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

Diploma Thesis in Information Systems Engineering

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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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Networked Systems Modeling

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Abgabe der Arbeit:	**25. November 2022**

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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, 25 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- problem: gap in knowledge, too expensive, too slow, a deficiency, superseded technology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

According to Kauffels [1] the first version of the Standard IEEE 802.11 was published in 1999 to enable a wireless alternative to token-ring - or Ethernet networks.

The author defines the following three basic architectures for IEEE 802.11.

The Infrastructure Basic Service Set (BSS) mode allows all stations to communicate via a central Access Point (AP). This mode allows three basic Since the limited range of an AP can only cover a certain area, the Extended Service Set ESS was introduced.

If two or more stations communicate directly without an AP, they form an ad hoc network. According to the author, this can be set up quickly and easily and is also called Independent Basic Service Set (IBSS). Wenn kein 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 [2] 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 [2] 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 **dhawankar_throughput_2018**.

According to **perahia_gigabit_2011**, 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 Sauter [2] 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 **abdelrahman_comparison_2015**, 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. **dhawankar_throughput_2018** 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). **khorov_tutorial_2019** 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

Parameter	IEEE 802.11ac	IEEE 802.11ax
Frequency bands	5 GHz	2.4 GHz, 5 GHz, 6 GHz
Symbol Length	3.2 µs	12.8 µs
OFDM Subcarrier Spacing	312.5 kHz	78.125 kHz
OFDM Subcarriers in 80 MHz	256	1024
max. MCS	256 -QAM	1024 -QAM
max. Guard Interval	0.8 µs	3.2 µs

Table 2.1 – Comparison of IEEE 802.11ac and IEEE 802.11ax

Analoger Kanal Störungen: thermisches Rauschen, Nebensprechen, Impulsstörungen

2.3 Analyzing Corn Harvest Processes

seifert_feldhacksler_1962 defines a forage harvester as an agricultural loading machine for nearly all types of animal feed. By mounting different cutting and loading devices, a forage harvester can load the following types of animal feed according to the authors:

- Hey
- Straw
- Corn
- Grass
- Clover

Faustzahlen_Landwirtschaft

In the harvesting and loading process of these large quantities of forage, the Forage Harvester (FH) loads the goods directly onto a Transport Machine (TM), which drives next to or behind the vehicle.

This harvesting process is an example for the use of an agricultural platooning system as described by **zhang_method_2009**. This creates a leader and follower system in which an unmanned tractor follows a leading manned tractor.

In the harvesting process, the FH sets the path and speed and the TM follows with a longitudinal and lateral offset as it is displayed in Figure 2.1

At the same time, the harvesting process is also an example of the video streaming use case. During the harvesting process of the spout of the FH must be controlled to set the loading position of the forage into the trailer of the TM.

According to **HMThesis**, different spout guidance and control systems have been developed for this reason, which use a camera attached to the spout to determine via machine vision the fill volume at each point of the trailer and set the spout to fill the empty parts of the trailer accordingly. The author describes the Autofill - system from Claas and the Intellifill - system from CNH Industrial as examples of spout guidance systems.

Streaming the video of the camera at the spout from the FH to the TM would be a useful application of the video streaming use case in the harvesting process. If the driver of the TM can watch a livestream of the trailer's fill level, he is always informed and knows when the trailer is full so he can drive the feed back to the farm.

To gain a better insight into the some requirements for the application ot the WIC use cases Platooning and Streaming Services in a corn harvest scenario, I collected GPS tracks of a FH and two to three TMs harvesting corn on two days on a field in Germany in September. For this, I placed tablets in the driver's cabs of the agricultural vehicles, which recorded the NMEA data stream of the GPS every second.

The workflow of the corn harvest was as follows. I handed out the tablets to the drivers, which left the farm with the tablets in the driver's cabs to drive to the

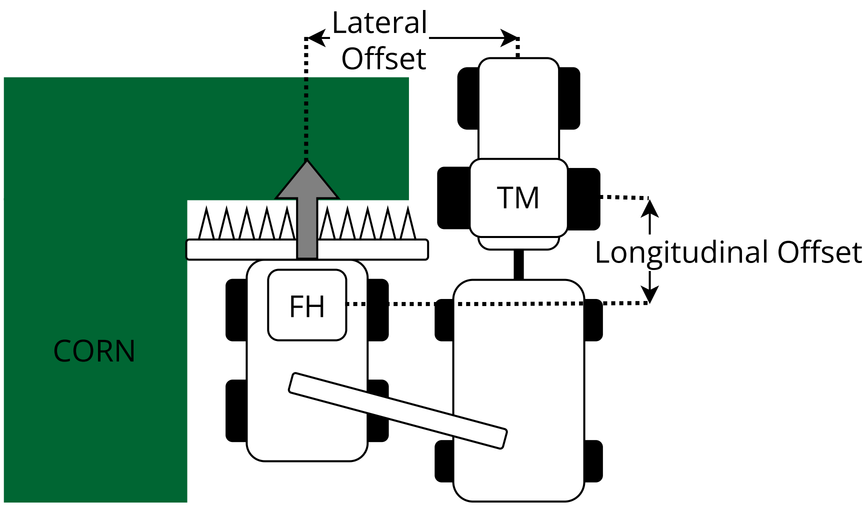

Figure 2.1 – Lateral and longitudinal Offset between the two agricultural machines FH and TM in a corn harvest scenario

field in the morning. The tablets recorded position and speed of the tractors all day long. During breaks, the tablets continued to capture NMEA data stream of their GPS even if the positions and speed did not change.

First, I anonymized the timestamps of the recorded NMEA files by deleting the first data points of the log files for the timestamps where the recorded accuracy of all log files was not yet less than 2 m. From the time when the accuracy of all log files was less than 2 m, I overwrote the timestamp and the date for all further data points with a continuous index.

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

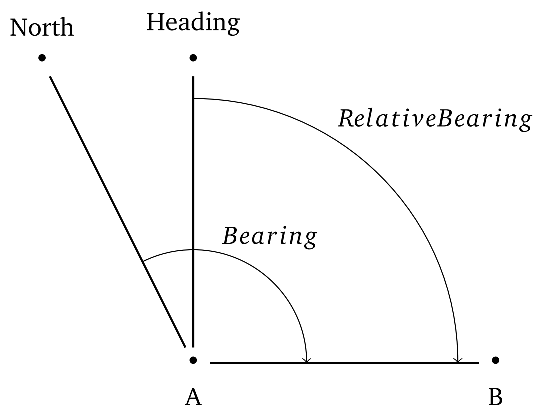

Figure 2.2 – Relative and True bearing between A and B

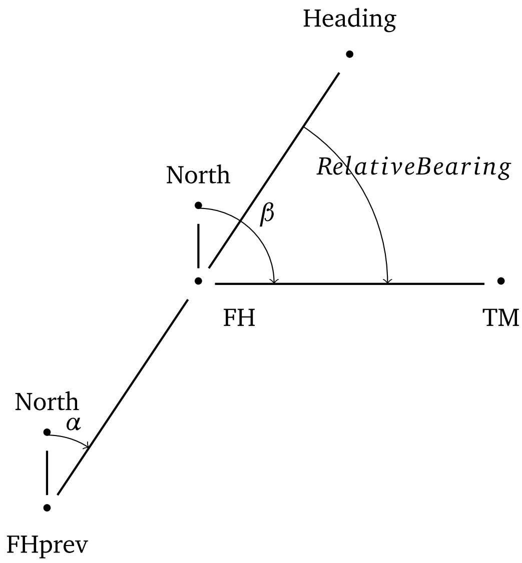

Figure 2.3 – Relative bearing between FH and TM which is calculated using the previous location of FH by the difference of β minus α

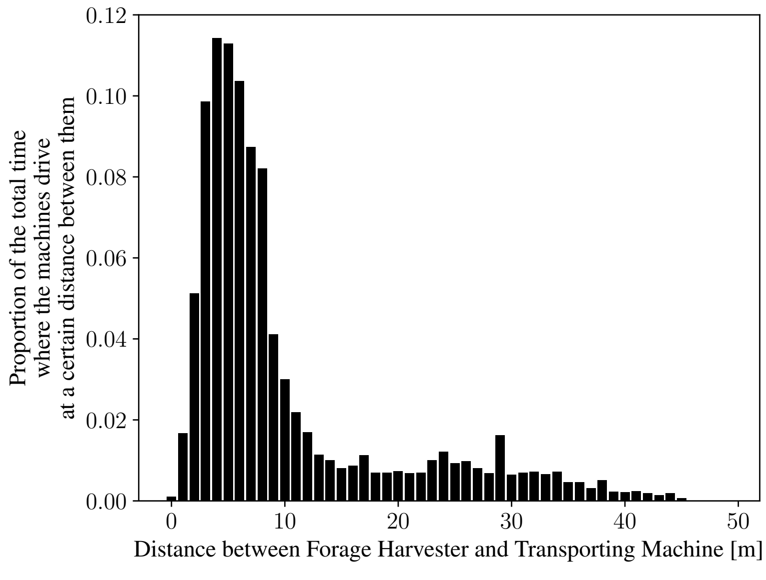

Figure 2.4 – Distribution of time proportions where a given distance was between FH and TM in a harvest platoon scenario.

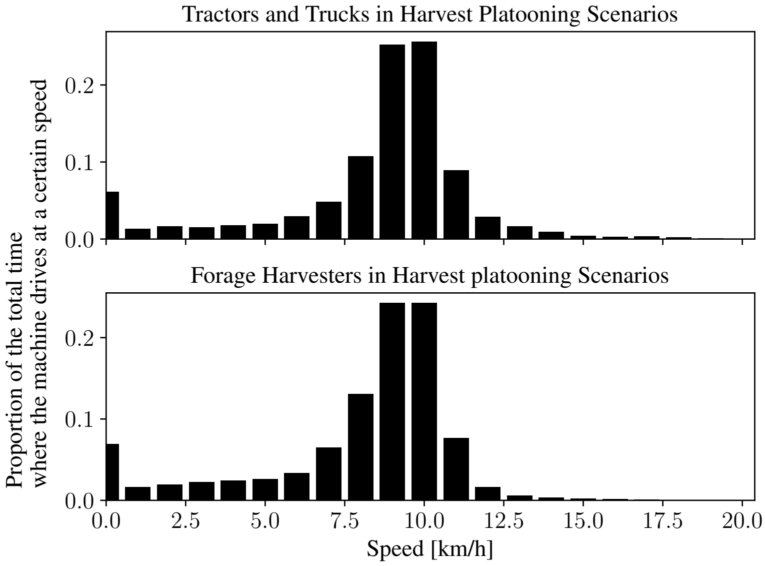

Figure 2.5 – Distribution of time proportions where FH and TM drove with a certain speed in a harvest platoon scenario

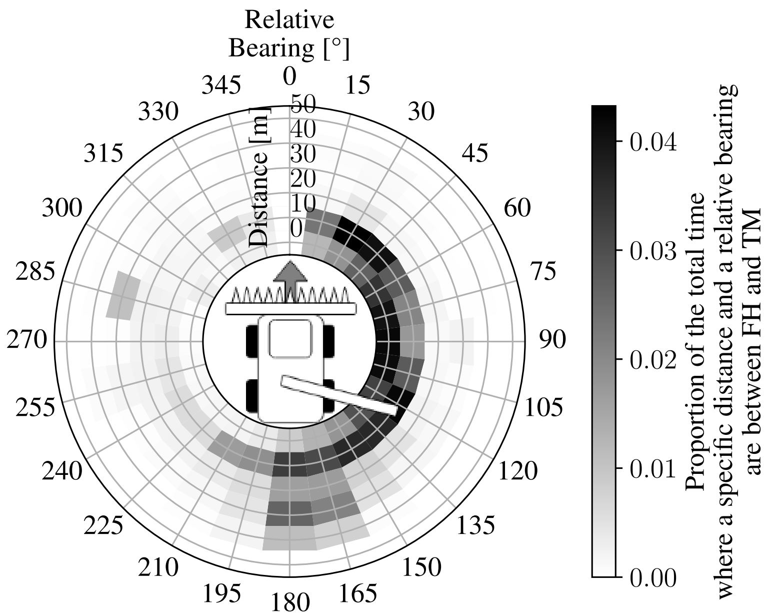

Figure 2.6 – Distribution of time proportion at specific distances and relative bearings between FH and TM

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
AP	Access Point
BSS	Basic Service Set
FH	Forage Harvester
FMIS	Farm Management Information System
IBSS	Independent Basic Service Set
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
TM	Transport Machine
WIC	Wireless-Infield Communication

List of Figures

List of Tables

Bibliography

[1] F.-J. Kauffels, Wireless LANs: drahtlose Netze planen und verwirklichen, der Standard IEEE 802.11 im Detail, WLAN-Design und Sicherheitsrichtlinien (Netzwerke), ger, 1. Aufl. Bonn: mitp-Verl, 2002.

[2] M. Sauter, "Wireless LAN IEEE 802.11," de, in *Grundkurs Mobile Kommunikationssysteme: 5G New Radio und Kernnetz, LTE-Advanced Pro, GSM, Wireless LAN und Bluetooth*, M. Sauter, Ed., Wiesbaden: Springer Fachmedien, 2022, pp. 265–338. DOI: `10.1007/978-3-658-36963-7_4`.

Todo list