Wireless Characteristics Study for Indoor Multi-Robot Communication System

Conference Paper · October 2018

DOI: 10.1145/3265997.3265999

4 authors:

Sipra Behera
Tata Consultancy Services Limited

Bighnaraj Panigrahi
Nokia Bell Labs

Hemant Kumar Rath
Tata Consultancy Services Limited

Arpan Pal
Tata Consultancy Services Limited

Wireless Characteristics Study for Indoor Multi-Robot Communication System

Sipra Behera
TCS Research & Innovation
sipra.b@tcs.com

Bighnaraj Panigrahi
TCS Research & Innovation
bighnaraj.panigrahi@tcs.com

Hemant Kumar Rath
TCS Research & Innovation
hemant.rath@tcs.com

Arpan Pal
TCS Research & Innovation
arpan.pal@tcs.com

ABSTRACT

Mobile robots are greatly influencing the growth of autonomous service and management in large e-commerce warehouses, modern-day smart factories, and industries in compliance with Industry 4.0 standards. The application requirements varies from low rate sensor data flows to high data-rate image and video transmissions. Coordination and communication among robots are vital for various applications in such indoor deployments. Due to the dynamic work-flow and mobility of the robots, wireless networks are being used as the underlying mode for communication among robots and between the robots and other network devices such as routers, gateways, etc. However, wireless behavior of the last-mile communication links is greatly affected due to various indoor constraints such as multi-path, blockage, interference, and mobility. In this paper, we present characteristics study of the wireless communication behavior in large-scale and complex multi-robot indoor systems. We also validate and select appropriate channel model for such robotic indoor communication systems. Through extensive simulations on ROS-OMNeT platform, we show effects of obstacles, their material types, node's mobility on the communication coverage as well as Signal To Noise Ratio (SNR), Packet Reception Rate (PRR), and throughput performances.

CNetSys'18, October 29, 2018, New Delhi, India

ACM ISBN 978-1-4503-5927-6/18/10...$15.00
https://doi.org/10.1145/3265997.3265999

ACM Reference Format:
Sipra Behera, Bighnaraj Panigrahi, Hemant Kumar Rath, and Arpan Pal. 2018. Wireless Characteristics Study for Indoor Multi-Robot Communication System. In *CNetSys '18: 1st Workshop on Complex Networked Systems for Smart Infrastructure, Oct. 29, 2018, New Delhi, India.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3265997.3265999

1 INTRODUCTION

Today, advancement in robotic systems are trying to bridge the intellegent management gaps in global economy by venturing into e-commerce, logistics, manufacturing, health-care, etc.[1]. For example, e-commerce and logistics companies such as Amazon, eBay are trying to achieve better automation and reliability, increase the productivity and reduce costs, by using new robotic systems. Such systems provide a flexible and scalable alternative to optimize tasks such as storage, transport, surveillance, remote monitoring, control, and maintenance. The operational environments in these use-cases can be either, an organized infrastructure such as warehouses, factory floors or an inhospitable environment, e.g., mines, nuclear power plants, etc.

In recent years multi-robot communications has made significant advancement in terms of designing new architectures, technologies, and protocols [2]. Out of several complex sub-systems, control and communication are two most important pillars in a multi-robotic autonomous systems. With the recent advancements, wireless networks such as Wireless Fidelity (WiFi) has become the de-facto choice for communication among robots and robotic systems. Apart from reduction in volume of wiring, it also provide the flexibility of ubiquitous control and communication among various, mostly mobile, robotic entities of such systems. There are mainly two types of multi-robot indoor communication using WiFi networks [3] such as: (i) Infrastructure-based: Robots communicating with each other via an Access Point

(AP), (ii) Adhoc-based: Robots communicating among each other directly without AP.

In a robotic automation system robots need to coordinate and perform assigned tasks in a cooperative manner. Apart from co-ordinating and communication with each other, robots aperiodically get control messages regarding navigation, actions, etc. from the central control unit. These tasks for robots can be of different types: e.g, placing, picking, managing items in racks and pallets in a warehouse, collecting video, sensory data from sensor deployed in factory floor, etc. In terms of the physical environment these scenarios vary from the typical open office spaces, semi/fully organized and rack filled warehouses, or a disorganized factory floors. These distinct indoor scenarios lead to blockage and coverage challenge in multi-robot wireless communication. Apart from this the multiple robots deployed in such environment have their own constraints like mobility, power, interference, etc. that pose major challenges in wireless communication [4]. For example, blockage in the navigation path of the robots affects significantly on the wireless channel characteristics. In certain scenarios even if the robot present inside the coverage boundary of an AP, it is not able to get enough signal strength because of a blockage in between. Moreover, depending on the type of blockage material such as a wooden or metallic rack, a glass or concrete door, an aluminum divider, the received signal characteristics also vary. Hence, in order to have a connected robotic network with guaranteed network coverage for navigation and task executions, underlying wireless network characteristics has to be analyzed.

In this paper, we study wireless characteristics of indoor robotic communication in a large warehouse. With varying blockage positions, blockage material types, distance between the robots and APs, we try to collect a holistic network view of the warehouse. The wireless characteristics vary with different indoor environments with changed layout designing, blockage positions, etc. This study will provide a way to design and manage the wireless network for such a multi-robot network. Robot Operating System (ROS) is a most commonly used robotic middle-ware that provides development framework for robotic scenarios [5]. However, ROS do not have modules for underlying wireless network layers. Hence, we use ROS with Objective Modular Network Test-bed (OMNeT) platform to study the wireless characteristics of a multi-robot network [6]. While ROS-Gazebo creates the warehouse robotic world, INET library of OMNeT is used for simulating the wireless communication stack for the multi-robot communication.

The main contributions of this paper are:

- To perform comparative analysis on indoor channel models that are suitable for indoor multi-robot wireless communication in a warehouse world.
- To study effects of blockages, blockage material types, distance, and interference from other neighbor communications on the wireless behavior of the communicating channels due to number .

The rest of the paper is organized as follows. In Section 2, we present the related work and in Section 3, we explain the system model, challenges and some possible solutions. We then discuss the simulation setup and results in Section 4. We conclude the paper in Section 5.

2 RELATED WORKS

The adoption of wireless communication in industrial environment like warehouse or factory floors provided the ease of deployment and scalability for a larger coverage area. With the recent focus on adopting Industry 4.0 authors in [7] addressed key wireless communication challenges with respect to factors like dynamic network topology and mobility. A typical warehouse or factory floor indoor environment have many blockages like metal or wooden storage racks with multiple levels, concrete walls, etc. These racks may store goods of different material types. The electromagnetic absorption of the wireless radio signals in such environment results in large variation in indoor propagation unlike indoor home or office environment [8]. Moreover, multiple robots moving in between the aisles of warehouse or factory floor environment need to communicate among themselves or with Access Point (AP) to coordinate their motion, complete the assigned task while avoiding single point failure. Because of dynamic environment and significant blockage in their path, a robot may face coverage challenge in such indoor scenarios. Hence there is a need of extensive study on wireless channel characterization based on path loss models in such environment for network planning in initial deployment.

Indoor wireless propagation models are classified into three broad categories [9]: empirical, deterministic and stochastic. In [10] authors investigated wireless communication solutions for warehouse environment by examining the channel characteristics and challenges of the environment based on 802.15.4 as the radio technology. Apart from this they considered the Log-distance path loss as a channel model to measure the coverage of the transmitter. However, due to limited maximum possible transmission power for 802.15.4 technology and unsuitability of Log-distance model to articulate the obstacle loss in dynamic warehouse environment, this model fails to address the coverage and blockage challenges in actual warehouse scenarios. Although ITU-R [11] is a more suitable channel model than Log-distance to model indoor environment but this also does not consider the obstacle loss. A new channel model proposed in [12] for warehouse environment that include key channel parameters like distance based path-loss component, frequency based path-loss co-efficient. However, the authors in [12] assumed the channel as stationary i.e. no moving device or objects in the warehouse environment. Hence [12] is not able to capture the realistic channel model for warehouse scenario which has a very dynamic environment. Also this model is not suffice to encounter the mobility of the communicating devices. In [13] authors used Ray-Tracing as channel model for warehouse scenario. Because of deterministic nature of Ray-Tracing model it dose not articulate the dynamic nature of the warehouse environment. In [14] authors proposed a more realistic channel model called Tata Indoor Path Loss model (T-IPLM), which is a non-deterministic statistical path loss model for indoor scenario. It not only provides the distance based path loss component but also factors like obstacle loss depending on material type, floor attenuation factor. However, authors in [14] did not show any observations explaining the dependencies of blocking material types on the wireless channel characteristics.

Log Normal, ITU-R, T-IPLM which are few of the broadly used models to characterize indoor communication channels. We study the characteristics of the three mentioned channel models under a large warehouse scenario with number of different types of blockages and other dynamics inside the warehouse. We have observed the dependencies of blockages, blockage materials on the wireless channel behavior of robots.

3 SYSTEM MODEL

In our system model we consider a multi-robot deployment in a large warehouse scenario. The robots are given tasks to perform and are moving to different parts of the warehouse to complete their tasks. The large warehouse is filled with racks of different sizes and materials for placing different types of inventories. A communication network is modeled with multiple Access points deployed at various strategic locations in the warehouse. Each robot is assumed to be connected to at least one of the APs at any given time. Fig. 1 shows a snapshot of our model where AP is a static wireless access point and $R1$-$R4$ are the deployed mobile robots. Our main idea is to study the wireless behavior of the mobile robots in the warehouse scenario. Most of the robots are mobile and have some assigned tasks to complete. While doing their tasks robots are collecting data and transmitting them to the cloud server through the APs.

In such indoor warehouse scenarios the communication network characteristics change dynamically due to different factors such as interior lay-out design, placement of racks, filling of inventories in racks, varying material types of the inventories, interference, etc. In this work we pin-point the wireless communication challenges faced by the robots due to indoor blockage, coverage range change, mobility, interference from other robots. Each robot in the deployment scenario has certain coverage boundary. However the dynamic behavior of the environment changes the channel characteristics of the robots and hence, affects their coverage. For

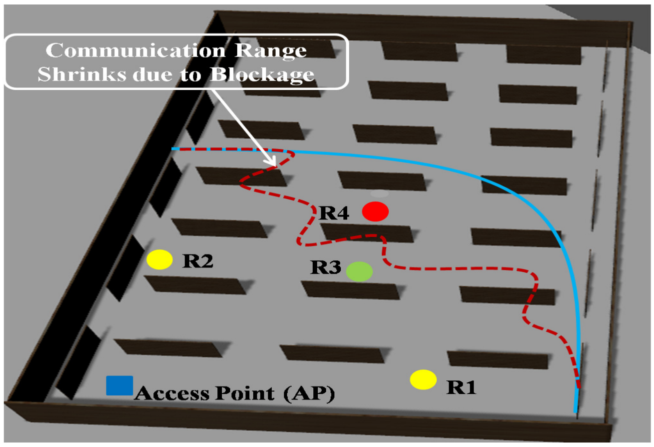

Figure 1: system model

example, in Fig. 1 the coverage range of the deployed AP is reduced at some location points due to effect of blockage. Therefore, the robot R4 which is actually inside the coverage range is now become out-of-range and hence can not be reached by AP. In some other scenarios, robots may get the interference from the nearby wireless devices or peer robots. Hence, these issues necessitate the need to identify such robotic wireless challenges so that robots can manage their position, mobility pattern, power levels and maintain better connectivity with AP.

To determine channel characteristics between the AP and robot we have used a modified version of Tata Indoor Path Loss Model (T-IPLM) [14]. With a fixed transmission power P_t, Receiver Sensitivity S_r received power is given as:

$$PL_{T-IPLM} = 20*log10(f)+N_T*log10(d)+\sum_w L_w+F-20 \quad (1)$$

Where, N_T is the power loss co-efficient due to distance d. f and F are the operating frequency and floor attenuation factors, respectively. L_w is the added component for loss factor of the material type of blockage between transmitter and receiver.

If there are no blockages between AP and mobile robot, Signal-to-Noise Ratio (SNR) of the link varies with distance. Therefore, λ_{snr} is the SNR threshold at the coverage boundary of the AP that helps to identify the robots suffering from wireless outage issues. However, presence of any blockages in terms of iron racks, glass divider, indoor walls, etc. between AP and robot abases SNR of the link. For example in Fig. 1, due to presence of racks as blockage, R_4 who is inside coverage area now becomes out of coverage. Due to the shrinking coverage and drop in SNR any ongoing or newly initiating applications, data and control message transmissions between the AP and robot gets hampered. To mitigate this effect following measures can be implemented:

- During mobility if the robot is moving towards the dead zone then by utilizing the proactive mobility it can change its direction to maintain connectivity with the AP.
- Enabling the AP to increase the Transmission Power in order to maintain connectivity with the robots at the coverage boundary.
- When robot's link with AP is not satisfying SNR criteria, it can relay its message to a neighboring robot which in turn forwards message to AP.

4 SIMULATION MODEL

We perform extensive simulations to characterize the multi-robot indoor wireless behavior. For our simulations, we use a joint Robot Operating System (ROS)-Gazebo [5] and Objective Modular Network Test-bed (OMNeT) platform with INET library [6][1]. We consider a 200×300 m^2 of rectangular indoor warehouse area with different blockages in terms of racks, pallets, dividers, etc. The indoor warehouse world along with interior lay-out design and placement of pallets and racks are created using Google Sketch software. The world environment will have all the obstacles with their coordinated positions. This design is then embedded into ROS-Gazebo simulator to simulate the robots in the warehouse along with their functionalities - mobility, tasks, topics. The interior designs (position of obstacles, racks) along with the robots' environments are then passed into the OMNeT module in order to simulate complete wireless protocol stack for communication among devices.

Fig. 2 shows the block diagram of the ROS-OMNeT module. The physical environment in the ROS platform is shared with OMNeT through the configuration called

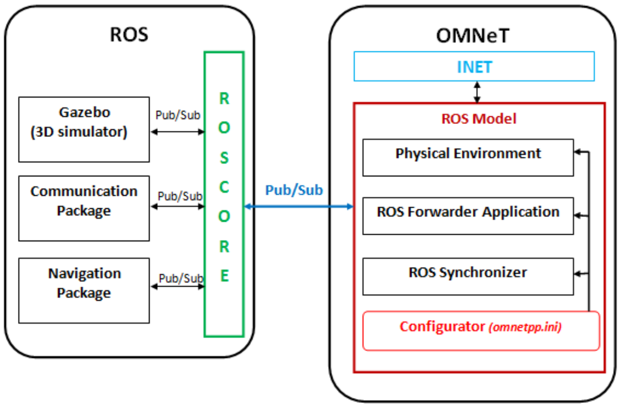

Figure 2: ROS-OMNeT Simulation Model

omnetpp.ini. This simulates any change in the environment and the material types of the blockage. It also abstracts the number of robots in ROS platform as ROS nodes in OMNeT platform. Each abstracted ROS node in OMNeT uses the INET library for wireless communication protocol stack implementation. The INET library adds wireless Network Interface Card (NIC) functionalities to ROS nodes that implements Radio and MAC module. Each NIC then communicate with the ROS application through *ROSForwarder* module in OMNeT. Using the *ROSForwarder* module we create a *ROSService* called *packetSenderService* which converts sender ROS node's messages into packets and attach destination ROS node's MAC address. The packet transmits through the *RadioMedium* which takes care of the propagation, path-loss, obstacle-loss, etc. in the environment. Note that, depending on the wireless channel characteristics SNR profile of the link between robot and AP can be computed. When packet reaches destination ROS node's NIC, depending on the underlying radio medium and the receiver sensitivity, determines if the packet is successfully received or not. The entire simulation setup between ROS and OMNeT is synchronized by *ROSSynchonizer* module in OMNeT. We have also considered two of the existing channel models like Log Normal, ITU-R of OMNET and included the T-IPLM model for comparison of the wireless behaviors.

4.1 Results and Discussions

We consider three different material types of the blockages like concrete, wooden and glass in order to study the wireless propagation characteristics of robots through them. The communication parameters for the simulation are shown in Table. 1. We compare the Received Power at a robot when it is moving away from the AP

[1]ROS do not have wireless communication stack

Table 1: Simulation Parameters

Parameters	Values
Frequency	2.4 GHz
Bandwidth	20 MHz
Modulation	BPSK
Transmit Power	100 mW (20 dBm)
Receiver Sensitivity	-90 dBm
Noise Power	-95 dBm
Channel Models	Log Normal/ ITU-R/ T-IPLM

with varying distance between them. The comparisons are done under two distinct scenarios, (i) *With Blockage* and (ii) *Without Blockage*. In our simulations we have compared the results of three different channel model schemes - (i) Log Normal, (ii) ITU, and (iii) modified T-IPLM. Among the three, only Tata Indoor Path Loss Model (T-IPLM) [3] is taking into account actual indoor characteristics in terms of obstacles, obstacle materials, etc. and hence more accurately depicting the real indoor wireless scenario. In Fig. 3 we show SNR profiles of the robot-AP link with varying distances and obstacle types. We compared the SNR profiles for three different channel model schemes. As it can be observed from the figure that T-IPLM has comparatively lower SNR profiles as it depicts the real indoor scenario accurately. Also, it can be observed from the Fig. 3 that in presence of obstacles, the actual communication range shrinks. For example, with wooden obstacle, the communication range (SNR threshold = 25 dB) is reduced from 82 meters to 60 meters. Similarly with glass obstacle communication range shrinks further to 48 meters. In case of the concrete obstacle type the SNR at the receiver robot is significantly lower than the required minimum of 25 dB and with the increase in Tx-Rx separation it results in negative value leading to packet drop, hence no communication possible.

We also observe the effect varying number of blockages on the SNR profile. As it can be seen in Fig. 4, the SNR profile for a fixed transmitter-receiver distance intuitively decreases with increase in number of obstacles between the transmitter and receiver. This is true for obstacle of any material types. We have also observed that in case of more than one concrete blockages the received power is lower than the Sensitivity of the receiving robot, which leads to significant packet drops. In order to observe the effect of multiple obstacles at different transmitter-receiver distances the wireless behavior at two different transmitter-receiver distance values as 30 and 82 meters are observed, respectively.

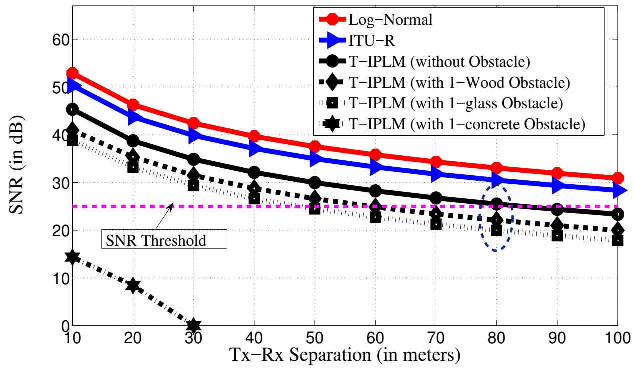

Figure 3: SNR vs Distance

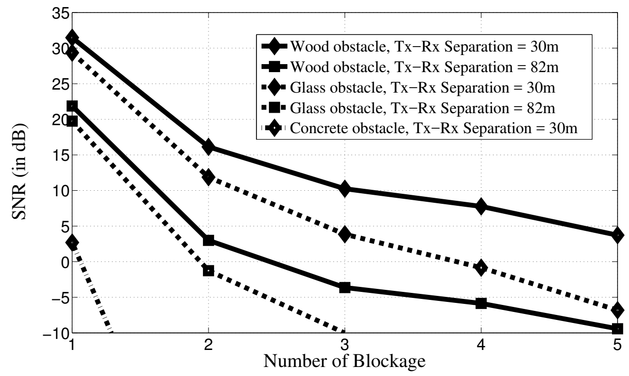

Figure 4: SNR vs Number of Blockage using T-IPLM channel model

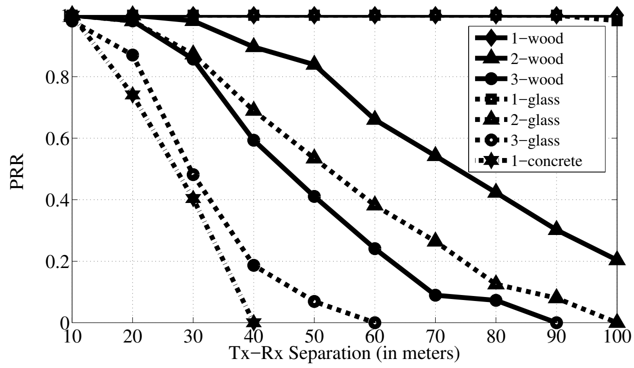

Figure 5: PRR vs Distance using T-IPLM channel model

The number of obstacles between the transmitter-receiver also effects the Packet Reception Ratio (PRR) (c.f. Fig. 5) and hence the link layer throughput (c.f. Fig. 6). We perform experiments to analyze the effect of number of obstacles, obstacle type (wood, glass, concrete), Tx-Rx separation on the throughput performance as shown in

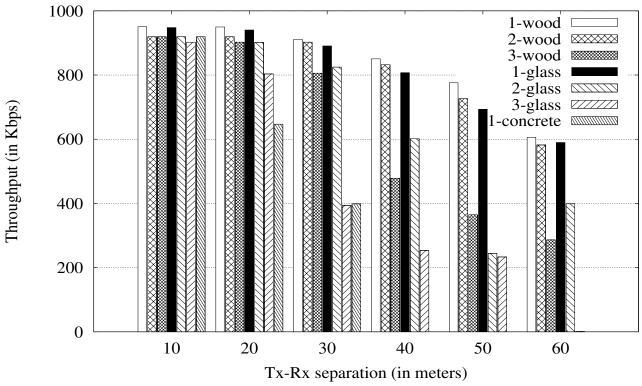

Figure 6: Throughput vs Distance using T-IPLM channel model

Data Rate	Link Layer Throughput (in Kbps)			
	2-Wood	2-Glass	3-Wood	3-Glass
1 Mbps	726.5	244.2	364.5	233
11 Mbps	8230.7	5548.6	3728.5	3

Fig. 6. It is observed that for an operating data-rate of 1 Mbps, throughput degrades with increase in number of obstacles. Also, in case of concrete obstacle, throughput becomes zero after transmitter receiver distance of 40 meters. This is because the PRR becomes zero due to concrete obstacle, indicating total loss of packets (c.f. Fig. 5). We also observe the impact of operating data-rate on link layer throughput as shown in Table. 4.1. In Table. 4.1 for a Tx-Rx separation of 50 meters and data rate of 1, 11 Mbps the link layer throughput is computed, which intuitively increases with increase in data rate. However, with three glass obstacle the coverage boundry of the robot shrinks so, even after oprating at a data rate of 11 Mbps, achieved link layer throughput is significantly low (3 Kbps).

5 CONCLUSION

In this paper we have observed the last mile wireless communication characteristics in an indoor warehouse robotic deployment. With the dynamic behavior of the environment in warehouse, the actual coverage boundary of each communicating robots shrinks. Using Robotic Operating System (ROS)-Gazebo and OMNeT based simulations we have shown the effect of obstacle blockages, obstacle material type, distance, etc. on the coverage boundary and wireless communication performance. By studying the effect of these factors on SNR, PRR and throughput we are able to identify the robot approaching the dead zone or outside the AP coverage. Timely analysis of these effects helps to provide proactive mobility to the robots to be in the coverage of any available APs in warehouse.

REFERENCES

[1] D Bowersox and M. V. Cooper Closs. 2008. Gesto da cadeia de suprimentos e logistica. *Rio de Janeiro: Elsevier* (2008).

[2] R. Pandey, A. K. Singh, and K. M Krishna. 2012. Multi-robot exploration with communication requirement to a moving base station. In *IEEE Int. Conf. on Automation, Science and Engineering (CASE) 23rd National Conf. on Communication.*

[3] A. Knoll and R Prasad. 2012. Wireless Robotics: A Highly Promising Case for Standardization. In *Int. Journal on Wireless Personal Communications*, Vol. 64. Springer, 611617.

[4] S. Arumugam, Kalle R. K., and Prasad A. R. 2013. Wireless Robotics: Opportunities and Challenges. In *Int. Journal on Wireless Personal Communications*, Vol. 70. Springer, 10331058.

[5] M. Quigley, K. Conley, B. P. Gerkey, J. Faust, T. Foote, J. Leibs, R. Wheeler, and A. Y. Ng. 2009. ROS: an Open-Source Robot Operating System. In *IEEE Int. Conf. on Robotics and Automation (ICRA) Workshop on Open Source Software.*

[6] A. Varga and R. Hornig. 2008. An Overview of the OMNeT++ Simulation Environment. In *ACM 1st Int. Conf. on Simulation tools and techniques for communications, networks, systems and workshops (Simutools).*

[7] A. Varghese and D. Tandur. 2014. Wireless requirements and challenges in Industry 4.0. In *IEEE Int. Conf. on Contemporary Computing and Informatics (IC3I)*. 634–638.

[8] J. F. Coll, P. ngskog, C. Karlsson, J. Chilo, and P. Stenumgaard. 2010. Simulation and Measurement of Electromagnetic Radiation Absorption in a Finished-product Warehouse. In *IEEE Int. Symposium on Electromagnetic Compatibility (EMC).*

[9] V. S. Abhayawardhana, I. J. Wassell, D. Crosby, M. P. Sellars, and M. G Brown. 2005. Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems. In *61st IEEE Vehicular Technology Conference (VTC).*

[10] A. Karaagac, J. Haxhibeqiri, W. Joseph, I. Moerman, and J. Hoebeke. 2017. Wireless Industrial Communication for Connected Shuttle Systems in Warehouses. In *13th IEEE Int. Workshop on Factory Communication Systems (WFCS).*

[11] P Series. 2012. *Propagation Data and Prediction Methods for the Planning of Indoor Radiocommunication Systems and Radio Local Area Networks in the Frequency Range 900 MHz to 100 GHz.* Technical Report Recommendation ITU-R P.1238-7.

[12] S. Sangodoyin, R. He, A. F. Molisch, V. Kristem, and F. Tufvesson. 2015. Ultrawideband MIMO Channel Measurements and Modeling in a Warehouse Environment. In *IEEE Int. Conf. on Communications (ICC).*

[13] L. Wang, B. Ai, D. He, G. Li, K. Guan, R. He, and Z Zhong. 2017. Channel Characteristics Analysis in Smart Warehouse Scenario. In *IEEE Int. Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting.*

[14] H. K. Rath, S. Timmadasari, B. Panigrahi, and A Simha. 2017. Realistic Indoor Path Loss Modeling for Regular WiFi Operations in India. In *23rd National Conf. on Communication (NCC).*