Creating a Robust and Resilient Uplink

Holly Roper

CONCEPT OF OPERATIONS

REVISION – 1
2 September 2022

Concept of Operations
for
Creating a Robust and Resilient Uplink

Approved by:

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Project Leader Date

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Prof. Kalafatis Date

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T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	9/2/2022	Holly Roper		First submission of CONOPs

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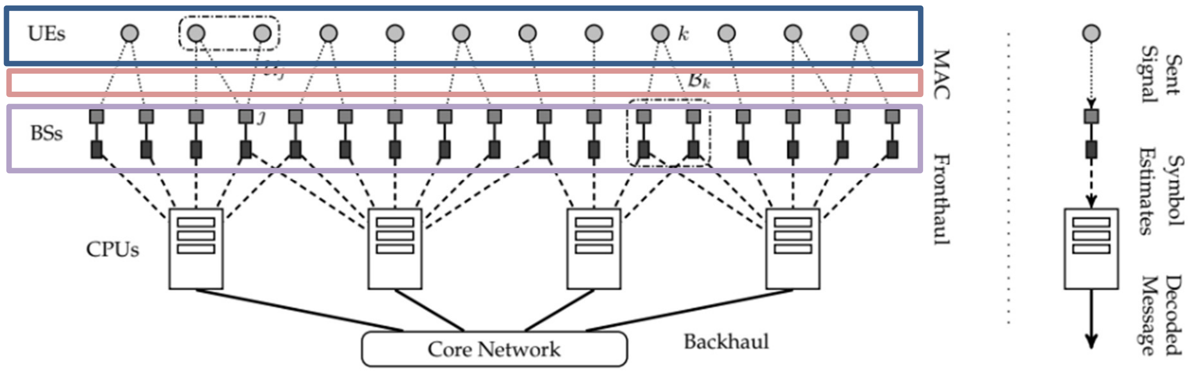

Figure 1. Sub-systems

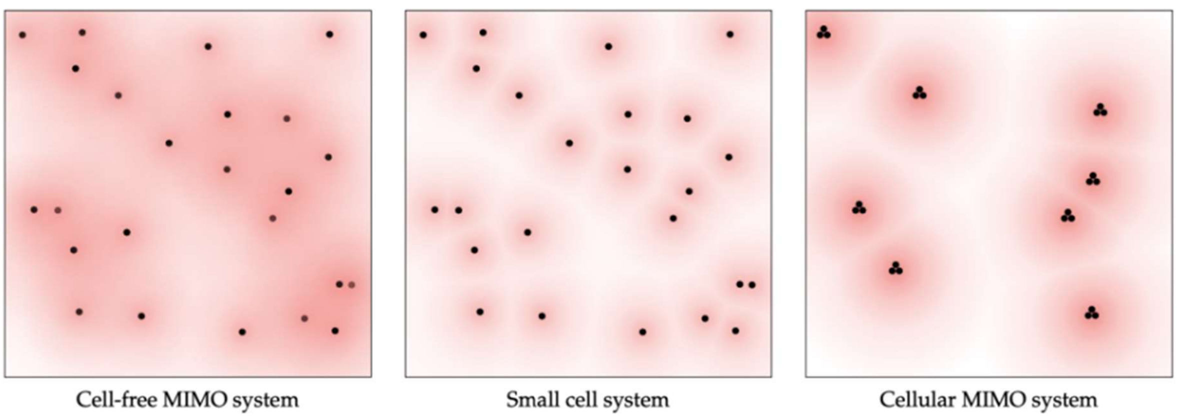

Figure 2. Wireless Systems

1. Executive Summary

The internet is all around us. From our cell phones to our doorbells, almost everything is connected to the internet. With the amount of devices accessing the internet surpassing the number of people on the earth how do we coordinate all those signals and make sure everyone still receives service? This research focuses on expanding cell coverage and resiliency. This will be done by developing an algorithm that allows a device to simultaneously communicate with multiple base stations. Specifically, working within the unsourced random-access (URA) framework that handles the transmission of unmanned devices communicating over wireless networks. These devices send uncoordinated signals and, unlike human operated devices, the signals are typically short and sporadic which is why they need to be handled differently. This project will examine the capabilities of algorithms already in place for a single base station model and compare the results with the developed algorithm for a multiple base station model. This is an important area of research because 5G will need to be updated within the next 10 years and a URA approach is the best way forward with the drastic increase in unattended devices. This research will detail and document a new algorithm and its effectiveness in terms of low complexity and low error probability.

2. Introduction

Can multiple base stations receive and decode a signal from a single device simultaneously within the Unsourced Random Access (URA) framework? URA handles the uplink transmissions of machine-type devices which are becoming increasingly prevalent in our Internet of Things (IoT) society. I will test already established URA algorithms that focus on communicating with a single base station (Coded Compressed Sensing (CCS) and Polar Coding with Random Spreading) and use that information to develop an algorithm that enables a device to communicate with multiple base stations. The goal is for the algorithm to be of low complexity and low error probability.

2.1. Background

Current wireless systems have already demonstrated the capability to support human-generated traffic at scale. Part of the challenge for future wireless comes from the fact that growth will come from unattended devices, which access the internet in fundamentally different ways than humans. Because of this we need to simplify and robustify uplink transmissions with uncoordinated access. This algorithm will replace the previous methods of coordinating that focus on downlink and receiving signals from humans.

2.2. Overview

I will complete a software program that simulates the environment of a wireless communication system and implements algorithms for testing them. I will focus on a model in which devices can communicate with two base stations at a time, therefore increasing the signal they receive and creating a more robust environment.

2.3. Referenced Documents and Standards

A. Goldsmith, Wireless Communications. Cambridge university press, 2005.

J. R. Ebert, V. K. Amalladinne, S. Rini, J.-F. Chamberland, and K. R. Narayanan, “Coded demixing for unsourced random access,” arXiv preprint arXiv:2203.00239, 2022.

O. T. Demir, E. Bjornson, L. Sanguinetti, et al., Foundations of user-centric cell-free massive mimo, Foundations and Trends in Signal Processing, vol. 14, no. 3-4, pp. 162-472, 2021.

Y. Polyanskiy, A perspective on massive random-access, in 2017 IEEE International Symposium on Information Theory (ISIT), pp. 2523-2527, IEEE, 2

3. Operating Concept

3.1. Scope

The goal of this project is to create an algorithm that will allow manned and unmanned devices to communicate with multiple base stations simultaneously while having a low probability of error. The algorithm will be applied to a device communicating with a single base station and a device communicating with two base stations. A wireless communication environment will be created in Python and will be assessed under Monte Carlo simulations.

3.2. Operational Description and Constraints

This project will be used in the digital communication world when developing new infrastructures. Internet of Things (IoT) devices and other unmanned interfaces will interact will multiple base stations to transmit signals. These devices as well as cellular phones are limited by the amount of power they can transmit, so that will play a role when developing the algorithm. There are also computational constraints that limit the complexity of the algorithm; we have to ensure that the devices and base stations have the capability of executing the algorithms needed to communicate.

3.3. System Description

The system will have three components: the transmitter, the channel, and the receiver as shown in the figure below. Each component will be programmed in Python to create a complete environment in which to simulate my algorithm.

The User Equipment (UE) is classified as the transmitter because this research focuses on uplink connectivity. This part of the program will simulate random signals coming from UE.

The Channel will be where noise and shadowing are added to the signal to simulate what a signal undergoes in the real world. The channel will direct the signals to one or two base stations depending on what we are trying to test.

The Base Stations (BS) are the receivers. This is where most of the algorithm will be implemented. The BSs will have to communicate with one another to see if they have both received the same signal from the device and ensure it is decoded correctly.

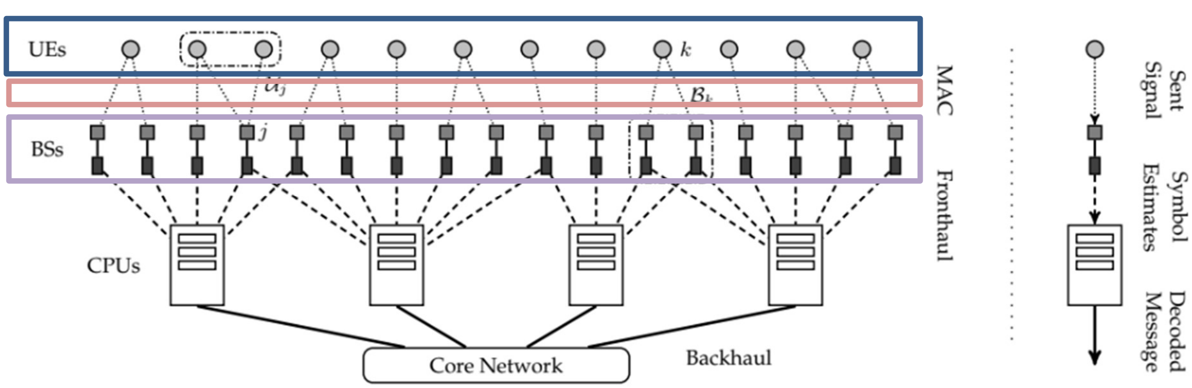

Figure 1. Sub-systems The blue box represents the transmitter, the pink box the channel, and the purple box the receiver.

3.4. Modes of Operations

There are two modes of operation: communicating with one base station or communicating with two base stations. The single base station approach focuses on optimizing coverage while utilizing only one base station to communicate with the device. The dual base station approach allows a device to communicate with two base stations thereby combining the signal strength of the two.

3.5. Users

This algorithm will be used by wireless communication researchers and people who are designing infrastructure for new communication systems. Designers and researchers will both need to have a detailed understanding of how the algorithm works in order to implement or expand upon it.

3.6. Support

A detailed document explaining how the algorithm works, what assumptions and models were used, as well as documentation of tests that were run will be made public with the release of my thesis. My thesis will also contain information on how I intend the algorithm to be implemented and any precautions that need to be taken.

4. Scenario(s)

Part of the algorithm will be focused on what mode the device needs to operate in: communicating with one or two base stations. The different scenarios that it will take into account are listed below.

4.1. Communicating with a Single Base Station

When a device is communicating in a suburb or city there are typically plenty of base stations nearby to provide a sufficient amount of coverage. When this is the case there is no need to complicate computations by having the device communicate with two base stations at once.

4.2. Communicating with Two Base Stations

In rural areas there tends to be less cell coverage due to a lack of infrastructure. Residents and travelers face little to no cell reception. In areas that are overcrowded there is not enough capacity in the network to provide everyone with service. In these cases, if a device is able to communicate with two base stations at once there is an increase in signal strength and therefore coverage.

5. Analysis

5.1. Summary of Proposed Improvements

The new algorithm will provide better coverage and resilience. The approach of Cell-free URA MIMO (Multiple Input, Multiple Output) creates a system with the most coverage as opposed to the traditional Cellular MIMO system as shown in the figure below. The algorithm will be evaluated and compared with previous approaches of communicating with multiple base stations.

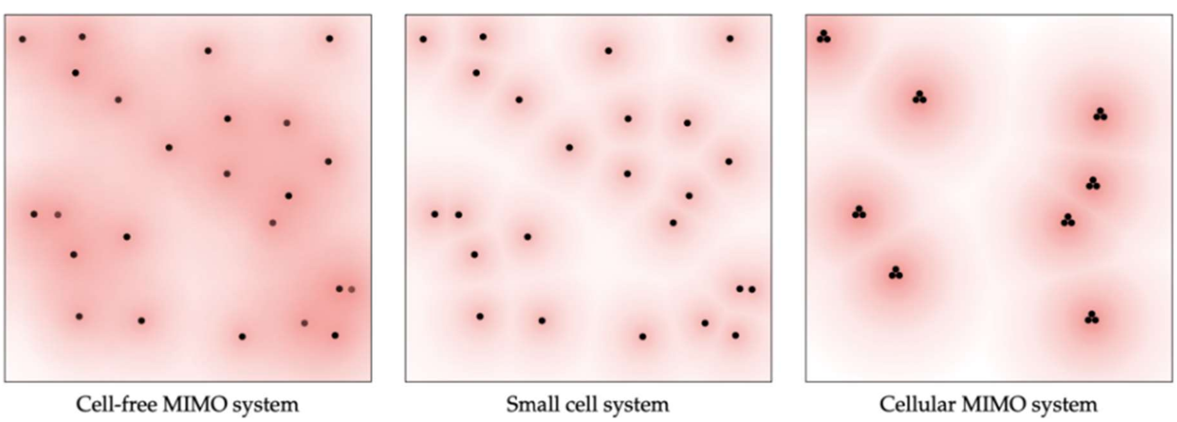

Figure 2. Wireless Systems

5.2. Disadvantages and Limitations

This project will be limited by the computational capacity of the devices and base stations. This is why it is important to create an algorithm of low complexity. There is also potentially a lot of overhead cost required to implement the designed system.

5.3. Alternatives

In the world of wireless communications there is always a trade-off in terms of complexity and cost. A more complex system might be able to increase performance, but if it becomes too computationally complex the base station/device might not be able to handle it. More complexity also leads to higher overhead costs in implementation.

5.4. Impact

My project will increase cell coverage. Where there is an increase in cell coverage there is also typically an increase in services to areas where there originally was not. Especially in rural communities that typically have poor cell coverage and minimal access to the services offered in a major city, an increase in coverage will likely lead to an increase in population and services.

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – Draft
25 September 2022

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
Creating a Robust and Resilient Uplink

PREPARED BY:

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Author Date

APPROVED BY:

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Project Leader Date

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John Lusher, P.E. Date

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T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	9/25/2022	Holly Roper		Draft Release

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6. Introduction

6.1. Purpose and Scope

The current wireless communication infrastructure is a network of cells. This infrastructure contains weak spots on the borders of all the cells which is why there has been a lot of interest in a cell free system. This project focuses on developing an algorithm that will operate in a cell free model, and thus, requires multiple base stations to pick up the same signal from a single device and identify the user.

This document outlines the technical requirements for my algorithm and details the three subsystems: the transmitter, the channel, and the receiver. The verification requirements are contained in a separate verification document.

6.2. Responsibility and Change Authority

I, Holly Roper, will be responsible for changes that need to be made to the project. Dr. Narayanan's approval must be given before any proposed changes may be implemented.

7. Applicable and Reference Documents

7.1. Applicable Documents

N/A

7.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
1	2017	A perspective on Massive Random Access
Vol. 14	2021	Foundations of User-Centric Cell-Free Massive MIMO
1	2022	Coded Demixing for Unsourced Random Access

7.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions. All specifications, standards, exhibits, drawings or other documents that are invoked as "applicable" in this specification are incorporated as cited. All documents that are referred to within an applicable report are considered to be for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

8. Requirements

This section defines the minimum requirements that the algorithm must meet.

8.1. System Definition

This project consists of a software program that simulates the environment of a wireless communication system and implements algorithms to enhance its performance. The implemented algorithm performance will be tested against existing methods. The three main subsystems of this project include modeling the transmitter, the channel, and the receiver.

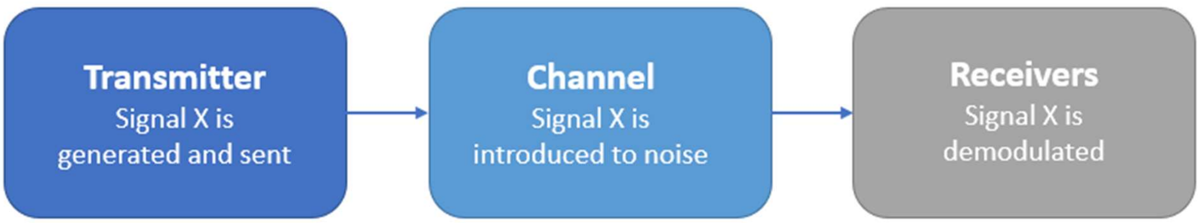

Figure 1. Block Diagram of System

The transmitter constructs a signal, X, that holds the message it is wishing to send. The signal is then sent through the channel where noise and shadowing change the signal. The receiver gets the noisy signal and demodulates it to determine the original message. There is freedom in the transmitter and receiver on the part of the operator to choose what type of signal is sent and what type of corruption it undergoes as it travels. My algorithm is focused on demodulation at the receiving end. Two receivers work together to demodulate the signal, their correspondence decreases the probability of error.

8.2 Characteristics

8.2.1 Functional / Performance Requirements

8.2.1.1 Probability of Misdetection / False Alarm

Misdetection occurs when a user is active in the system, but the base station claims that they are not. A False Alarm occurs when the base station perceives a user as being active, but they are not. The algorithm must have a low probability of misdetection and false alarm.

Rationale: If the algorithm does not enhance the current functionalities of a network it will not be used.

8.2.2 Software Requirements

8.2.2.1 One base station

Must process the signal it receives and identify the user who sent it.

8.2.2.2 Two base stations

The CPU will have to combine the information received from both the base stations and process it to determine who the active users are.

9. Support Requirements

The software will be delivered to the customer, as is, with no warranty.

10. Appendix A: Acronyms and Abbreviations

URA	Unsourced Random Access
MIMO	Multiple Input Multiple Output
IoT	Internet of Things
CCS	Coded Compressed Sensing
UE	User Equipment
BS	Base Station
CPU	Central Processing Unit

11. Appendix B: Definition of Terms

Unsourced Random Access: Multiple access paradigm for machine type uplink communication

Internet of Things: The interconnection of machines via the internet

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Holly Roper

INTERFACE CONTROL DOCUMENT

REVISION – Draft
22 September 2022

INTERFACE CONTROL DOCUMENT
FOR
Creating a Robust and Resilient Uplink

PREPARED BY:

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APPROVED BY:

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Project Leader Date

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John Lusher II, P.E. Date

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T/A Date

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12. Overview

This document describes the interface of the three subsystems of the digital communication model. The three subsystems are the transmitter, channel, and receiver. This document will detail how each of these subsystems interact with one another, and provide information for a future programmer to understand how they operate.

13. References and Definitions

13.1. References

B. Goldsmith, Wireless Communications. Cambridge university press, 2005.

J. R. Ebert, V. K. Amalladinne, S. Rini, J.-F. Chamberland, and K. R. Narayanan, “Coded demixing for unsourced random access,” arXiv preprint arXiv:2203.00239, 2022.

O. T. Demir, E. Bjornson, L. Sanguinetti, et al., Foundations of user-centric cell-free massive mimo, Foundations and Trends in Signal Processing, vol. 14, no. 3-4, pp. 162-472, 2021.

Y. Polyanskiy, A perspective on massive random-access, in 2017 IEEE International Symposium on Information Theory (ISIT), pp. 2523-2527, IEEE, 2

13.2. Definitions

AWGN	Additive White Gaussian Noise

14. Software Interface

14.1 Transmitter

The transmitter sends a signal, X, that will travel through the channel and be picked up by the receiver. We take X to be a k-sparse vector of length N. X is generated by utilizing the permutation function in the NumPy library to generate what positions in X will be non-zero. There are different methods one can use to create the non-zero values of X, the most simplistic is to make every non-zero value equal to one. For more complex signals, the random functions in NumPy can be used to create random variables with a specified mean and standard deviation.

14.2 Channel

The channel is what the signal will travel through to get to the receiver and this is where noise and shadowing come into effect. There are different models that can be used to simulate the channel, the most basic of which consists of only inducing Additive White Gaussian Noise (AWGN). In this program the noise is always denoted as 'z'. The effects due to shadowing/fading are labeled as 'h'. The program can be expanded upon by creating different channel models and seeing how performance is affected.

14.3 Receiver

At the receiver is where we try to reconstruct the original signal based on the signal we received. This process is called demodulation. This is where the algorithm I developed comes into play. My algorithm focuses on reducing the probability of error by having two base stations receive and demodulate the same signal. Currently, I am programming and testing existing algorithms to generate a performance baseline and to gain some insight on how my algorithm should operate.

15. Execution and Verification Plan

15.1 Execution Plan

9/11	9/28	10/5	10/30	11/15	11/30
Gain understanding of wireless channel model.	Simulate simple communication system and evaluate its BER.	Simulate existing URA algorithms for a single bases station model.	Explore deep learning and algorithm unrolling.	Continue algorithm unrolling.	Measure new algorithms BER and False Alarm/ Misdetection rate.
	Determine metrics for performance.	Compute the performance efficiencies.	Implement AMP in deep learning.	Run Monte Carlo simulations.	Expand to two base stations.

15.2 Verification Plan

The system will be tested with different signals and sensing matrices and its performance evaluated. If its performance is better than that of existing algorithms, it will be considered a success.