Wireless Factory Automation: Radio Channel Evolution in Repeated Manufacturing Processes

[Extended Abstract]

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***Abstract*—Wireless industrial automation is seen as the basis for efficient and highly flexible production processes in future factories. This is one key aspect to achieve the fourth industrial revolution, also referred to as Industrie 4.0. However, enhancing wireless technologies to fulfill the latency and reliability constraints of mission-critical machine-type communication (MTC) becomes highly challenging. In this paper, we discuss an indoor channel measurement campaign with a focus on communication between industrial robots and their controller entities over short distances. The measurements were performed in a representative automation lab at 5.85 GHz. We study a repeatedly performed pick-and-place process within one automation cell under the condition of other active machinery and personnel nearby. Based on the power delay profile (PDP) and the corresponding power spectral density (PSD), we observe a high channel correlation between measurement snapshots on equal positions in the repeated process. Hence, the precision of the process trajectory is sufficient to obtain significant correlation benefits during the repetitions. Furthermore, this means that the scattering and reflection effects from active and moving obstacles in the neighbourhood are limited. Our findings allow a channel-aware planning of wireless control loops by optimized link adaption and, hence, reliability improvements.**

***Index Terms*—Wireless factory automation; Radio channel measurements; Industrial robots; Machine-type communication; M2M**

I. Introduction

Recently, wireless technologies have gained attention from the industrial automation community. It is expected that wireless solutions will enable highly efficient and highly flexible operation of production processes in factory automation if they can fulfill the challenging latency and reliability requirements in the context of mission-critical machine-to-machine (M2M) services [1], [2].

A manufacturing process requires short operation cycles - usually less than or around 10 ms - and fail-safe transfer of sensor and actuator signals. The end-to-end latency for the transmission of wireless signals is often stated as < 1 ms. The packet error rate is requested to be up to 10^{-9} while the packets contain only little payload in the range of bytes to kilobytes. According to automation equipment manufacturers, the communication range within a common automation cell is typically short, e.g. below 10 m.

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In this paper, we will present results from a measurement campaign targeting short-range communication between industrial robots and their controller entities over the air. The measurements were performed at 5.85 GHz carrier frequency using a broadband channel sounder. We studied a repeatedly performed pick-and-place process within one automation cell of a representative factory facility. At the same time, other active machinery were operating in neighbouring cells.

Our main observations stated in this extended abstract and later on discussed in the full paper are the following: We obtain a highly deterministic channel in static measurement situations which translates into a high correlation of the radio channel between measurement snapshots on equal positions during the repeated process. We show that this correlation holds in the short-range profile of our measurement setup despite the fact that neighbouring production systems and even persons alter the scattering and reflection characteristics of the wireless channel over time. Basis of our findings is the analysis of the power delay profile (PDP) and the corresponding power spectral density (PSD).

This work extends our findings in [3] where we characterized the industrial radio channel at 5.85 GHz with a focus on channel delay statistics and the impact on latency-optimized symbol design for industrial applications.

The results from this paper motivate the channel-aware planning of reliable control loops for the wireless control of industrial robots. In this regards, one can utilize the channel pre-knowledge gained from the process repetitions in oder to achieve link adaption improvements and feedback optimization. Related work can be found in [4], where the authors analyzed communication-aware motion planning, channel estimation and prediction in robotic networks.

II. Experimental Setup

A. Measurement Environment

Our channel measurement campaign took place in the Smart Automation Lab at the WZL at RWTH Aachen University, Germany. The automation lab is a highly sophisticated production system comprising of several machine tools, automated transportation systems, sensors and industrial robots, including robots with parallel kinematics and articulated robots. The dimension of the automation lab is 29×15 m and the height is 7.3 m. The building has a metallic ceiling, a concrete floor and some open metallic joists. A map is shown in Fig. 1.

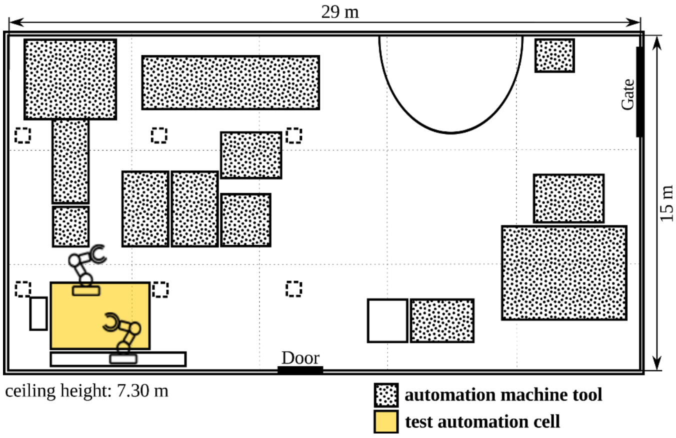

Fig. 1: Environment map of the Smart Automation Lab at the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University.

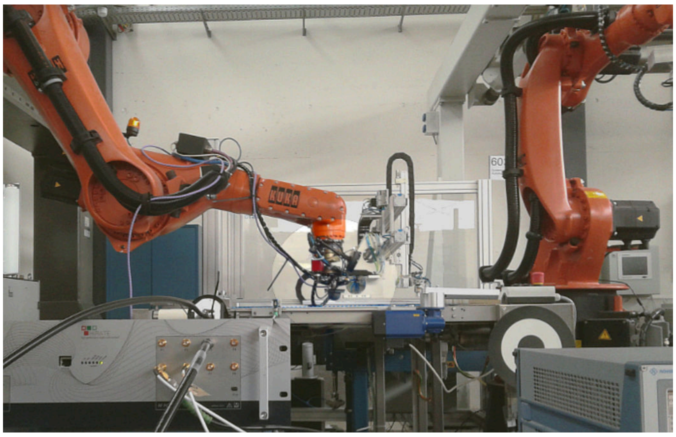

Fig. 2: The test automation cell with the measurement antenna installed at the robot gripper in the Smart Automation Lab at the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen University.

We consider a *test automation cell* of approx. 4×5 m area with two articulated industrial robots in a corner of the building, see Fig. 2. We use the top-mounted robot system which is installed on a translational axis for the measurement campaign. The channel measurements were conducted in a live production environment, where other active automation machine tools and personnel were nearby. Following, the neighbouring production systems and persons alter the scattering and reflection characteristics of the wireless signals over time.

B. Channel Sounder

The measurement equipment used for real-time channel sounding was the High Performance Digital Radio Testbed (HIRATE) [5]. It was precisely calibrated and configured to support a baseband signal bandwidth of $B = 250$ MHz, corresponding to a sampling interval of $T_S = 4$ ns. Furthermore, Frank-Zadoff-Chu sequences [6] of length $N = 1024$ were used as the periodic correlation sequences for the channel measurements. For the sequence period time, we satisfied $T_P = N/B \ll T_{coh}$, where T_{coh} denotes the coherence time of the channel. In order to increase the measurement quality of the channel impulse response (CIR) and to reduce noise effects, the channel sounder performed instant averaging of 64 sequence periods, giving one measurement snapshot. Snapshots were continuously recorded each 12.29 ms. The basic configuration parameters of the measurement setup are given in Table I. The measurements were conducted with one receiver and one transmitter unit of HIRATE. For frequency stability and time synchronization a clock cable connected both units.

Scenario	short-range industrial indoor (automation hall with industrial robots)
Meas. type	mobile
Center frequency	5.85 GHz
Bandwidth	250 MHz
Sampling resolution	4 ns
Path resolution	1.2 m
Speed on trajectory	0.4 m/s
Recorded snapshots	$\approx$ 49000 (700×70 repeated processes)
Tx & Rx antennas	Huber+Suhner multiband antenna model no. SWA 2459/360/7/20/V_2, omni-pattern, linear / vertical polarized

TABLE I: Basic Measurement Setup

C. Investigated Manufacturing Process

We conducted a predefined and repeated *pick-and-place process* of an industrial robot picking up items that move on a conveyor belt. The gripper at the end of a flexible robot arm starts a process run from its home position. It picks an item at an initial position which is located on a table and places it at a target position before returning to the home state. We assume that the process is under supervision of a robot control (RC) unit located at a specified spot in the automation cell. We measure the link between the Tx antenna of the controller and the Rx antenna attached to the gripper of the robot arm. For the ease of measurement, we left the antenna orientation of both Tx and Rx antennas constant during the whole process run. The tool center point of the robot gripper moves on predefined trajectories at nearly constant speed of 40 cm/s. This is $40\ \%$ of the real-time speed of such pick-and-place processes (approx. 1 m/s) and means that between each recorded snapshot, a distance of 4.9 mm was covered. The snapshot rate is closely matched to the cycle intervals of the robot control, which sends updates of the position along the trajectory every 12 ms. We interpolate the trajectory information of the robot to achieve a positioning grid that is consistent with our measurement snapshot rate. The pick-and-place process had a total runtime of approx. 8.6 seconds and was repeated 70 times.

III. Radio Channel Analysis (Initial Results)

We preprocess the recorded channel impulse response (CIR) of the HIRATE system and obtain a power delay profile (PDP)

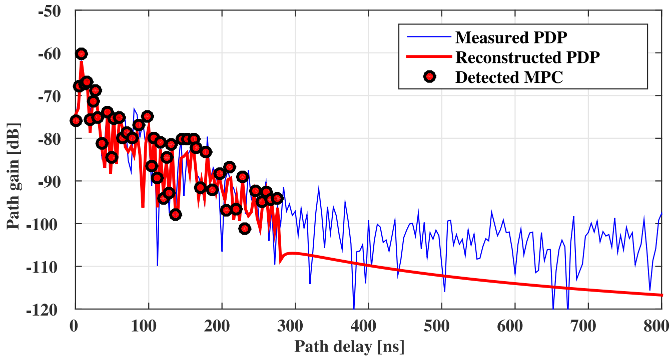

Fig. 3: Measured PDP and reconstructed PDP after refinement by detection of the most dominant multipath components (MPCs) for a single measurement snapshot at 5.85 GHz.

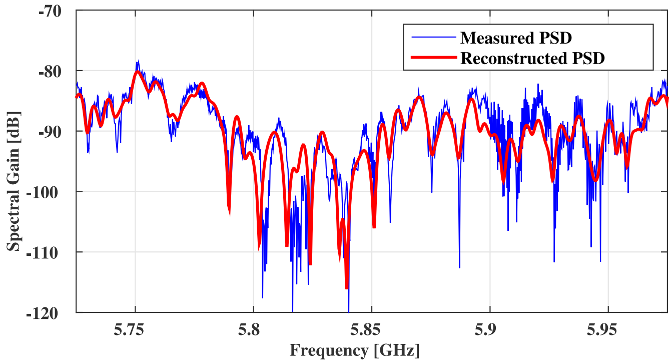

Fig. 4: PSD for the measurement snapshot of Fig. 3.

and the power spectral density (PSD) for each snapshot of the measurement track, see Fig. 3 and Fig. 4.

By considering the sum over all power taps in time domain or over all spectral power components, we obtain the total received power. Fig. 5 shows that the total received power has a very similar profile when comparing the process repetitions. Usually, the surrounding environment, e.g. production systems and moving personnel nearby, alter the scattering and reflection characteristics of the wireless signals over time, leading to a time evolution of the wireless channel. However, we see that this effect is limited in our represenative factory automation setup.

Fig. 6 provides even more insights. Here, we obtain the PSD

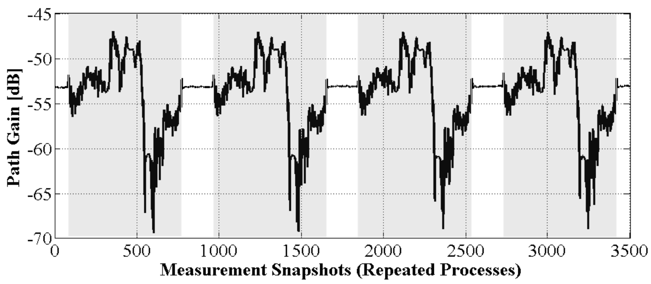

Fig. 5: Evolution of the total received power in repeated automation processes. Stop intervals occur prior to each process run.

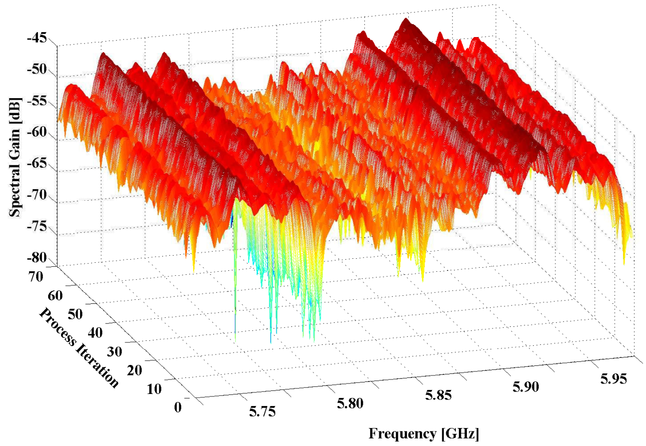

Fig. 6: Evolution of the PSD in repeated automation processes by observing a snapshot at the same spatial position.

over the complete 250 MHz frequency band for equal spatial positions in multiple iterations of the pick-and-place process. We observe a very similar PSD, concluding that not only the total channel power but even the single spectral components or delay taps are highly correlated. This also concludes, that the process trajectory is sufficiently precise over multiple process iterations.

IV. Outlook

In the final version of this paper, we will highlight in more details how we determine the dominant multipath components from the recorded channel impulse responses in order to obtain the PDP and PSD for each measurement snapshot. Moreover, we will further analyze the correlation of equal-positioned channel profiles in the repeated process. In addition to the spectral gain, we will present and discuss the evolution of the phase component of the channel. Furthermore, we will evaluate the channel correlation statistically.

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