Technische Universität Berlin
Fakultät IV - Elektrotechnik und Informatik
Institut für Telekommunikationssysteme
Fachgebiet Theoretische Grundlagen der Kommunikationstechnik
Communications and Information Theory (CommIT)
Wintersemester 2014/15

Wireless Digital Communications
Lab 1

Jiawei Zhang, 368434
Yi Ji, 000000

Lecturer:
Dr.-Ing A. Kortke

June 12, 2016

Contents

Preliminaries

This protocol is a general review of the practicum Wireless Digital Communications Lab I, where two students work together at one PC as a group. The main task is to detect and receive the signal from wireless channel under the UMTS structure.

UMTS (Universal Mobile Telecommunications System) is a 3^{rd} generation cellular mobile communication system and standardized by 3GPP (Third Generation Partnership Project). Several air interface (physical layer) specifications have been introduced:

- UTRA FDD
- UTRA TDD
- CDMA 2000

0.1 Signal Structure

0.1.1 Complex phase modulation: QPSK

The Quadrature Phase-Shift Keying (QPSK) uses four points on the constellation diagram. After modulation each symbol contains 2 information bits. The mapping table is defined as follow:

Consecutive binary bit pattern	complex symbol
00	+j
01	+1
10	-1
11	-j

Table 1: QPSK Mapping Table

0.1.2 Transmit pulse shape filter

The transmit pulse-shaping filter is a root-raised cosine (RRC) with roll-off 0.22 in the frequency domain. The impulse response of the chip impulse filter $\mathrm{RC}_0(t)$ is:

$$\mathrm{RC}_0(t) = \frac{\sin\left(\pi \frac{t}{T_C}(1-\alpha)\right) + 4\alpha \frac{t}{T_C} \cos\left(\pi \frac{t}{T_C}(1+\alpha)\right)}{\pi \frac{t}{T_C}\left(1-\left(4\alpha \frac{t}{T_C}\right)^2\right)}$$

Where the roll-off factor $\alpha = 0.22$ and the chip duration: $T_C = \frac{1}{chiprate} \approx 0.26042\mu s$

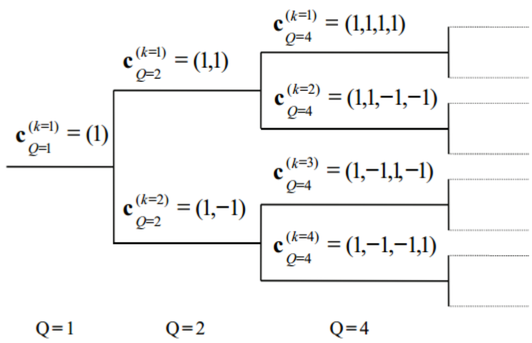


Figure 1: OVSF code tree 1

0.1.3 CDMA Spreading

Spreading codes are used for different users. These codes require the property of good auto- and cross-correlation function. Since the multiplication of two Hadamard matrix produces an identity matrix. We can make use of the columns of the matrix (based on Walsh sequences) as the Spreading code. The code-tree for generation of Orthogonal Variable Spreading Factor (OVSF) codes for channelization Operation is shown in Figure 1.

0.1.4 Scrambling

Since adjacent cells use the same carrier frequency, signal separation of different base stations is realized by particular scrambling sequences which are specific for adjacent cells. These scrambling sequences are complex valued and have a fixed length of 16 elements (*aka.* chips). 16 consecutive chips of the spread data are element-wise multiplied by the given scrambling sequence, which is called Hadamard vector product.

0.1.5 Burst Types

Midamble Length	Use Case
512	uplink & downlink: independent of the number of active users in one time slot
256	uplink: if the bursts within a time slot are allocated to less than four users downlink: independent of number of the number of active users in one time slot

0.1.6 Timeslot Structure

A timeslot is composed of 3 parts: two data parts and the midamble part, which is shown in figure 2.

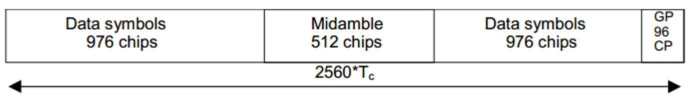


Figure 2: Time slots [1]

0.1.7 Midamble sequences

Midamble sequences are applied for channel estimation and synchronization. For the UTRA TDD midamble sequences, adjacent base stations use different midamble sequences. In downlink the mobile station can estimate their individual channel state information by receiving the midamble sequences from the BS, while in uplink, the BS will receive a superimposed version of the midambles from all the mobile stations, each of which is derived from a cyclic shift of a basic midamble.

0.2 The SDR platform (Wireless Experimental System II)

The SDR platform is used for remote controlled indoor transmission from one or two transmit antenna(s) to one or two receive antenna(s). The carrier frequency varies from 2000 to 2500 MHz. There are two base band signal bandwidth: 250M Hz (wideband mode) or 15.625 MHz (downsampled). The approximate transmit power is -6dBm (250 µW). The offline signal processing will be done with Matlab. The sampling frequency for UMTS and WLAN transmission experiments is 15.625 Msps (4 samples per UMTS-CDMA-chip).

Every group uses a SDR device connected to a host notebook via a PCIe interface. All working groups can use a remote control Matlab function, called "RemoteTransmission()" to have access to the SDR device. This function requires a parameter with Matlab parameter structure "TransmissionParameter", which contains information like transmit power, the antenna attenuation for both transmitter and receiver, the name of existing transmit signals and bandwidth.

After running the RemoteTransmission() a Matlab data file will be generated, which involves the received signal samples, status information of the SDR system during the transmission, as well as a string variable whose name is the transmit signal. The received signal samples comprise inphase and quadrature component signal samples, cell-array with messages about the transmission procedure, Group ID, bandwidth, transmission parameter structure and system parameters that were active during the transmission.

0.3 Organization of this Protocol

Our first experiment is dealing with a single transmit signal of a mobile station, which is transmitted to a base station over DPCH (uplink). There will be no multipath propagation effects and hence a simple match filter receiver is sufficient to receive and detect the signal.

Chapter 1

Transmission and detection of a single CDMA signal

1.1 Scenario

A single transmit signal of a mobile station is transmitted to the base station over the DPCH (uplink).[1]

1.2 Task

In the experiment we should receive and detect the data symbols from the received signal. Usually there is multi path propagation because of reflections at walls, ceiling etc. However, in our case it is sufficient to implement a simple matched filter receiver. (why???)

1.3 Information about transmit signal

- Signal name: TxSignal_1.mat
- Parameter specifications:

burst type	1
spreading factor	8
number of data symbols per data field	122
channelization code sequence	$[11111111]$
midamble ID	Basiscode : 1, User : 1
scrambling code ID	1

Table 1.1: Parameters of the transmit signal

1.4 Algorithm description[1]

1. Transmission of the UMTS signal as described above.

2. Load the file with the received signal as well as the file with the transmit signal information (1.3) into the Matlab workspace
3. Select one of the two received signal sample streams: xi = xi(1,:); xq = xq(1,:);
4. normalize the signal samples to get a convenient range of sample values: xi = xi/2^{14}, xq = xq /2^{14}
5. Remove the mean values of vectors xi and xq
6. Establish a complex signal vector out of the inphase and quadrature components:
   x = xi + 1i*xq: or x = complex(xi,xq);
7. Apply the digital Rx pulse shape filter: x = RxFilter(x);
8. Cut out the 15 signal bursts which are contained in the time slots of the filtered signal vector. The first time slot begins around sample index 1000, the length of the signal bursts is 10240 samples
9. The code sequences "midamble", "code", "scr" contain one element per signal chip. To use these sequences for signal processing they have to match our oversampling of eight samples per chip. We do the fitting by so called "zero stuffing" of the code sequence vectors by means of the Kronecker product.
10. The next steps have to be done in a loop for every signal burst:
    (a) Remove the mean value from the burst signal
    (b) Increase the sample time resolution by signal interpolation
    (c) Calculate the cross correlation function of the up-sampled signal burst with the zero-stuffed mid-amble sequence
    (d) Search the position of the maximum absolute value of the cross correlation vector
    (e) Cut out the signal samples of the first data part of the signal burst
    (f) Cut out the signal samples of the second data part of the signal burst
    (g) Correct the signal phase rotation by multiplying the data part vectors by the complex conjugate value of the cross correlation value at vector index Imax
    (h) De-scramble the data parts by using "descramble()"
    (i) De-spread the data parts by using "despread()"
    (j) Decide the data symbols by using "decide()"
    (k) Determine and count the number of data symbol detection errors

1.5 Observation and interpretation

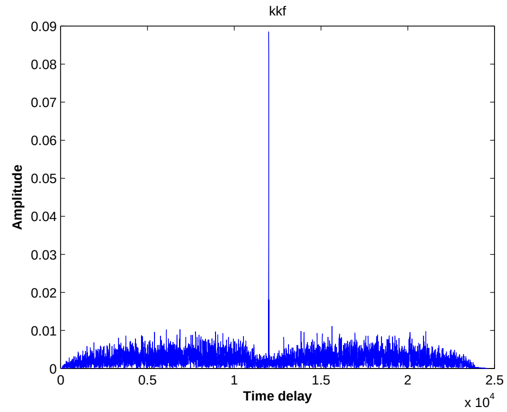


Figure 1.1: Cross correlation function

The operation of KKF can get rid of the time delay in the channel. In figure 1.1 we can see there is a peak with index Imax. This is the position of last midamble bit. After detecting the Imax we can cut out the first and the second part of the data from the following positions:

The first part start index: $Imax - (976 + 512) * 8 + 1 = Imax - 11903$, length: $976 * 8 = 7808$

The second part start index: $Imax + 1$, length: $976 * 8 = 7808$

After the operation of phase rotation we can get figure 1.2. It is hard to recognize them with respect to the original QPSK data. After the operation of descramble, we can plot the data like figure 1.3(a). Furthermore, after the operation of despread we get data as shown in figure 1.3(b). Then, we can simply use the decide function to decide the final data.

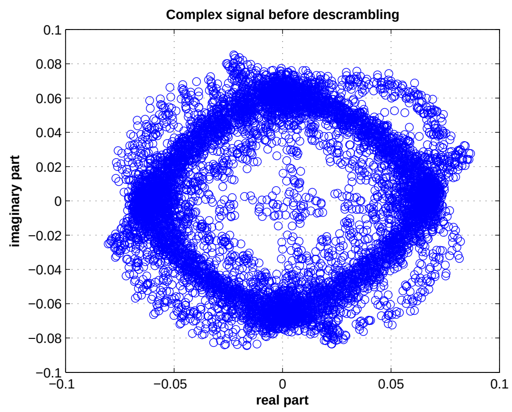
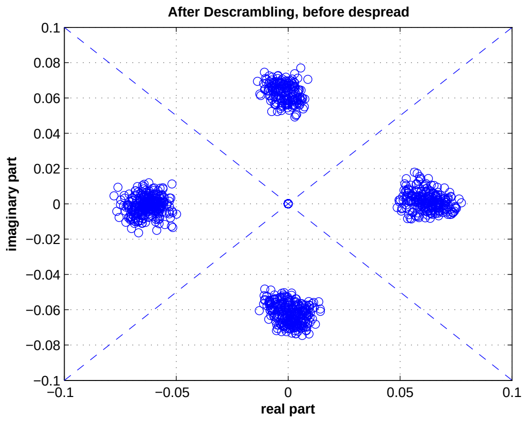
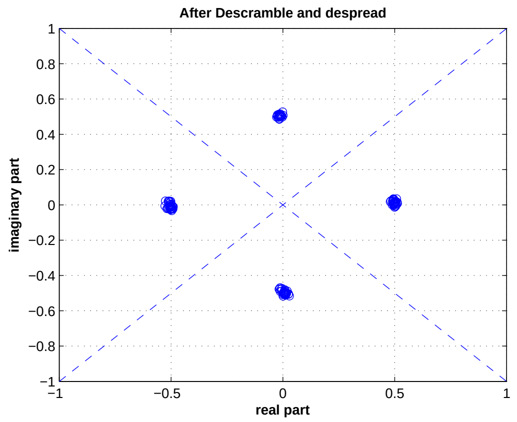


Figure 1.2: Complex signal before descrambling



(a) after descramble



(b) after despread

Figure 1.3: Complex signal after descramble or despread

1.6 Summary

From the symbol error checking after the decide function we get no error in our experiment. In other words, in our experiment environment we can achieve an error free transmission. From this first exercise we have a general idea of how a single CDMA Signal is transmitted in the wireless channel, what is the basic procedure of signal processing in UMTS (eg. descrambling and despreading). Meanwhile we realize the importance of frame synchronization in wireless communication (in our case, we first try to find the Imax to identify the frame start). In order to guarantee the accurate detection of data symbols, an oversampling is also a requirement in our experiment.

Chapter 2

Transmission and detection of superimposed CDMA signals

2.1 bilblibli

Chapter 3

Multipath wave propagation and rake receiver

Chapter 4

Receive antenna diversity

Chapter 5

Wideband Channel Measurement

5.1 Scenario

Modern wireless channels have many characteristics, namely time variance, frequency selectivity, time dispersion, frequency dispersion etc. In the last experiment of Wireless Digital Communication Lab 1, we will measure these wireless channel characteristics by means of a measurement device called channel sounder, which consists of a transmitter generating and transmitting sounding signal and a receiver receiving and processing the received signals.

If the system components have ideal characteristics, the characteristics of the wireless channel is equivalent to the "equivalent baseband channel", which is shown in figure 5.1. However, in real systems this is not necessarily the case.

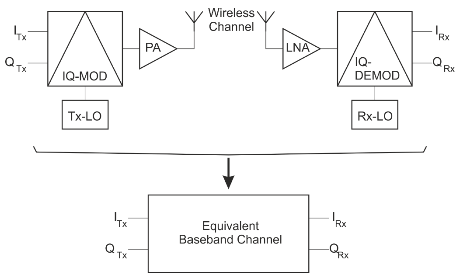


Figure 5.1: Equivalent baseband model of the channel measurement [2]

Our SDR platform uses wideband mode for the channel measurements. The sampling frequency in this mode is 250 MHz. We transmit signal sequence periodically to have periodic measurements of the wireless channel. The duration of a signal period a sequence of 256 elements (chips); each chip duration is $1/f_{samp} = 4$ ns. The total sequence period duration is therefore 1024 µs, which has to be larger than the channel excess delay, in our case in the range of 0.1 µs to 10 µs.

Figure 5.2 shows the derivation of the measurement concept implementation. The third configuration which shifts the second sequence generator and the correlation function element to the receiver part is appropriate to be implemented, since its input signal comprises of several low energy pulses.

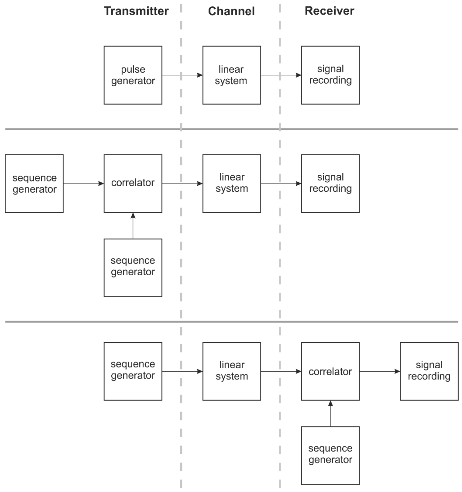


Figure 5.2: Derivation of the measurement concept implementation [2]

Meanwhile the additive measurement noise need to be considered during the signal processing. Averaging signal periods is utilized to increase SNR. The time interval of averaging is termed "snapshot". Regarding the rotation velocity, radius of copper patches and the carrier frequency the maximum Doppler frequency shift is $f_{doppler,max} = f_{carrier} \cdot \frac{v_{max}}{c} = 167\,\text{Hz}$. The minimal time intervals of the snapshots should be $\frac{1}{2f_{doppler,max}} = 3\,\text{ms}$.

The time structure of the channel measurements is displayed in Figure 5.3. A certain number of consecutive snapshots composes a measurement "set" and fast time variations of the channel characteristics are included in it. We can calculate the Doppler resolved channel impulse response function from one set, which features the magnitude and the individual Doppler frequency shifts of all multi-path components.

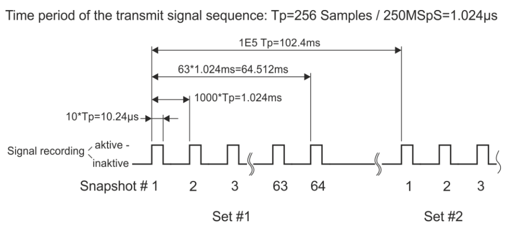


Figure 5.3: Time structure of channel measurement [2]

5.2 Task

By means of Matlab script "ChannelSounderTransmission.m" we should process the received signal so as to calculate the channel transfer function, channel impulse response function as well as the Doppler resolved channel impulse response function (on the condition of rotating disks).

5.3 Information about the transmit signal

- Signal name: CHANNELSOUNDER
- Parameter specifications:

Parameter	Symbol	Value
Sampling frequency	f_s	$250\ MHz$
Sample time interval	ΔT_s	$\frac{1}{f_s} = 4ns$
Length of the transmit signal sequence	L_p	$256\ Samples$
Period time of the transmit signal sequence	T_p	$L_p \Delta T_s = 1.024\mu s$
Number of sequence periods within a channel measurement „snapshot“	N_p	10
Time duration of one snapshot	T_{snap}	$10\ T_p = 10.24\mu s$
Time distance of consecutive snapshots	ΔT_{snap}	$1000\ T_p = 1.024ms$
Number of snapshots within a measurement „set“	N_{snap}	64
Time duration of one set	T_{set}	$63\ \Delta T_{snap} + T_{snap} = 64.52\mu s$
Time distance of consecutive sets	ΔT_{set}	$10^5\ T_p = 102.4ms$
Number of sets within a transmission	N_{set}	10
Length of the received signal in number of samples		$L_p N_p N_{snap} N_{set} = 1638400$

Figure 5.4: Parameters of the signal [2]

5.4 Algorithm description [2]

The suggested algorithm is given below:

1. Transmit the channel sounding signal with the Matlab script "ChannelSoundertransmission.m". Include the group ID into the local copy of the Matlab script. Select antenna signal x1 for further signal processing.
2. Reshape the signal vector to a matrix, whose rows is equal to the length of the transmit signal period $L_p = 256$ and the columns is equal to the product $N_p N_{snap} N_{set} = 6400$.
3. Average every snapshot for SNR enhancement and obtain a single vector of $L_p = 256$ elements for each snapshot.
4. Perform a FFT in column direction (dimension of delay time)
5. Calculate the time variant transfer function $H(f, t)$. The transformation result vectors should be divided element wise by the elements of the calibration vector Y_{cal} (in our case $Y1_{cal}$).

Since the SDR system cannot transfer the DC component (frequency 0 Hz), the value of the transfer function at this point should be replaced by a linear interpolation value:

$$H(0,t) = \frac{1}{2}\left(H(-\Delta f, t) + H(\Delta f, t)\right)$$

6. Depict the results of the time variant (magnitude) transfer functions by different diagrams for consecutive measurement sets or by Matlab function "surf".

7. Calculate the time variant impulse response functions. All columns of transformation result should be element wise multiplied by the elements of the "windowed correction vector" $W_{FD}./Y_{cal}$. Its effect is to reduce artificial oscillations (side lobes) in time domain. Instead of using rectangular windowing, in that it produces severe oscillations in the transformation space, we use Gaussian-shape frequency domain window function W_{FD}. A time discrete version of the window function $W_{FD}(k)$ should be calculated and it consists of L_p elements and meanwhile be normalized with the mean value 1. The linear interpolation is also required to correct the DC frequency.

8. Transfer the result to time domain and plot the result as step 6.

9. Calculate the Doppler resolved channel response functions. The time variant impulse response function should be windowed in observation domain by Gaussian window function:

   $$W_{TD}(t) = \exp\left(-\left(\frac{t - T_{set}/2}{t_g}\right)^2\right)$$

   . The cutoff frequency should be chosen to be $t_g \approx 15\Delta T_{snap}$. A time discrete and normalized version of the window function should be calculated:

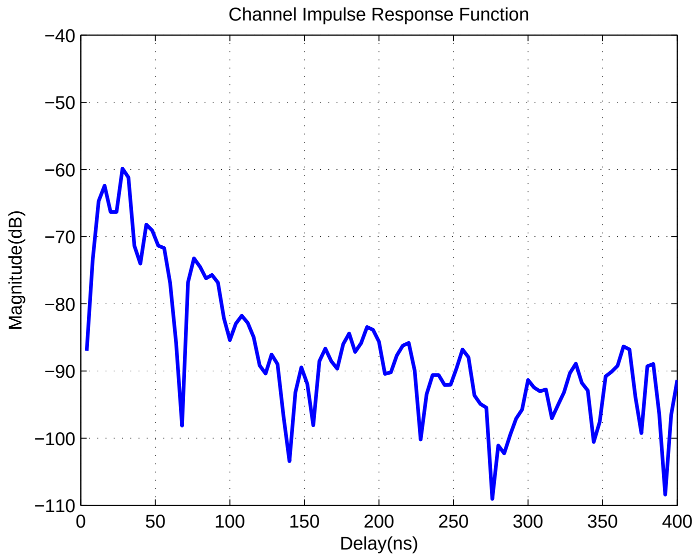
   $$W_{TD}(n) = \frac{W_{TD}(n)}{\frac{1}{N_{snap}}\Sigma W_{TD}(n)}$$

10. Perform a FFT transformation with respect to observation time - not delay time. Divide the transformation output the number of snapshots per set N_{snap} so that the magnitude level of the multipath contributions here are the same as in the time variant impulse response function.

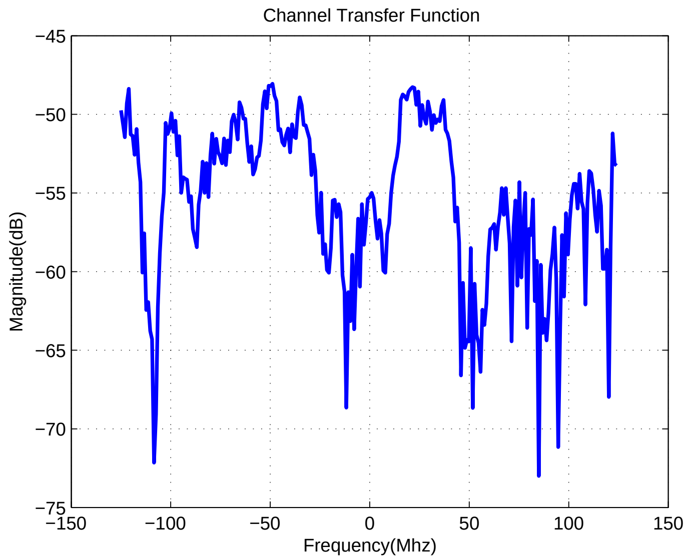
11. Depict the Doppler resolved channel impulse response functions by Matlab function: "surf"

5.5 Observation and interpretation

After implementing the algorithm mentioned above we depict the results shown as follows.



(a)



(b)

Figure 5.5: Measured channel impulse response function 5.5(a) and measured channel transfer function 5.5(b)

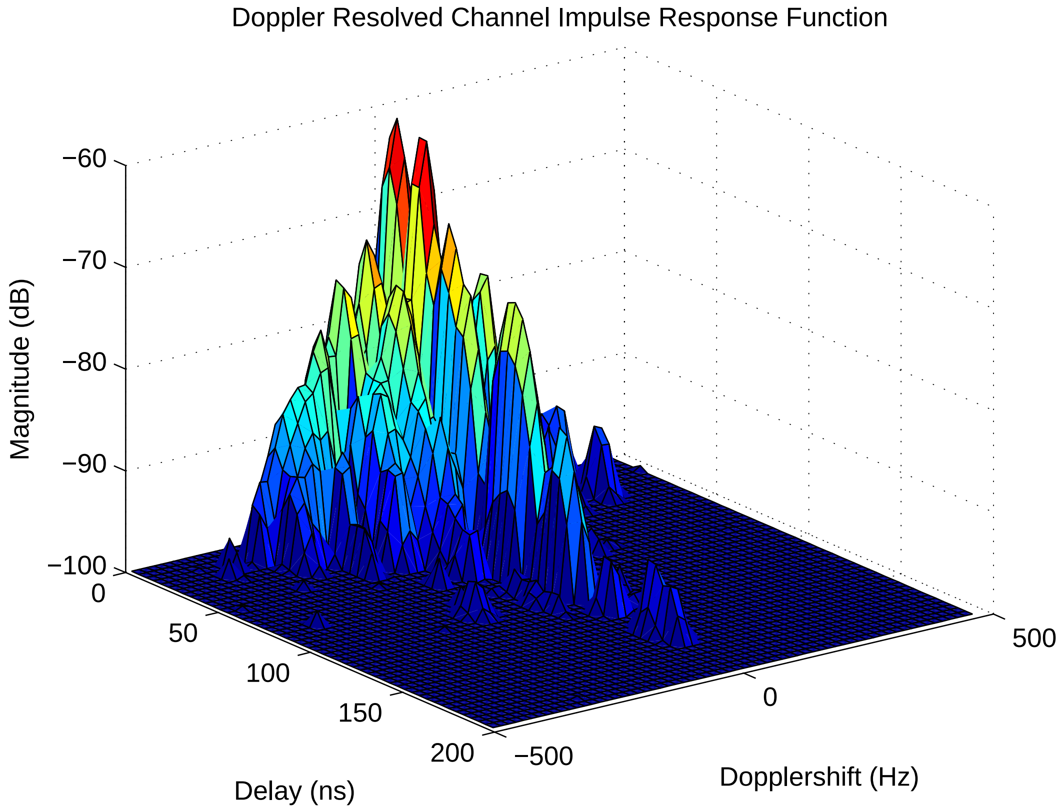


Figure 5.6: Measured Doppler resolved channel impulse response functions (magnitude), rotating disks

5.6 Summary

In the experiment we have measured the wireless channel characteristics with the help of channel measurement device channel sounder. Meanwhile we have also calculated and analyzed the relationship like time variant transfer function, channel impulse response and so on. They are calculated by Fourier transform. From the Doppler resolved channel impulse response function we can observe the multipath amplitude as well as the Doppler shift caused by the rotation of the disk.

Bibliography

[1] WDC Lab1 Exercise 1: Transmission and detection of a single CDMA signal according to the UTRA-TDD air interface specification, A. Kortke

[2] WDC Lab1 Exercise 5: Wideband Channel Measurement, A. Kortke