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Abstract

In this report, we present network measurement of an ISA100.11a industrial wireless network operating in the presence of WiFi interference. The IEEE 802.15.4–based ISA100.11a wireless protocol operates at the 2.4 GHz band for various industrial applications. IEEE 802.11 WiFi also may operate at the 2.4 GHz band for industrial and data applications in the same environment. The existence of IEEE 802.11 wireless network would have a negative impact on the rated performance parameters of the ISA100.11a networks. In this work, we study WiFi interference impacts on the performance of a single ISA100.11a node using the National Institute of Standards and Technology (NIST) wireless testbed.

Key words

Industrial Wireless; Interference; Measurement Criteria.

Acknowledgments

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1. Introduction

The use of wireless sensor networks (WSN) in industrial automation offers several advantages compared to their wired counterparts. It obviously adds more flexibility of the network setup by eliminating the need for cabling, which reduces the network installation cost as well. Additionally, the deployment of WSN allows for improved productivity and better system management by increasing the number of sensors and collecting larger amounts of data. However, the practical implementation of WSN faces some challenges. One of the main challenges is the interference by other existing wireless devices in the industrial environment. Many industrial wireless protocols, including ISA100.11a, operate in the unlicensed 2.4 GHz frequency band. That allows for the WSN to be more exposed to interference by both industrial and non-industrial wireless networks. WiFi is considered one of the major sources of interference in the 2.4 GHz frequency band.

In the report, we have studied with a team from Yokogawa Corporation[1] the effect of WiFi interference on the performance of ISA100.11a WSN composed of Yokogawa equipment. Yokogawa has developed a number of products for industrial WSN. Their products are developed to operate in typical industrial environments including refineries and chemical plants. We used the National Institute of Standards and Technology (NIST) wireless testbed to evaluate the performance of the ISA100.11a networks with the existence of controlled WiFi interference. The testbed contains a radio frequency (RF) channel emulator to replicate the industrial environment.

In this report, we present slides containing the results obtained during a visit of the Yokogawa team to NIST where the experiments took place. The enclosed presentation slides were prepared by NIST staff to document the activities and results of the collaboration with Yokogawa, and were presented by NIST to the Yokogawa team during their visit. This publication provides the material as presented and discussed at this meeting in its original form. We start with the testbed description where the components and their roles in the system are briefly discussed. Two testing scenarios are then described and their parameters are quantified, including the levels and type of WiFi interference. In each scenario, the corresponding channel parameters are mentioned. Then, two classes of measurement criteria are considered, namely, network-level and signal-level criteria. In each class, the definitions of the criteria are stated. The results are then specified where comparisons between the two scenarios and the comparable signal-level and network-level criteria are done. Finally, conclusions are drawn.

[1] Commercial equipment and materials are identified to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

2. Testbed Description

- The testbed includes a high-performance programmable logic controller (PLC) to produce the input signal $x(t)$.
- The network is composed of ISA100.11a wireless sensors and a gateway for infrastructure connectivity between nodes.
- A vector signal generator with an arbitrary waveform output is used to produce the WiFi interference signal.

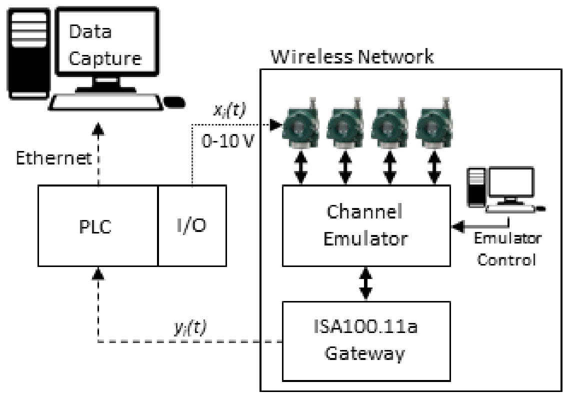

Figure 1 Testbed Architecture

- The testbed includes a radio channel emulator capable of replicating the multi-path and path loss environments for a mesh network of up to 8 physical nodes.
- The output of the wireless network $y(t)$ is compared to the input to measure various error and delay criteria.

Figure 2 A Photo of the NIST Industrial Wireless Testbed

3. Scenarios: Basic Setup

- The system is composed of a single sensor, gateway, and WiFi interferer.
- The system studied for various sensor-gateway and interferer-gateway distances (dashed lines).
- Two scenarios are studied: "Free-space" and "Oil Refinery" where the wireless channels are different in the loss exponent and the channel impulse response (CIR).
- The wireless channels effects are generated using the channel emulator.

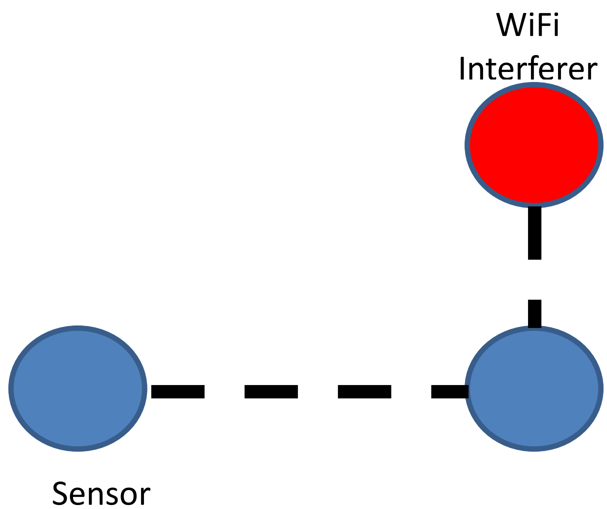

Figure 3 Scenario Setup

3.1. Free-space Scenario

- Loss Exponent = 2 (i.e., an isotropic radiator)
- Ideal Channel Impulse Response (No Multipath)
- Three different distances between the sensor and the Gateway {100m, 180m, 260m}
- The injected interference is WiFi IEEE 802.11n (20 MHz Bandwidth) transmitting at 17dBm on channel 6 with a 50% duty cycle.
- Three different settings for the interferer
  - No Interference, 5m, and 15m from the Gateway

3.2. Oil Refinery Scenario

- Loss Exponent = 2.7
- Channel Impulse Response is IEEE 802.15.4a LOS.
- Three different distances between the sensor and the Gateway {10m, 30m, 50m}
- The interference is WiFi IEEE 802.11n (20 MHz Bandwidth) transmitting at 17dBm, channel 6, and 50% duty cycle.
- Three different settings for the interferer {No Interference, 5m, 15m from the Gateway}

4. Measurement Criteria

- Two classes of measurement criteria are considered
    - Signal level and network level
- The signal level criteria are obtained through comparing the input and output analog signals.
- The network level criteria are obtained through a network monitoring tool provided by the device manufacturer and dealing with transmitted and received data packets.
- A maximal length pulse code is used as the input signal with each pulse have a 2 second pulse width.

4.1. Signal Level Criteria

- Root Mean Square (RMS) Error

$$\min_d \sqrt{\frac{1}{T}\int_0^T (x(t-d)-y(t))^2 dt}$$

- Average Absolute Error

$$\min_d \frac{1}{T}\int_0^T |(x(t-d)-y(t))| dt$$

- Normalized Peak Cross Correlation

$$\max_d \frac{\int_0^T x(t-d)y(t)dt}{\int_0^T x^2(t)dt}$$

- End-to-End Delay

$$\operatorname{argmax}_d \int_0^T x(t-d)y(t)dt$$

4.2. Network Level Criteria

- Packet Error Rate (PER)

    The number of error packets divided by the total number of received packets.
- Average Latency

    The average time it takes for a packet of data to get from one designated point to another.
- Maximum Latency

    The maximum time it takes for a packet of data to get from one designated point to another.
- Received Signal Strength Indicator (RSSI)

    The relative received signal strength in a wireless environment which is an indication of the power level being received by the receive radio.

5. Results

5.1. RMS Error

Table 1 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.3361	0.3419	0.3978
15m (-64dB)	0.3877	0.3884	0.4136
5m (-54dB)	0.3955	0.4129	0.4590

Table 2 Oil Refinery

	10m	30m	50m
No Interference	0.3118	0.3329	0.3532
15m	0.3556	0.3593	0.3639
5m	0.3618	0.3883	0.3953

5.2. Absolute Error

Table 3 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.1130	0.1169	0.1583
15m (-64dB)	0.1503	0.1509	0.1710
5m (-54dB)	0.1565	0.1705	0.2107

Table 4 Oil Refinery

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.1130	0.1169	0.1583
15m (-64dB)	0.1503	0.1509	0.1710
5m (-54dB)	0.1565	0.1705	0.2107

5.3. PER

Table 5 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0%	2%	22%
15m (-64dB)	12%	15%	34%
5m (-54dB)	19%	36%	56%

Table 6 Oil Refinery

	10m	30m	50m
No Interference	0%	0%	0%
15m	0%	0%	5%
5m	1%	13%	14%

5.4. PER vs Absolute Error (Free-space)

Table 7 PER

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0%	2%	22%
15m (-64dB)	12%	15%	34%
5m (-54dB)	19%	36%	56%

Table 8 Absolute Error

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.1130	0.1169	0.1583
15m (-64dB)	0.1503	0.1509	0.1710
5m (-54dB)	0.1565	0.1705	0.2107

5.5. PER vs Absolute Error (Oil Refinery)

Table 9 PER

	10m	30m	50m
No Interference	0%	0%	0%
15m	0%	0%	5%
5m	1%	13%	14%

Table 10 Absolute Error

	10m	30m	50m
No Interference	0.1090	0.1108	0.1247
15m	0.1265	0.1291	0.1253
5m	0.1309	0.1508	0.1609

5.6. End-to-End Average Signal Delay in Seconds

Table 11 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	2	2.5	3
15m (-64dB)	2.5	2.5	3
5m (-54dB)	2.5	3	3.5

Table 12 Oil Refinery

	10m	30m	50m
No Interference	2	2	2.5
15m	2	2	2.5
5m	2	2.5	2.5

5.7. Average Network Latency in Seconds

Table 13 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.5	0.6	0.9
15m (-64dB)	0.6	0.7	1.1
5m (-54dB)	0.8	1	1.2

Table 14 Oil Refinery

	10m	30m	50m
No Interference	1.1	1.2	1.2
15m	1.1	1.2	1.2
5m	1.1	1.2	1.2

5.8. Maximum Network Latency in Seconds

Table 15 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	1.2	1.3	2
15m (-64dB)	1.3	1.3	3.6
5m (-54dB)	1.5	3.3	7.5

Table 16 Oil Refinery

	10m	30m	50m
No Interference	1.3	1.3	1.3
15m	1.3	1.3	1.3
5m	1.3	1.3	1.3

5.9. Delay vs Latency (Free-space)

Table 17 End-to-End Average Signal Delay in Seconds

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	2	2.5	3
15m (-64dB)	2.5	2.5	3
5m (-54dB)	2.5	3	3.5

Table 18 Average Network Latency in Seconds

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.5	0.6	0.9
15m (-64dB)	0.6	0.7	1.1
5m (-54dB)	0.8	1	1.2

5.10. Delay vs Latency (Oil Refinery)

Table 19 End-to-End Average Signal Delay in Seconds

	10m	30m	50m
No Interference	2	2	2.5
15m	2	2	2.5
5m	2	2.5	2.5

Table 20 Average Network Latency in Seconds

	10m	30m	50m
No Interference	1.1	1.2	1.2
15m	1.1	1.2	1.2
5m	1.1	1.2	1.2

5.11. Normalized Peak Cross-Correlation

Table 21 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	0.8823	0.8818	0.8305
15m (-64dB)	0.8479	0.8485	0.8419
5m (-54dB)	0.8410	0.8349	0.7589

Table 22 Oil Refinery

	10m	30m	50m
No Interference	0.8945	0.8910	0.8799
15m	0.8709	0.8623	0.8614
5m	0.8667	0.8620	0.8611

5.12. RSSI

Table 23 Free-space

	100m (-82dB)	180m (-85dB)	260m (-88dB)
No Interference	-90dBm	-91dBm	-91dBm
15m (-64dB)	-90dBm	-93dBm	-90dBm
5m (-54dB)	-90dBm	-93dBm	-90dBm

Table 24 Oil Refinery

	10m	30m	50m
No Interference	-54dBm	-66dBm	-71dBm
15m	-51dBm	-64dBm	-70dBm
5m	-49dBm	-64dBm	-70dBm

6. Conclusions

- There is less performance variations in the case of the oil refinery with realistic channel impulse response compared to the free-space case.
- The interference has larger effect at edges of the communications range of the network.
- The signal level performance criteria, which are more representative to the system performance, are more robust to the channel variations and the interference.
- Network latency does not represent a major part in the signal end-to-end delay. As a result, interference has a small effect on end-to-end delay.
- Wi-Fi interference may degrade the performance significantly in industrial environments and hence its use has to be monitored and controlled.