Implementation and Analysis of Heterogeneous and LTE-R Network Test-bed in Practical Fading Scenarios

by

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Abstract

There has been a significant increase in the study of cognitive radios for efficiently utilizing the electromagnetic spectrum. It has been observed that the spectrum occupancy is not uniform across all frequency bands, resulting in numerous spectral white spaces. In order to more efficienty utilize the spectrum, dynamic spectrum access (DSA) has been proposed. To opportunistically access the idle channel, spectrum sensing is considered to be a significant technology enabling DSA. Although several spectrum sensing techniques have been proposed in the open literature, energy detection is widely used due to its low implementation complexity. The development of a reliable wireless network for high speed trains is not a simple task and it is still an emerging technology. Global System for Mobile Communication (GSM-R), was a wireless communications standard designed for high speed trains, but it turned out not to be reliable enough and possess several limitations. Subsequently, LTE proposed a promising solution for achieving broadband data rates in high speed trains that can overcome various GSM-R limitations.

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Chapter 1

Introduction

1.1 Motivation

There has been an exponential growth in the internet landscape. The devices like smartphones, computers, laptops, tablets will continue to increase along with multitude of other devices that are connected to internet. This has facilitated the research in dynamic spectrum access (DSA) [1, 2] for efficient utilization of spectrum resources to sustain billions of Internet of Things (IoT) devices. There has been a significant increase in the study of cognitive radios for efficiently utilizing the electromagnetic spectrum. It has been observed that the spectrum occupancy is not uniform across all frequency bands, resulting in numerous spectral white spaces [3]. To opportunistically access the idle channel, spectrum sensing is considered to be a significant technology enabling DSA. Although several spectrum sensing techniques have been proposed in the open literature, energy detection is widely used due to its low implementation complexity [4]. We discuss some of the spectrum sensing techniques along with energy detection below.

- In energy detection (ED) scheme the energy of the signal is detected in the frequency location and based on the threshold value we decide whether the signal is present or absent.

- Cyclostationary Feature Detection is a complex scheme to implement compared to ED and it is mostly used when we need to also classify the signal present based on their modulation scheme.

- When secondary user has a priori knowledge of primary user signal, matched filter (MF) detection is applied. Detection by using matched filter needs less detection time compared to ED but primary user information is required.

These spectrum sensing techniques can be used in a non-cooperative manner but it is very challenging to get an accurate estimate using a single-sensor system under a practical fading environment. Various non-idealities such as shadowing, multipath and fluctuating noise variance can make it difficult to detect the primary user [5, 6]. Cooperative spectrum sensing can mitigate the effects of multipath and shadowing by utilizing the spatial and temporal diversity of a multiple radio network [7, 8]. In cooperative spectrum sensing, each sensor node collects the spectral data and transmits it to a fusion center (FC) for decision making. Figure 1.1 shows how a heterogeneous sensor network exploits the spatial diversity.

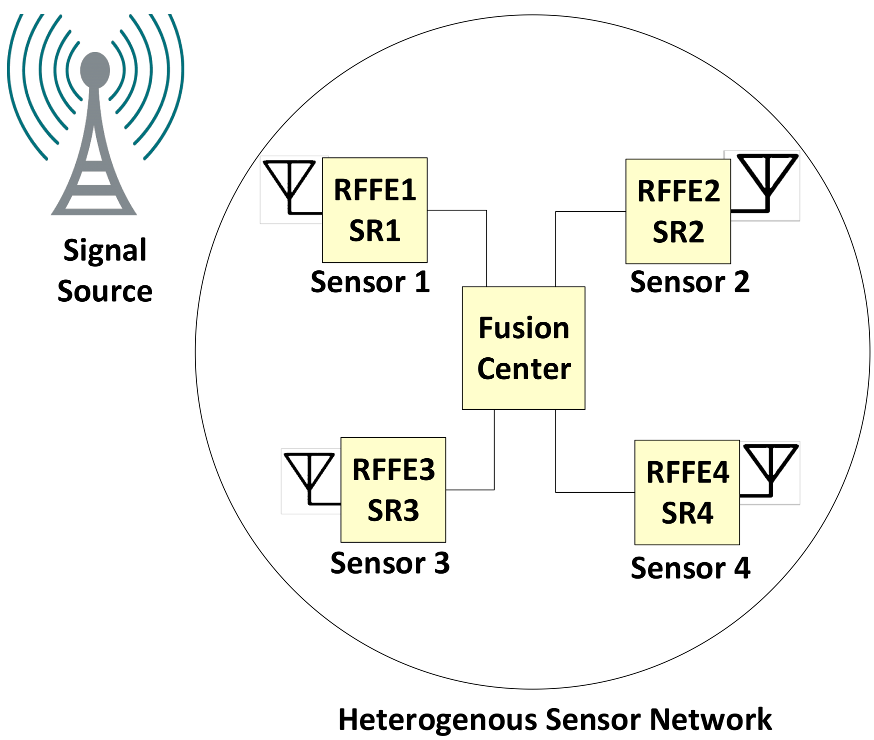

Figure 1.1: Heterogeneous sensor network employing cooperative spectrum sensing. $RFFE_i$ and SR_i represents different front end and sampling rates for the SDR units.

We have also analyze the performance of Long Term Evolution for Railways (LTE-R) in a tunnel environment. In recent years, the use of trains have witnessed tremendous growth due to their increasing speeds, which has led to the demand for reliable wireless communication systems with these transportation systems. The development of a reliable wireless network for high speed trains is not a simple task and it is still an emerging technology. Global System for Mobile Communication (GSM-R) [9], was a wireless communications standard designed for high speed trains, but it turned out not to be reliable enough and possess several limitations. Subsequently, LTE [10] proposed a promising solution for achieving broadband data rates in high speed trains that can overcome various GSM-R limitations [11, 12].

LTE-R is a high speed communication standard based on the existing LTE system architecture [12]. There has been several studies regarding the assessment of LTE-R as a viable choice for next generation high speed communications for railway applications [13, 14]. Most LTE systems operate at 1.8 GHz – 2.6 GHz bands, which possesses a high propagation loss and severe fading effects. Highly mobile trains inside tunnel environment makes the design of reliable communication links very challenging. To achieve reliable radio coverage inside tunnels, leaky feeder cables have been proposed [15]. With LCX, more uniform coverage can be achieved and installation is also comparatively simple. Each slot in the cable is equivalent to an antenna, which can transmit and receive signals. Figure 3.1 shows the LOS propagation environment inside a tunnel for a high speed train with velocity v.

1.2 State of the Art

Both soft data fusion and hard data fusion have been extensively studied [16, 17, 18], with several algorithms being implemented for each scheme. In a hard decision approach, each local decision statistic from sensor node is transmitted to an FC via overhead channels. The FC merges the sensing data and makes a global decision based on various algorithms such as majority rule, OR rule and AND rule [19]. For a soft decision scheme, each SU sends its local sensing data to the FC, which makes decision based on a global test statistic G. Soft decision combining improves the cooperative gain but it also possesses several limitations. With an infinite bandwidth, the real floating values can be transmitted to the FC, which can lead to a reliable decision mechanism. However, due to bandwidth constraint

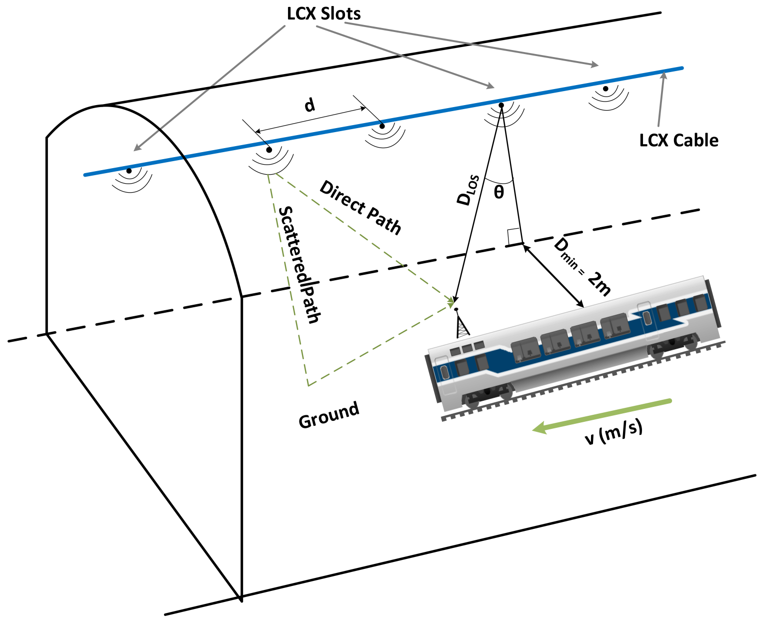

Figure 1.2: High speed train inside a tunnel for LTE-R. D_{LOS} is the distance between transmitter and receiver, d is the distance between the LCX cable transmission slots.

we have to quantize the data and this leads to error in the energy values. In hard decision combining, we can just transmit the decisions of the sensor nodes to the FC which can be binary values with 1 indicating that signal source is present and 0 indicating that a signal source is absent.

In open literature, most channel modeling have considered open areas with high speed trains [13, 14], while relatively little research has been conducted in tunnel environments. Due to various challenges presented by tunnel environments, it is important to derive a channel model for LTE-R involving high speed trains. In this paper, we analyze the effects of high Doppler shift and multipath due to tunnel environments. Experimental studies conducted inside tunnel environments have shown that the field amplitude distribution fits smoothly over a Rician distribution [20]. Several research efforts have been conducted on large-scale and small-scale fading of wideband communication systems inside tunnel environments. To the best of the authors knowledge, none of these studies have been conducted for LTE-R, which employs Orthogonal Frequency Division Multiplexing (OFDM) signals for data transmission inside tunnels. The large Doppler shifts caused by high speed trains will potentially lead to ambiguity in extracting the carrier frequency, which can drastically increase the BER [21]. Therefore, it is important to study the effects of high Doppler shift and multipath fading for LTE-R communications in tunnel environments such that equalizers can be design efficiently.

1.3 Thesis Contributions

This thesis will contribute the following to the cognitive radio communications and cellular wireless field:

- A cooperative spectrum sensing test-bed with normalized energy detection using both soft data fusion and hard data fusion implemented on available software defined radios.
- For soft data fusion, Maximum Normalized Energy (MNE) and Equal Gain Combination (EGC) algorithms are used. Hard data fusion is also implemented using majority rule, AND, and OR approaches. Both USRP N210s [22] and RTL-SDRs [23] are employed for the implementation of the heterogeneous sensor network.
- A performance assessment and simulation of LTE-R communications in a tunnel environment experiencing severe fading.
- Dynamic K-factor for a tunnel environment is derived using the classical two-ray propagation model [24] and is used to build Rician fading model for the tunnel.

1.4 Thesis Organization

This thesis will be organized into the following chapters: Chapter 2 provides background knowledge on heterogeneous cooperative spectrum sensing and focuses on heterogeneous networks, cooperative spectrum sensing and software-defined radios. Chapter 3 discusses LTE-R in detail and provides the necessary understanding of the LTE-R implementation in a tunnel environment. Leaky Coaxial Cable (LCX) , channel impairments and two-ray propagation model is also discussed in detail. In chapter 4 and 5 implementation of heterogeneous cooperative spectrum sensing (CSS) test-bed and LTE-R performance analysis in a tunnel is discussed. Chapter 6 presents the results of the implementation of heterogeneous CSS test-bed and LTE-R in a tunnel. Chapter 7 concludes this thesis, summarizing the accomplishments and outlines possible future work.

Chapter 2

Heterogeneous Cooperative Spectrum Sensing (CSS)

This chapter provides the background information needed to understand the chapters that follows. It examines the basic outlines of a heterogeneous networks and how cooperative spectrum sensing (CSS) can help in enhancing the accuracy of signal source estimation. The fusion center (FC) collects the data from the sensor node network and process it to make the reliable decision. Secondly, this chapter investigates various algorithms which can be used in heterogeneous network to estimate signal source. Finally, it also outlines the necessary hardware and software tools used in the implementation of heterogeneous CSS chapter.

2.1 Cognitive Radios

Cognitive radio is a communication systems paradigm that focuses on employing highly agile, environmentally aware, intelligent wireless platforms in order to autonomously choose and fine-tune device operating parameters based on the prevailing radio and network environmental conditions. In many situations, SDR technology is primarily responsible for making cognitive radio a reality due to its operational agility resulting from a digital baseband that is entirely implemented in software and/or programmable logic. In order to enable a substantial level of intelligent decision making in these cognitive radio systems, machine learning techniques have been proposed to either partially or entirely automate the (re)configuration process . However, the solutions produced by these techniques often depend on explicit inputs by the human operators, which require some knowledge of the wireless device and the target networking behavior (e.g., high data rates, high error robustness, and low network latency). Moreover, the target behavior specified by the human operators may not match the actual target behavior[Di Pu/A. Wyglinski].

2.2 Heterogeneous Networks

Heterogeneous CR network, in which each SU may be equipped with different numbers of antennas and sampling rates. In addition, each SU may experience distinct channel fading and suffer from different noise levels due to their respective locations and device performances, such as amplifier and ADC. As a result, each SU may have different sensing capabilities and reliability values. This is a universal and fundamental characteristic of a heterogeneous CR network, which has not been taken into account in any previously proposed cooperative spectrum sensing schemes.[GuoshengYangHetNetPaper]

2.3 Cooperative Spectrum Sensing

Cooperative sensing (CS) with soft combination, i.e., multiple SUs sense the common signal in a coordinated mode, has been proven to be more reliable than single SU sensing [4][13] under a practical fading environment. For its low implementation complexity, energy detection (ED)-based cooperative spectrum sensing has been widely investigated in recent years. In particular, the maximum ratio combining (MRC) and the square-law combining (SLC) have been studied in [9] and [12]. However, the MRC scheme needs the channel state information (CSI) from the PU to the SUs and from each SU to the fusion center (FC). If the SLC scheme is applied with a variable amplification factor at each SU, the CSI from the PU to the SUs and from the SUs to the FC are also needed. As a result, both MRC and SLC schemes have substantially high complexity. In contrast, cooperative ED with equal gain combination (EGC) is often considered in practical implementation due to its low complexity [9], [13].[GuoshengYangHetNetPaper]

2.4 Software Defined Radios

Now that the signal processing techniques have been discussed, a platform for implementation is needed. The alley chosen for this thesis is to utilize a new hardware frontier called Software-Defined Radio, which will be discussed in this section.

For the past two decades there has been a paradigm shift is the definition of a radio device. The conversation has to do with the question of where hardware ends and where software begins. The term Software Defined Radio, coined by Dr. J. Mitola III, defined as a set of digital signal processing (DSP) primitives, a meta-level system for combining the primitives into communication system functions (transmitter, channel model, receiver, etc.), and a set of target processors on which the software radio is hosted for real-time communications [42]. Dr. Mitola understood how software provided the flexibility that hardware never could, and as time made it more mailable SDR would become dominant.

SDRs can be flexible enough to avoid the limited spectrum assumptions of designers of previous kinds of radios, in one or more ways including: Ultrawideband transceivers, cognitive radio, dynamic mesh networks, software-defined antenna arrays among others [43]. One of the first SDR implementations was a project called SpeakEasy. The original purpose of SpeakEasy was to use programmable processing to emulate more than ten existing military radios, operating in frequency bands between 2 MHz and 2 GHz [44]. Therefore with this single radio, the operator could talk to ten radios operating under ten different standards. As simple enough idea, but unfortunately the implementation left much to be desired. For example, physically the device encapsulated the entire back of a common pickup truck [44]. This might be great for a ground station that does not move, but for a mobile unit this was highly impractical. Secondly, in 1992 field programmable gate arrays (FPGA) required significant time, comparatively to re-flash or change their operational parameters. Again, this also limited SpeakEasys flexibility.[Travisthesis]

2.4.1 GNURadio

The first software package to be discussed by this thesis is GNU Radio. GNU Radio provides the reconfigurable signal processing blocks that are necessary for software defined radios. GNU Radio is an open source project allowing for SDR developers to develop unique signal processing blocks and SDR systems. GNU Radio was started in 2001, originally forked from the SpectrumWare project developed at the Massachusetts Institute of Technology [46]. Since 2001, the code base has undergone massive changes, containing almost no code from the original SpectrumWare project. Physically the code consist of three languages Python, C++, and SWIG. Python provides the overarching control of the system or program, while C++ provides the actual signal processing blocks and mathematics. SWIG is a wrapper for C++ which allows Python to dynamically wrap around C++ and control or compile with it. A diagram below better illustrates this architecture. It is also important to mention that there as significant paradigm shifts in the community, pushing more and more code to Python rather than C++, due to its easier programming syntax and structure.

GNU Radio provides a very structured framework of flow design. Data processing segments are extremely self contained to minimize error propagation during system debugging. Since the software is open-source full access to all code is provide, giving low-level access to all operation within GNU Radio. Much of the actions have been abstracted to limited the knowledge of the lower layers, but if specific actions are required for an application. Then serious depth or knowledge is needed about the overall projects structure, which is quite overloading.[Travisthesis]

2.4.2 MATLAB

MATLAB is an extremely well known engineering, mathematical, biological, and financial software suite. MATLAB provide massive data leverage and advanced communication system models and algorithm for significant data processing. Since 2007, they have also provided hardware compliance with specific SDR platforms through their Simulink platform, and more recently within MATLAB itself [47]. This thesis primarily utilizes the signal processing and communication system aspects of MATLAB, since MATLAB cannot fully utilize all aspects of the chosen hardware. It is important to note under alternate constraints, MATLAB can provide adequate performance directly interfacing with hardware, especially when accessing its targeting features seen here [48]. Figure 2.10 shows an example of a common MATLAB SDR model through Simulink.[Travis]

2.5 Summary

This chapter outlined and examined the topics of jamming and anti-jamming techniques, and provided a foundation in communication system theory and advanced equalizer design. Secondly it setup an understanding of Software-Defined Radio, the power of such an architecture, and examples of implementations and existing software for future designs. Next, this thesis will consider a new anti-jamming technique and design an implementation of such a system. After the implementation is investigated, the result of specific experiments on such an implementation will be analyzed.

Chapter 3

Long Term Evolution for Railways (LTE-R)

3.1 LTE-R Communication System

LTE-R System Description To provide improved and more efficient transmission for HSR communications, it is vital to consider frequency and spectrum usage for LTE-R. HSRs are important stra- tegic infrastructure, and, in some countries, this argument is being leveraged to convince governments that large spectrum chunks need to be allocated specifically for it. Some industry bodies, including the European Railway Agency (ERA), China Railway, and UIC, are working to secure spectrum allocation for HSR use. Currently, most LTE systems work at the bands above 1 GHz, such as 1.8, 2.1, 2.3, and 2.6 GHz, although 700900-MHz bands are also used in some countries. Large bandwidth is available in the upper bands, giving a higher data rate, whereas lower frequency bands offer longer distance coverage. Figure 1(b) summarizes the possible frequen- cy bands for LTE-R in China, Europe, and Korea. As a high-frequency band has larger propagation loss and more severe fading, the radius of an LTE-R cell would be ¡2 km [due to the strict requirement of signal-to-noise ratio (SNR) and BER in HSR], leading to frequent handovers and a requirement of substantial investment for higher BS density. Therefore, the low-frequency bands, such as 450470 MHz, 800 MHz, and 1.4 GHz, have been widely considered. The 450470-MHz band is already

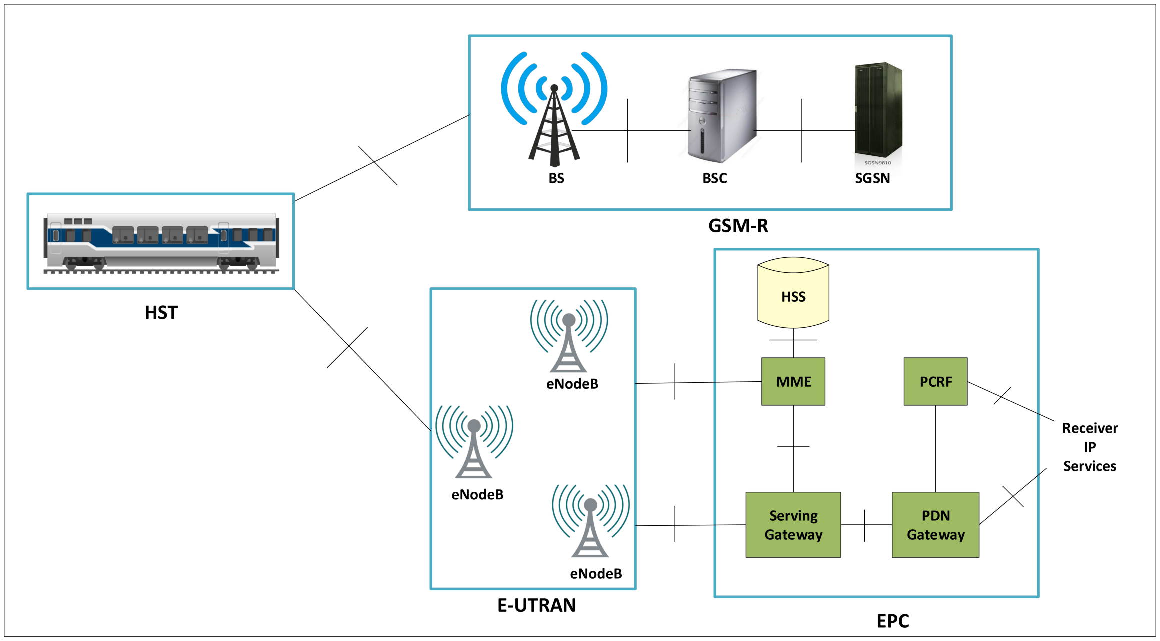

Figure 3.1: High speed train inside a tunnel for LTE-R. D_{LOS} is the distance between transmitter and receiver, d is the distance between the LCX cable transmission slots.

well adopted by the railway industry; therefore, dedicated bandwidth for professional use can still be allocated from local regulators. Furthermore, the carrier aggregation capability of LTE will permit the use of different bands to overcome problems of capacity. Figure 1(b) presents the detailed frequency allocation of 450 470 MHz in China [12], and it is feasible to allocate enough bandwidth for LTE-R within this band. In Europe, the FRMCS of UIC would like to build on the current GSM-R investment by reusing the existing mast sites, which could save as much as 8090% of the cost of a network. Railways are also concerned about continu- ing to make use of their GSM-R masts, and, therefore, a spectrum allocation under 1 GHz is more cost effective in Europe. However, the selection of frequency band depends on government policy and differs by country.

Standard LTE includes a core network of evolved packet core (EPC) and a radio access network of Evolved Universal Terrestrial Radio Access Network (E-UTRAN). The Internet protocol (IP)-based EPC supports seamless handovers for both voice and data to cell towers, and each E-UTRAN cell will support high data and voice capacity by high-speed packet access (HSPA). As a candidate for the next-generation communication system of HSR, LTE-

R in- herits all the important features of LTE and provides an extra radio access system to exchange wireless signals with onboard units (OBUs) and to match HSR-specific needs. The future architecture of LTE-R according to [4] is pre- sented in Figure 2, and it shows that the core network of LTE-R is backward compatible with GSM-R.

Compared with the public LTE networks, LTE-R has many differences, such as architecture, system parameters, network layout, services, and QoS. The preferred parameters of LTE-R are summarized in Table 1, based on the future QoS requirements of HSR communications. Note that LTE-R will be configured for reliability more than capacity. The network must be able to operate at 500 km/h in complex railway environments. Therefore, quadrature phase-shift keying (QPSK) modulation is preferred, and the packet number of retransmission must be reduced as much as possible.[RuisiHeBoAiGongpuWang/HSRCommunications]

3.2 Leaky Coaxial Cable

Substantial work has been done for the radio communication in tunnel environments. Authors of [2]measure the radio channel frequency response; the large scale and small scale fading in tunnel are investigated through field experiments. Statistical characteristics of the propagation channels are suggested in [3]. Both [2] and [3] indicate that WLAN cannot achieve good performance when used in tunnel environments. As a result, leaky waveguide and leaky coaxial cable are used in wireless communication due to their stability and robustness from the interference. The availability of train ground communication in subway systems by waveguide is analyzed in [4] and [5]. Meanwhile, leaky coaxial cable is lso studied. H. Cao [7] introduces the way to calculate frequency range of LCX and shows experimental results about LCX performance at 1.8GHz. Authors of [11] introduce the propagation at 2GHz in an enclosed area using a leaky coaxial cable. Authors of [12] study the theory of leaky coaxial cable with periodic slots, and frequency band of the studied LCXs is from 450MHz to 900MHz. However, few people specialize in the performance of leaky coaxial cable at 2.4GHz band, especially the application in tunnels.[HongweiWangBinNingandHailinJiang]

3.3 Channel Impairements Inside a Tunnel

The tunnel environment is affected by multipath and diffraction effects due to multiple reflections from the tunnel walls, which leads to a substantial fading environment. By deploying LCX cables, we can eliminate the large penetration loss due to tunnel walls. However, small-scale fading can still cause a large amount of errors and decrease the QoS for the communication link.

High velocity trains experience very high Doppler shifts and a fast fading channel. These problems can lead to significant BER degradation of the LTE system. The frequency shifts caused by the Doppler phenomenon can lead to shifts in the sub-carrier frequencies for OFDM, which leads to synchronization errors. The maximum Doppler shifts for a train traveling at 500 km/h is 2.314 kHz for a 5 GHz carrier frequency. This large Doppler shift can also lead to significant drops in the quality of wireless signals and increase the bit error rate. Thus, to develop an efficient and reliable communication link inside tunnels, we need to properly model this channel impairment and build our proposed channel model by taking into account these tunnel phenomenons. These impairments are described in detail in the following subsections.[OwnPaper]

3.3.1 Multipath Fading

The following time-varying multipath channel impulse response considers the effects of Doppler shift and scattering [11]: where is the path delay, t is time in seconds, [k (t)] is the impulse response, f c is the carrier frequency, h k (t) is the envelope of the time-varying channel and consists of both large and small-scale fading components. Since the structure of LCX is almost the same as a leaky waveguide, the large scale fading of channel can be modeled linearly [8]. There is also no signal shadowing and the line-of-sight (LOS) signal component is always present along the tunnel. This type of channel fading can be best described by a Ricean fading model. The probability density function p() of a Rician fading model is given by [10]: where K is the Rician factor and is the complex amplitude of the channel response function that has a unity second moment.

3.3.2 Doppler Shift

The 3GPP channel model [14] is used for its Doppler shift profile in high speed railway environment. The measurements obtained for the Doppler frequency shift are implemented for two scenarios. The first scenario is for an open space while the second scenario is for high speed trains. Doppler shift is not taken into consideration. There exists a third scenario for tunnels using multiple antennas. Since the slots of LCX can be modeled as multiple antenna system, we use this Doppler shift profile for our proposed channel. The Doppler shift variation f s (t) is described by

3.4 Two-Ray Propagation Model

3.4.1 Classical Two-Ray Propagation Model

3.4.2 Dynamic K-factor

3.5 Summary

This chapter outlined and examined the topics of jamming and anti-jamming techniques, and provided a foundation in communication system theory and advanced equalizer design. Secondly it setup an understanding of Software-Defined Radio, the power of such an architecture, and examples of implementations and existing software for future designs. Next, this thesis will consider a new anti-jamming technique and design an implementation of such a system. After the implementation is investigated, the result of specific experiments on such an implementation will be analyzed.

Chapter 4

Heterogeneous CSS

Implementation

4.1 Overview

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4.2.2 Sensor Nodes Setup

4.3 Hard Fusion

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4.4.1 EGC Scheme

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4.5 Summary

This chapter outlined and examined the topics of jamming and anti-jamming techniques, and provided a foundation in communication system theory and advanced equalizer design. Secondly it setup an understanding of Software-Defined Radio, the power of such an architecture, and examples of implementations and existing software for future designs. Next, this thesis will consider a new anti-jamming technique and design an implementation of such a system. After the implementation is investigated, the result of specific experiments on such an implementation will be analyzed.

Chapter 5

LTE-R Communication System Implementation

5.1 Overview

5.2 LTE-R Testbed in Matlab

5.2.1 HST Channel Model

5.2.2 LTE-R OFDMA

5.3 Analysis

5.4 Summary

This chapter discussed the implementation fall-backs and successes of the BLISS system. The entire AS^6 system was outlined and scrutinized for feasibility and operational performance. Spectral Subtraction and Signal Separation were transitioned from original research goals to more manageable problems, with simplified solutions. Overall it can be said that optimality and technical complexity were sacrificed in the end for realizability. Many directions needed to be changed, especially in the Signal Separation block, and constraints needed to be tightened on the Spectral Subtraction block. Although AntSS couldn't be realized a solid foundation exists for future work.

Chapter 6

Experimental Results

6.1 Overview

6.2 Heterogeneous CSS Results

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6.3 HST LTE-R in a Tunnel

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6.3.3 Real-time BER in a Tunnel

6.4 Summary

Spectral Subtraction in a extremely well studied area in signal processing, but no existing literature exists for its application in a digital communication system. It has been shown here that it can be quite difficult for it to be applied, even under strict constraints. Under the conditions of this thesis, the assumptions are quite reasonable, but due to the large amount of error in the results, more may need to be considered. These may include accuracy requirements for physical equipment, primarily to reduce carrier frequency drift. Burst scenarios may also be considered to reduce bit error rate. Overall, for a completely non-existent field of study, these results point the possibility of operational success. Future work will we required, especially during the implementation phase of designs.

Chapter 7

Conclusions

7.1 Research Outcomes

7.2 Future Work

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Appendix A

SS.m

```
clc;
!sudo sysctl -w net.core.rmem_max=50000000
!sudo sysctl -w net.core.wmem_max=1048576

!LD_LIBRARY_PATH="" && /home/sdruser/COLLINS/SS/
    top_block_SS_R.py

%% Spectral Subtraction
addpath('/home/sdruser/GNURadio/gnuradio/gnuradio-core/src/utils
    ');
received=read_complex_binary('received.txt');
received_GMSK=read_float_binary('received_GMSK.txt');

known=read_complex_binary('known_modulated.txt').*0.1;

%remove startup transient
cut=20001;
received=received(cut:end);
```

```
recSig=received;

%% Timing Recovery
L=2;
g=0.07;
hSync = comm.MuellerMullerTimingSynchronizer('SamplesPerSymbol',
    L, ...
      'ErrorUpdateGain', g);

% Estimate the delay from the received signal
[sig, phase] = step(hSync, recSig);

% apply phase
recSig=recSig.*exp(1i*phase(end)*pi/180);



%% find data
r=double(sign(received_GMSK));



s_saved=[ -1    1    1    1    1   -1    1   -1];
s_saved=[s_saved s_saved s_saved]';
prea=s_saved;
s=s_saved.';

% Find Preambles
indexs=[];
for i=1:length(r)-length(s_saved)-2000
     x=sum(r(i:i+length(s_saved)-1)==s_saved);
```

```
    %if x>10
    %      disp(x);
    %end
    if sum(r(i:i+length(s_saved)-1)==s_saved)==length(s_saved)
         indexs=[indexs i];
    end
end


% Retry is no signal found
if isempty(indexs)
     disp('Looped');
     SS_Final;
     break
end

%% calculated channel coefficients
loc=indexs(1);
w=zeros(10,1);
%Real message
dd=read_char_binary('/home/sdruser/COLLINS/SS/input.txt');
true_message=de2bi(dd',8,'left-msb');
mbits=reshape(true_message',size(true_message,2)*size(
    true_message,1),1);
mu=0.001;
e_s=[];
for i=length(w)+1:length(mbits)-length(w)
     rr=mbits(i:-1:i-length(w)+1);
```

```
    disp([w'*rr  received_GMSK(loc+i-1)  mbits(i)]);

    e=w'*rr-received_GMSK(loc+i-1);
    e_s=[e_s  e];

    w=w-mu*rr*conj(e);

end

%% Section of Signal
large_SR=recSig;
frames=20;
sample=18*8*2*frames;
section=filter(w,1,known);
error_saved=[];
for i=1:sample:length(large_SR)-sample

recSig=large_SR(i:i+sample-1);

%% Find position of Frame in full signal
section=filter(w,1,known);
xc = xcorr(recSig,section);
middle=ceil(length(xc)/2);
xc=xc(middle:end);
%stem(real(xc));
[~,index]=max(real(xc));
section=filter(w,1,known);

if index+length(section)>sample
```

```
    continue
end
% Spectral Subtract
subtraction=1;
result=[];
section=recSig(index:index+length(section)-1);

for i=index:length(section):length(recSig)-length(section)

     result=[result;recSig(i:i+length(section)-1)-section.*
         subtraction];

end

% Try Catch if no signal found
if isempty(result)
     continue
end

%% Plots
figure;
plot(real(recSig(index:index+length(result)-1)));
hold on;
plot(real(result),'r');
plot(real(section*subtraction),'g');
xlabel('Samples')
ylabel('Magnitude')
title(['Spectral Subtraction Over Subtraction Factor ',num2str(
    subtraction)]);
```

```
legend('Original Signal','Subtracted Result','Estimate of
    Original');
hold off;
%refreshdata
%drawnow

disp('Paused');
pause(.1);
error_saved=[error_saved sum(abs(result))];

end

%% Plots
figure;
plot(error_saved(1:300));
title('Error Across Transmission Frames')
xlabel('Frames');
ylabel('Error');
```