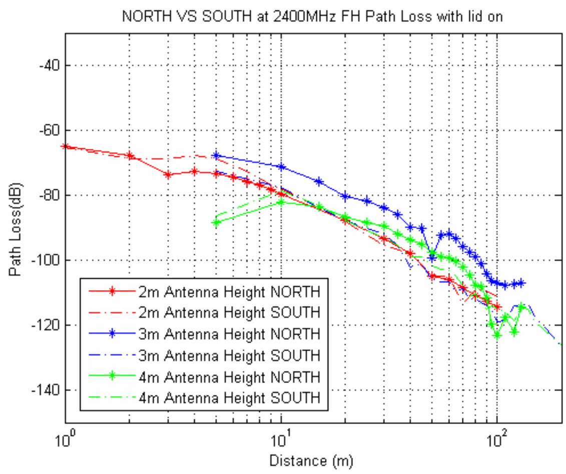

Fig.7 2400MHz Direction Analysis lid on

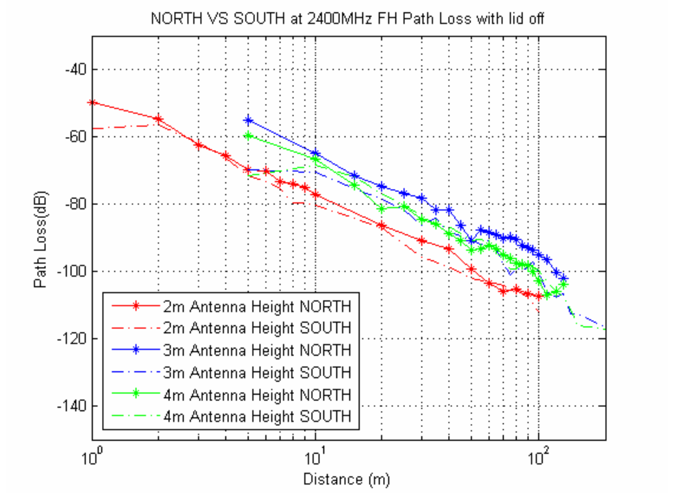

Fig.8. 2400MHz Direction Analysis lid off

C. *Commericial product operating range*

Since 2.4GHz has better path loss performance than 868MHz, we proceeded to estimate the operating range of a typical commercially available wireless sensor. For example, JN5139–xxx-M02/04 by Jennic Ltd [15], which is a 2.4GHz Zigbee product, has a receive sensitivity of -100dBm with a transmit power of 19dBm. This means we can afford to have a maximum *PL* of approximately -120dB. If we allow a fade margin of 20dB, then we can sustain a mean path loss of -100dB. Assuming the lid is on, in Table 1 we present the estimated operating ranges based on the results presented in Fig.7.

Direction	Antenna Height	Range
North	2m	42m
	3m	80m
	4m	60m
South	2m	42m
	3m	39m
	4m	42m

Table 1 Conservative Operating Range at 2.4GHz with lid on

If we reduce the fade margin to 10dB, we can achieve the estimated operating ranges, shown in Table 2.

Direction	Antenna Height	Range
North	2m	80m
	3m	100m
	4m	90m
South	2m	80m
	3m	73m
	4m	80m

Table 2 Typical Operating range at 2.4GHz with lid on

Therefore, it looks feasible to set up the water distribution monitoring network inspite of the hostile underground to surface channel. Although transmitting at 19dBm may imply a large power consumption penalty, we do no require frequent transmission in our application. For example, the monitoring period only takes place at night for a duration of 2 hours with only a brief transmission taking place every 15 minutes or so.

V. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a WSN based solution for monitoring the water distribution network for the purpose of leakage detection. After presenting the measurement scenario, we then addressed our propagation measurement concerns and described how to overcome the fast fading effect. We then presented our measurement results and analysis in terms of operating frequency and direction with both lid on and off. These results show that 2.4GHz has a better path loss performance than 868MHz and yields a conservative operating range estimate for the JN5139–xxx-M02/04 Jennic device of 39m – 80m; and a typical operating range of 73m – 100m. Further measurements are needed in order to determine an empirical channel model for the underground to above ground scenario. This is necessary so that we can implement a WSN in any location using any particular node type. Therefore, for future work, we would like to do more measurements at a higher resolution which may help to uncover the underlying propagating mechanisms that in turn may enable us to propose a suitable analytical model.

REFERENCES

[1] Simon R. Saunders, “Antennas and Propagation for Wireless Communication Systems”, WILEY, 1999.

[2] BBC news, “South East England still in drought”, http://www.bbc.co.uk/weather/features/understanding/drought2006.shtml, 2006.

[3] Sarah Mukherjee, BBC environment correspondent, “Testing the water on desalination”, http://news.bbc.co.uk/1/hi/uk/5009540.stm, BBC NEWS, 23 May 2006.

[4] Economist, “London Water Sunk Costs”, 13th July 2006.

[5] OFWAT, “Security of supply, leakage and the efficient use of water”, 2003-2004 Report.

[6] Ian F. Akyildiz, Erich P. Stuntebeck, “Wireless underground sensor networks: Research challenges”, Elsevier B.V. 2006.

[7] Erich P. Stuntebeck, Dario Pompili, Tommaso Melodia, “Wireless Underground Sensor Networks using Commodity Terrestrial Motes”, IEEE SECON 2006, Reston, VA, September 2006.

[8] Ms. Abiola Fanimokun, Jeff Frolik , “Effects of antural propagation environments on wireless sensor network converage area”, System Theory, IEEE Proceedings of the 35th Southeastern Symposium, page 16-20, 2003.

[9] J.M. Molina-Garcia-Pardo, et al, “Channel Model at 868MHz for Wireless Sensor Networks in Outdoor Scenarios”, International Workshop on Wireless Ad Hoc Netowrks, IWWAN 2005, London, May 2005.

[10] Jakes W.C., “Microwave Mobile Communications”, John Wiley, New York, 1994.

[11] J.D.Parsons, “The Mobile Radio Propagation Channel”, 2nd Edition, John Wiley, 2000.

[12] R.H.Clark, “A statistical theory of mobile-radio reception”, B.S.T.J. Vol. 47, pp. 957-1000, July-Auguest 1968.

[13] Raymond Steele and Lajos Hanzo, “Mobile Radio Communication”, 2nd Edition, Wiley, 1999.

[14] E Green, “Radio link design for microcellular systems”, Br Telecom tehnol Jorunal, Vol. 8, No. 1, January 1990.

[15] Jennic Ltd, “IEEE802.15.4/ZigBee Module Family”, www.jennic.com, 2007.