INTERFERENCE CHARACTERISTICS OF CONSTRUCTION ENVIRONMENT FOR WSN APPLICATIONS

Sun-Chan Bae[1], Won-Sik Jang[1], Sang-Dae Park[1] and Won-Suk Jang[2]

[1] Graduate Research Assistant, Department of Civil Engineering, Yeungnam University, Korea
[2] Assistant Professor (corresponding author), Department of Civil Engineering, Yeungnam University, Korea
Correspond to wsjang@ynu.ac.kr

ABSTRACT: Advent of Wireless Sensor Networks (WSN) has provided potentials to a variety of construction applications. It is well appreciated that WSNs have advantages over traditional wired system, such as ease of installation and maintenance with increased cost savings and efficiencies. However, the obstruction of wireless signal from physical objects in the heterogeneous construction environment often brings challenges to WSN measurement system. This paper analyzed the obstruction characteristic of construction environment where construction materials, equipment, and built structures obstruct the wireless signal yielding negative effect of measurement system. By adopting evaluation criteria, such as packet reception rate, field experiments have been implemented to quantitatively identify the interference of wireless signal from penetration, reflection, and network traffic under the construction environment. The results show that reliable performance of wireless sensor in construction environment depends on the optimal separation distance between a receiver and a transmitter, obstruction types, obstruction thickness, and transmission interval. In addition, the methodology and experimental results of this paper could be used in the practical design of network topology when hundreds of sensor nodes form a mesh network in the large scale construction applications.

Keywords: Wireless Sensor Network; Interference; Construction; Zigbee; Packet Delivery Rate, Received Bit Rate

1. INTRODUCTION

The advent of sensor and mobile technologies has envisioned potential possibility to realize the ubiquitous computing in construction areas. Especially, efficiency and mobility inherited from wireless sensor network has gained great attention in the area of materials tracking, real-time monitoring, and localization applications. As the size and complexity of the construction projects become larger, the needs and demands to automated information management using top-notch technologies are increased. Recent paradigm of construction industry has gradually changed the legacy system to IT-based automated system to increase the efficiency and productivity [1]. Typical wireless technologies include Radio Frequency Identification (RFID), ZigBee, and Ultra Wideband (UWB), and these emerging technologies are incorporated together with wired system to generate more efficient and user-friendly tool for various applications [2]. As consequence, material tracking, facility maintenance, labor and equipment monitoring, building automation are possible application areas that are benefited from the new technologies.

While many literatures have dealt with the potentials of WSN in various applications areas, it is hard to find the analytical and experimental performance measures of signal propagation and coverage range for practical adoption. Theoretically, the radio travels through air medium and the received power is inversely proportional to the separation distance of a transmitter and a receiver. There exist various radio propagation models that predict the received power level in an ideal situation such as far-field clear line of sight. However, typical construction site has irregular shape of built structure and obstructions that affect the radio propagation. Theoretical propagation model usually does not explain the obstructed environment at construction site, and more sophisticated approaches are needed to analyze the complicated behavior of radio communication. When various obstructions block the radio signal, received power and coverage of the radio signal may be seriously decreased according to the material type and thickness. In worst case, the reliability of the entire wireless monitoring system may be problematic unless careful design of network topologies is made. As the size of the wireless network increases, the problem could be worsened because it is technically impossible to individually confirm the communication success among distributed nodes.

This paper presents WSN interference characteristics when used in construction sites where a variety of heterogeneous obstruction exists. Field experiment was conducted by using ZigBee module which follows IEEE802.15.4 standards for low power, low cost, and networking flexibility and measurement performance considering the interference effect was analyzed for possible application at construction site [3]. Quantitative outcomes of signal attenuation may be used as a practical guideline when WSN is deployed as a major tool of remote data collection.

2. BACKGROUND OF CASE STUDIES

Fast changing construction industry is now moving to u-City paradigm with information technology and computing science. Especially, wireless technologies gains rapid interests to construction engineering for automated construction management and maintenance.

In the area of monitoring system, Chae et al. presented long-term bridge monitoring system using wireless technology to overcome high cost burden and efforts on bridge maintenance. This research adopted ZigBee and CDMA targeting maintenance of Youngjong Grand Bridge in Korea. The monitoring system provides real-time measurement of various components, such as acceleration, temperature, and wind speed, and near- and far-field wireless networks are achieved for low cost and efficient maintenance practices [4]. Chae and Yoshida also proposed safety monitoring system which can prevent equipment accidents in construction site. Location information between crews and equipment are processed using active RFID [5].

In the area of tracking system, Wu et al. introduced localization methodology to determine the distance between crews and hazardous objects using ultrasonic sensor. Based on accident history, ultrasonic sensors are placed at accident black spot and a couple of routers equipped with ZigBee transmit the measured location data to main server. If any dangerous situation is detected from the system, an alarm system is activated to alert the site crew for safety [6]. Shen et al. presented an asset tracking system to position the major construction materials and equipment based on RSSI localization method. This system provided potential possibility to track the construction assets located even at indoor environment using short range wireless network [7].

3. EXPERIMENTAL CONFIGURATION

This research aims at finding out the interference effect of construction obstructions in ubiquitous sensor environment. 2.4GHz ZigBee module is selected and the performance index was experimentally analyzed in the surroundings where major construction materials are placed. In order to quantify the interference effect, both line-of-sight (LOS) and non-line-of-sight (NLOS) path are configured. Also, open field is selected to prevent unwanted interference such as other radio signals and multipath. In LOS configuration, a receiver node and 17 end nodes are separated by *L*, e.g. 5 and 10 meters, to form a star network without any obstructions as is shown in Figure 1. On the other hand, in NLOS, major construction material, e.g. concrete block and steel plate, are placed to block the radio signal transmitted to the receiver, which is shown in Figure 2. Then, the number of activated end node increased from 1 to 17, and interference effect caused by obstruction and network traffic was measured by packet delivery rate (PDR) from total 100 packets transmitted at the end nodes in each number of activation. PDR is an important measurement factor that indicates the success of communication in a practical way.

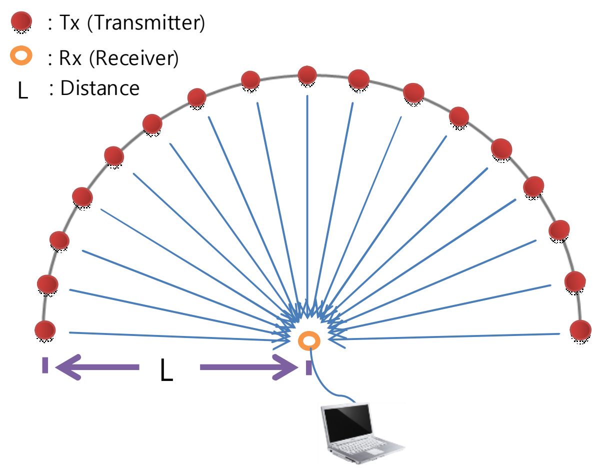

Figure 1. Experimental setup for LOS

Concrete and steel are major construction materials that are used in most construction wall, column, slab, and other structural component. In LOS configuration, a sample of concrete block with each dimension of 300*300*120mm was placed as a blocking object. Similarly, a 300*300*30mm sample of steel plate is configured as another blocking object. Each material was placed in a triangular shape of wall to perfectly prevent the reflection or multipath. Then, each end nodes were set to 10Hz as transmission interval.

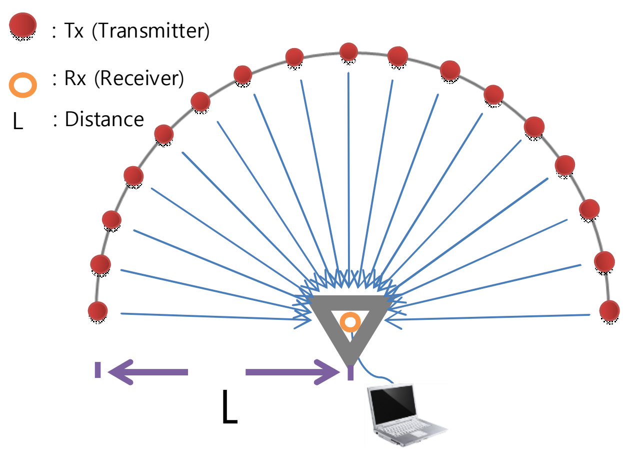

Figure 2. Experimental setup for NLOS

4. ANALYSIS OF INTERFERENCE EFFECTS

In this experiment, PDR is used as quantifiable measures of interference by averaging total received packet rate. High PDR indicates good communication reliability between a transmitter and a receiver, and low PDR shows poor reliability of communication. It is noted that there might exist a circumstance where the receiver has low PDR with high received signal strength and high link quality. In the practical point of view, this case cannot ensure enough reliability of communication even with high performance index because users may not be able to utilize the whole spectrum of packets received. This is important when individual packet shows meaningful indication, such as used in the application of emergency preparedness or analysis of bridge health/ behavior.

Figure 3 shows the packet delivery rate measured at 5 meter separation distance in both LOS and NLOS environment according to number of active nodes. In LOS, it can be found that network traffic affects a certain amount of communication performance where PDR ranges from 60 to 100 percent. Similarly, network traffic plays a role to reduce the PDR as the number of active nodes increase, but the attenuation rate of NLOS is larger than that of LOS. This might be attributed from the obstruction interference caused by major construction materials. In NLOS with steel plate, the attenuation rate decreases seriously ranging from 50 to 82 percent

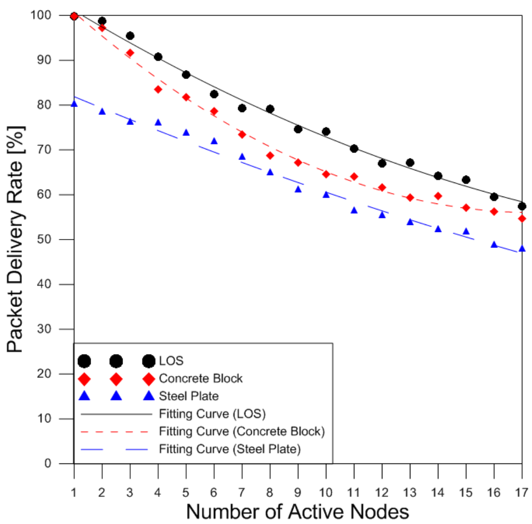

Figure 3. PDR measured at 5m T-R separation

Figure 4 shows the PDR measured at 10 meter separation distance with similar configuration. In LOS, PDR ranges from 45 to 100 percent as the number of active nodes increase. When all the 17 nodes transmit the packet in 10Hz interval, more than 15 percent packet losses are observed even in LOS environment, which implies that heavy network traffic affects the packet reception at a receiver node. Similarly, PDRs measured from the obstruction of concrete block are also decreased more than the case of 5 meter separation distance, ranging from 35 to 100 percent. Obstructed environment with steel plate shows lower PDR than 5 meter separation distance ranging from 26 to 80 percent.

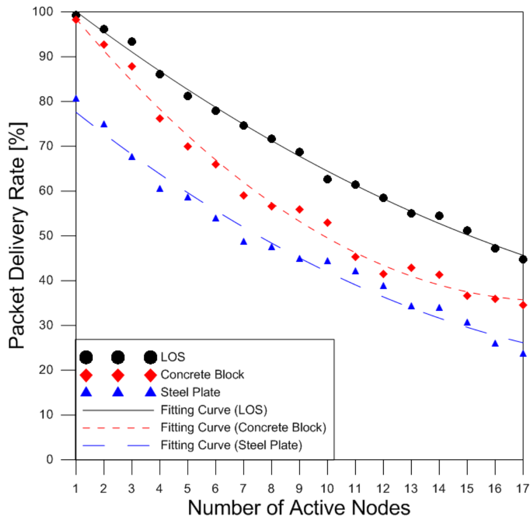

Figure 4. PDR measured at 10m T-R separation

Received bit rate (RBR) is also well-known performance index by which users are capable of estimating how many actual data packet can be delivered in given period of time. While received bit rate is directly proportional to PDR, it is also related to the packet design and transmission interval. Therefore, it is important to predict the actual number of bits transferred from the end nodes to ensure the level of reliability of the monitoring system.

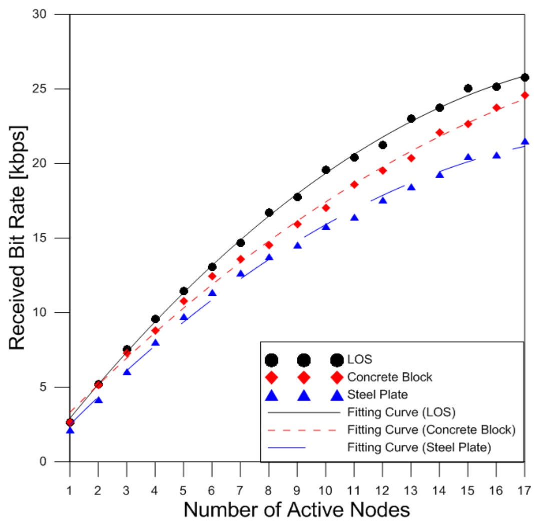

Figure 5. BRB measured at 5m T-R separation

In order to measure the received bit rate, each packet transmitted from the end nodes was designed in a way that parent's ID, counter, power level, and time stamp were assigned to 33 bytes payload. Figure 5 and 6 show the actual received bit rate (kbps) received at 5 and 10 meters with 10Hz interval in both LOS and NLOS environment. Like the PDR results, high PDRs generate more packets delivered. However, PDRs and RBRs are not proportional as the number of active nodes increase. As is shown in the figures, the total RBR delivered to the receiving node is generally increased at larger active nodes. In LOS environment, RBR ranges from 2.5 to 25kbps at 5 meters and 2.5 to 20kbps at 10 meters. Similarly, RBR ranges from 2.5 to 24 kbps at 5 meters and 2.5 to 14 kbps at 10 meters when concrete block obstructs the wireless signal. It ranges 2.3 to 20kbps at 5 meters and 2.3 to 12kbps at 10 meters in the case of steel plate. It is noted that the relationship between RBR and the number of active nodes is not linearly proportional because packet delivery rate decreases as the number of active nodes increase due to network traffic congestion.

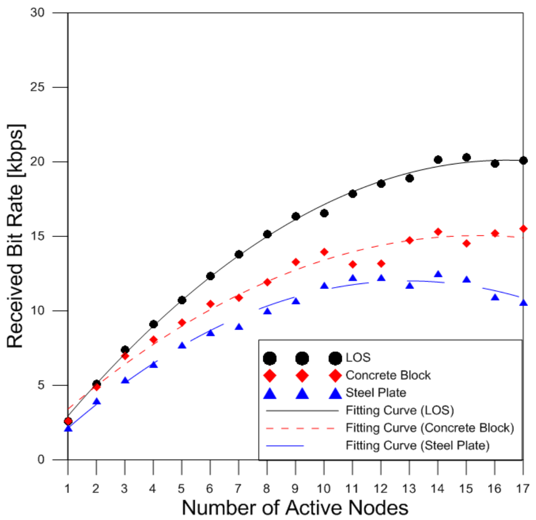

Figure 6. BRB measured at 10m T-R separation

5. CONCLUSIONS

This paper analyzed the interference characteristic of construction environment where construction materials, equipment, and built structures obstruct the wireless signal yielding negative effect of measurement system. By adopting evaluation criteria, such as packet reception rate (PDR) and received bit rate (RBR), field experiments have been implemented to quantitatively identify the interference of wireless signal from penetration, reflection, and network traffic under the construction environment. By selecting the major construction materials (e.g. concrete block and steel plate), obstructed configuration was set to experimentally analyze the pure influence of interference effect caused by the obstructions. Also, total 17 end nodes are set to form a star network to identify the network traffic problem.

The test results confirm that PDR, a practical performance index, decreases when 1) the separation distance between transmitters and receivers increases, 2) high interfering material (e.g. steel plate as a conductor) is used, and 3) the network traffic becomes dense (e.g. the number of transmitting node increases). In addition, BRB, a measure for data processing, is also a function of the number of active nodes as well as PDR and separation distance between nodes. It should be noted that adoption of WSN in construction applications requires in-depth analysis on actual performance and interference effects of wireless signal. This is because it is practically impossible to separately confirm the communication success in large-scale, highly dense application domain, such as construction site, when thousands of wireless sensors are in consideration to be arbitrarily placed. The test results could also provide a practical guideline to form a network topology in the applications of civil and construction areas.

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REFERENCES

[1] Wei-Ho Chung, Pi-Cheng Hsiu, Yuan-Yao Shih, Ai-Chun Pang, Yu-Kai Huang, and Kuan-Chang Hung, “Mobility-Robust Tree Construction in ZigBee Wireless Networks”, *Wireless Communications and Networking Conference (WCNC)*, Issue 5, pp. 1-6, 2011

[2] E. J. Jaselskis and T. EI-Misalami, “Implementing Radio Frequency Identification in the Construction Process”, *Journal of Construction Engineering and Management, ASCE*, Vol. 129, Issue. 6, pp.680-688, 2003

[3] P. Manjunatha, A. K. Verma, and A. Srividya, “Routing Path Optimization to Maximize the Lifetime of Wireless Sensor Network”, *International Journal of Reliability, Quality and Safety Engineering*, Vol. 16, No. 6, pp. 509-520, 2009

[4] M.J. Chae, H.S. Yoo, J.R. Kim, and M.Y. Cho, “Bridge Condition Monitoring System Using Wireless Network (CDMA and ZigBee)”, *International Symposium on Automation and Robotics in Construction*, pp. 332-334, 2006

[5] Soungho Chae and Tomohiro Yoshida, "Application of RFID technology to prevention of collision accident with heavy equipment", *Automation in Construction*, Vol. 19, No. 3, pp. 368-374, 2010

[6] Weiwei Wu, Huanjia Yang, David A. S. Chew, Shuang-hua Yang, Alistair G. F. Gibb, and Qiming Li, “Towards an autonomous real-time tracking system of near-miss accidents on construction sites”, *Automation in Construction*, Vol. 19, Issue 2, pp. 134-141, 2010

[7] Xuesong Shen, Wu Chen, and Ming Lu, “Wireless Sensor Networks for Resources Tracking at Building Construction Sites”, *TSINGUA SCIENCE AND TECHNOLOGY* Vol. 13, Number S1, pp.78-83, 2008