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# Suitability of Modern Wi-Fi for Wireless-Infield-Communication of Agricultural Machines

Diploma Thesis in Information Systems Engineering

22 November 2022

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# Suitability of Modern Wi-Fi for Wireless-Infield-Communication of Agricultural Machines

Diploma Thesis in Information Systems Engineering

vorgelegt von

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angefertigt an der

**Technischen Universität Dresden**
**Fakultät Informatik**
**Networked Systems Modeling**

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Abgabe der Arbeit: **22. November 2022**

# Erklärung

Ich versichere, dass ich die Arbeit ohne fremde Hilfe und ohne Benutzung anderer als der angegebenen Quellen angefertigt habe und dass die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen hat und von dieser als Teil einer Prüfungsleistung angenommen wurde.
Alle Ausführungen, die wörtlich oder sinngemäß übernommen wurden, sind als solche gekennzeichnet.

# Declaration

I declare that the work is entirely my own and was produced with no assistance from third parties.
I certify that the work has not been submitted in the same or any similar form for assessment to any other examining body and all references, direct and indirect, are indicated as such and have been cited accordingly.

(Karl Christian Lautenschläger)
Dresden, 22 November 2022

This template is for use with `pdflatex` and `biber`. It has been tested with TeX Live 2020 (as of 25 Oct 2020).

# Abstract


about 1/2 page:

1. Motivation (Why do we care?)
2. Problem statement (What problem are we trying to solve?)
3. Approach (How did we go about it)
4. Results (What's the answer?)
5. Conclusion (What are the implications of the answer?)

The abstract is a miniature version of the thesis. It should be treated as an entirely separate document. Do not assume that a reader who has access to an abstract will also have access to the thesis. Do not assume that a reader who reads the thesis has read the abstract.

# Kurzfassung

Gleicher Text (sinngemäß, nicht wörtlich) in Deutsch

# Contents



The table of contents should fit on one page. When in doubt, adjust the `tocdepth` counter.

## Chapter 1

# Introduction

- general motivation for your work, context and goals.
- context: make sure to link where your work fits in
- problem: gap in knowledge, too expensive, too slow, a deficiency, superseded technology
- strategy: the way you will address the problem
- recommended length: 1-2 pages.

## 1.1 Wireless-Infield Communication

- **Real-Time Machine-to-Machine Control**is the exchange of control data under real-time conditions with defined latency policies. This use case enables leader-follower scenarios where agricultural machines follow a leading agricultural machine at a lateral and longitudinal distance.
- **Streaming Services** are communications that stream video from remote cameras and monitors at a high data rate and low latency. As a result, this data is available on another agricultural vehicle and can be analyzed and processed there. The authors estimate the distance between the communication participants to be less than 100 m.
- **Process Data Exchange** describes the exchange of process data. One example is the exchange of already sprayed field areas in order to prevent multiple spraying of fertilizers and pesticides on the same field area by different machines. According to the authors, long-range technologies must be used here because agricultural fields around the world can be very large.

- **Fleet Management & Logistics** is the potential retrieval of data from the ongoing agricultural process. This information can influence economic or agronomic decisions of agricultural enterprises or service companies and is therefore required in a Farm Management Information System (FMIS). Since not all agricultural machines may be connected to the FMIS, the WIC project group is looking at how to use Machine-To-Machine (M2M) communications to bridge the missing communications infrastructure until the data reaches a machine that can connect to the FMIS.

- **Road Safety** describes a use case which is already a project between the European Telecommunication Standard Institute and the Agricultural Industry Electronics Foundation (AEF). Since agricultural vehicles are repeatedly underestimated in their size and speed by other road users when they suddenly turn off the field onto the road, the other road users need to be warned in this situation. In this way, smart technologies in cars and motorcycles can be used to brake the vehicles in advance and prevent possible accidents.

# Chapter 2

# Fundamentals

- describe methods and techniques that build the basis of your work
- include what's needed to understand your work (e.g., techniques, protocols, models, hardware, software, ...)
- exclude what's not (e.g., anything you yourself did, anything your reader can be expected to know, ...)
- review related work(!)
- recommended length: approximately one third of the thesis.

## 2.1 Wireless Lans according to IEEE 802.11

**kauffels_wireless_2002**

IEEE 802.11 = Ethernet network mit der Grundlage Funk Kommunikation **kauffels_wireless_2002** definiert die folgenden drei grundlegende Architekturen für IEEE 802.11. Der Infrastructure BSS Moder ermöglicht allen Station über einen zentralen AP zu kommunizieren. Dieser Modus erlaubt es sind drei grundlege Da man mit der begrenzten Reichweite einen AP nur einen bestimmten Bereich abdecken kann, wurde das Extended Service Set ESS eingeführt. Basic service set = AP and multiple Stations Extended service Set = multiple AP and multiple Station Adhoc Modus = mehrere Stations ohne AP

Zugriffsverfahren: CSMA-CA

2.4 GHz Spread Spectrum 2 options = Frequency Hopping Sprectrum or Direct Sequence Spread Spectrum Spread Sectrum mehr Bandbreite für besseres SNR

Modulation Coding Schemes QAM

auswirkungen auf die Stabilität

ab 802.11a OFDM auswirkungen Stabilität

Roll-Off-Faktor QAM-Verfahren höherer Roll-Off-Faktor need for Guard interval intersymbol interferenz

Wellenausbreitung Überlagerungseffekte Reflexsion

Reflexsion nicht bei Metall.

Physical Layer

Data Link Layer

Medium Access Control

Zugriffsverfahren:

CSMA /CA Point Coordination Function

**sauter_wireless_2022** DCF oberbegriff für CSMA /CA

IEEE 802.11e DCF erweiterung für Video Streaming

CSMA CA Backoff zeit Network allocation Vector NAV Zeitspanne Datensendungsdauer

MAC Header

Netzeintritt: passives und Aktives Scanning Service Set Identifier Timing Synchronisationsfunktion TSF Timer-Wert

**sauter_wireless_2022** every package management or usage data send ackknowledgement

Hidden Station Szenario Reservieren RTS CTS meist nicht konfiguriert / ausgeschalten, bei großen Paketen sinnvoll

Authentifizierung - Open System -Authentification - Shared key Authentification (nach neu nicht mehr verwendet

### 2.1.1 IEEE 802.11ac - Wi-Fi 5

The 5th generation WLAN is IEEE 802.11ac (802.11ac) and operates in the 5 GHz frequency range **Dhawankar2018indoorAC**.

According to **perahia2011acOverview**, 802.11ac is a further evolution of IEEE 802.11n, where 802.11ac adds to the known bandwidth of IEEE 802.11n of 40 MHz the bandwidths 80 MHz,160 MHz and the interrupted bandwidth of 80 MHz + 80 MHz.

nach **sanser_irgendwas** ist die Aufspaltung in zwei 80 Mhz Kanäle sehr nützlich, wenn das frequenzband reservierte Regionen enthält. Dadurch kann ein 160 Mhz breiter Kanal um eine reservierte region des frequenzbandes gebaut werden.

The modulation technique used is Orthogonal Frequency-Division Multiplexing (OFDM). Additionally, a new Multiple Input Multiple Output (MIMO) Downlink functionality for multiple users, called DL MU-MIMO, with up to 8 partial streams is introduced according to the authors. Together with the new Modulation and Coding Scheme (MCS) from 64 Quadrature Amplitude Modulation (QAM) to 256

QAM, these three enhancements ensure that a higher data rate can be achieved. The maximum data rate is 6.9 GHz according to the authors.

As declared by **abdelrahman2015comparison**, the 5th generation of WLAN has made it possible to expect better performance as in addition to a longer communication range compared to the previous IEEE 802.11 standards This statement could be proven at least for indoor range. **Dhawankar2018indoorAC** were able to demonstrate that 802.11ac with a range of over 60 m enables a longer indoor communication range than previous IEEE 802.11 standards.

new Physical Layer Very High Throughput (VHT) Physical Layer

80 Mhz

Beamforming

### 2.1.2 IEEE 802.11ax - Wi-Fi 6

The 6th generation of WLAN is IEEE 802.11ax (802.11ax). **khorov2019ax** reveals what has changed from 802.11ac to 802.11ax. For this, the authors make the following statements.

802.11ax uses the same bandwidths in the 5 GHz range and can also operate in the 2.4 GHz frequency range with a maximum bandwidth of 40 MHz. Similar to DL MU transmission, 802.11ax enables UL MU transmissions. These can also use Orthogonal Frequency-Division Multiple Access (OFDMA) in addition to the already known MIMO of 802.11ac. OFDMA groups the orthogonal frequency subcarriers into Resource Unit (RU)s, which can be selected by the transmitter for optimal transmission to the receiver. This increases the Signal-to-Interference-plus-Noise Ratio (SINR).

An extension in the PHY layer are the new MCS's of up to 1024-QAM. However, these should only be used with very good channel characteristics. For better outdoor communication 802.11ax increases the OFDM symbol duration from 3.2 µs for 802.11ac to up to 12.8 µs and the OFDM Guard Interval from a maximum of 0.8 µs for 802.11ac to up to 3.2 µs.

MIMO und OFDMA MU Streams

BSS Coloring

Backward Kompatibilität über CTS Reservierungen.

Tabelle Vergleich

## 2.2 Modell für drahtlose Übertragungssysteme

Abb 2.3.1 Modell einen Übertragungssystems

Beschränkungen und Regelungen Frequenzwahl, Sendeleistung

Analoger Kanal Störungen: thermisches Rauschen, Nebensprechen, Impulsstörungen

## 2.3 Analyzing Corn Harvest Processes

Definition Feldhäcksler Nach Feldhäcksler 1962 ist ein Feldhäcksler eine Lademaschine für fast alle Futterarten:

Heu und

Mais als Grünmais für die tägliche Fütterung und als Silomais Gras und Klee für die tägliche Fütterung und für die Silage Heu und Stroh

Introduction Corn Harvest, Forage Harvesters

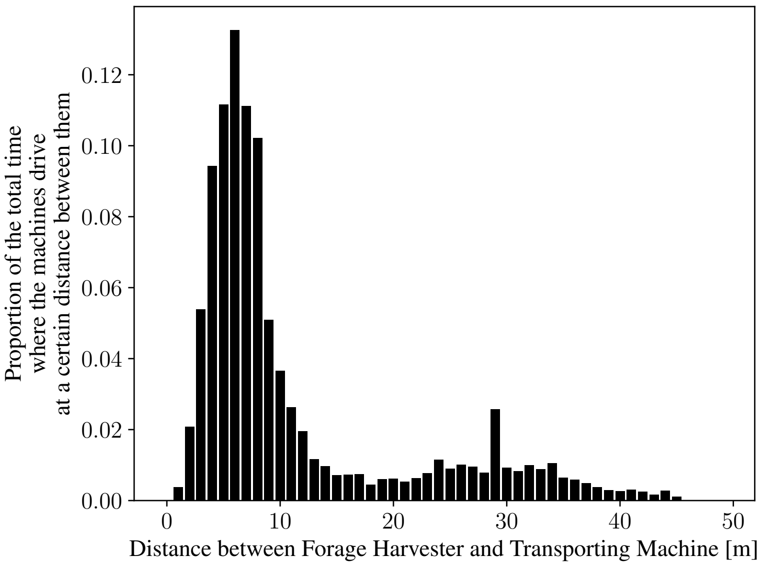


**Figure 2.1** – Distance Harvest Szenario

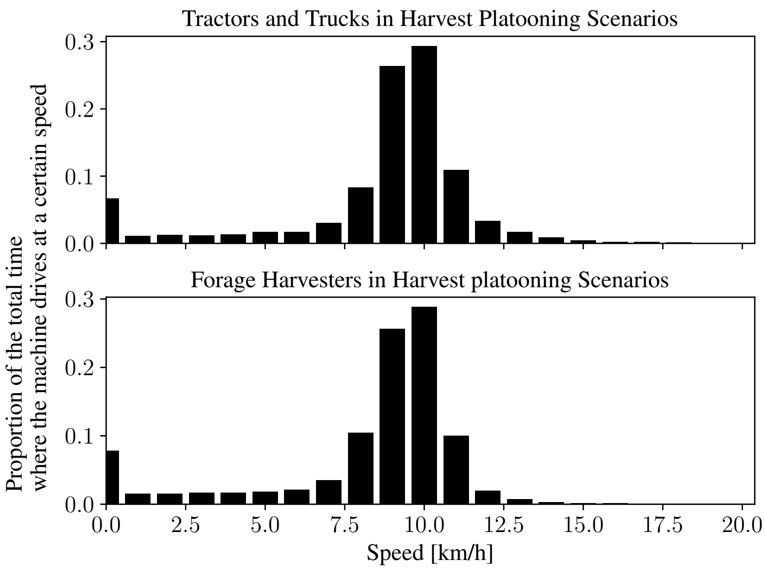


**Figure 2.2** – Speed Harvest Szenario

# Chapter 3

# Field Measurements

## Chapter 4

# Developed architecture / System design / Implementation / ...

- describe everything you yourself did (as opposed to the fundamentals chapter, which explains what you built on)
- start with a theoretical approach
- describe the developed system/algorithm/method from a high-level point of view
- go ahead in presenting your developments in more detail
- recommended length: approximately one third of the thesis.

# Chapter 5

# Simulation

# Chapter 6

# Evaluation

- measurement setup / results / evaluation / discussion
- whatever you have done, you must comment it, compare it to other systems, evaluate it
- usually, adequate graphs help to show the benefits of your approach
- each result/graph must not only be described, but also discussed (What's the reason for this peak? Why have you observed this effect? What does this tell about your architecture/system/implementation?)
- recommended length: approximately one third of the thesis.

## Chapter 7

# Conclusion

- summarize again what your paper did, but now emphasize more the results, and comparisons
- write conclusions that can be drawn from the results found and the discussion presented in the paper
- future work (be very brief, explain what, but not much how, do not speculate about results or impact)
- recommended length: one page.

# List of Abbreviations

| | |
|---|---|
| **802.11ac** | IEEE 802.11ac |
| **802.11ax** | IEEE 802.11ax |
| **AEF** | Agricultural Industry Electronics Foundation |
| **FMIS** | Farm Management Information System |
| **M2M** | Machine-To-Machine |
| **MCS** | Modulation and Coding Scheme |
| **MIMO** | Multiple Input Multiple Output |
| **OFDM** | Orthogonal Frequency-Division Multiplexing |
| **OFDMA** | Orthogonal Frequency-Division Multiple Access |
| **QAM** | Quadrature Amplitude Modulation |
| **RU** | Resource Unit |
| **SINR** | Signal-to-Interference-plus-Noise Ratio |
| **WIC** | Wireless-Infield Communication |

# List of Figures

# List of Tables

# Todo list