NTNU
Det skapende universitet

Ytelse for multippel antenne teknikker i LTE

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Oppgavetekst

Den nye standarden for mobilt bredbånd, Long Term Evolution (LTE), tar i bruk nye og avanserte multippel antenneteknikker, blant annet MIMO, for å oppnå ønsket ytelse. I den forbindelse er det vesentlig å forstå mulighetene og begrensningene til disse teknikkene. Telenor har installert et testnett for LTE på Fornebu som blir benyttet til å gjøre funksjons- og ytelsestester.

Studenten skal studere ytelsen til de ulike multippel antenneteknikkene som er definert i LTE. Dette skal gjøres som en kombinasjon av litteraturstudier, teoretisk arbeid og praktiske tester. Testene skal gjøres som deltakelse i Telenors uttesting av LTE-teknologien. Det er blant annet ønskelig å finne ut hvordan de ulike metodene fungerer med ulike antennekonfigurasjoner på basestasjonene for å få en bedre forståelse av hvordan de framtidige nettene skal planlegges og bygges ut. Resultatene skal analyseres og sammenliknes med resultater fra tilgjengelig litteratur.

Oppgaven gitt: 10. Desember 2010
Hovedveileder: Torbjørn Ekman, IET

Preface

This thesis is written to achieve the Masters of Science degree from the Norwegian University of Science and Technology. It is an continuation of the topic explored in the preliminary project last autumn. The thesis was made with cooperation with Telenor Corporate Development. I would like to thank my supervisor Per-Hjalmar Lehne at the Telenor. I would also like to thank all the other employees at Telenor who have helped me.

The intension of the thesis was to find out how MIMO as best as possible can be implemented, due to antenna configurations and MIMO Transmission Modes, when Telenor will be deploying the new Fourth Generation mobile system (4G) network in the future. The data collected is not enough to draw final conclusions, but gives some indications on the subject. There are left other topics like stationary and high speed terminals but to avoid to many parameters it has been left out. I prioritized too look at antenna distance, polarizations and transmission modes.

Eystein Bjerke
Fornebu, 20. May 2011

Summary

This thesis is about doing test runs at an LTE base station at Telenor at Fornebu. The tests are performed to find out how good the systems work, and specifically for this thesis to explore the possibilities of spectral bandwidth gain exploiting multiple antenna and spatial multiplexing.

All tests were done by vehicle at Oksenøya outside Oslo. The tests were done at approximately between 20 and 40 kph. The main tests resulted in 16 test-files with combinations of 4 different physical antenna configurations and 4 different transmission modes, driving the route in both directions. Since Telenor's equipment at the moment only supports 2x2 MIMO, there was no testing of higher channel ranks than 2. The antenna configurations was combinations of co-polarity and cross-polarity and co-located and distance separated antennas.

The interesting aspect of this thesis is to fin if it is possible to use co-located antennas only for 2x2 MIMO, 4x2 MIMO and 4x4 MIMO, which may result in large outcome savings when deploying LTE for commercial use. It was not expected to perform as good as a distance separated antenna configuration.

The results was not concluding, but gave an indication to that the MIMO performance will suffer dramatically from this setup, and leaves the question of what will be the best solution. This is a question that will have to be answered by more test results.

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1 Introduction

The Long Term Evolution (LTE) technology, often referred to as 4G, is regarded as the successor of High-Speed Downlink Packet Access (HSDPA) as the new Mobile Broadband system. The technology differs from previous systems using Orthogonal Frequency Division Multiplexing (OFDM). OFDM has been regarded difficult to implement because of the high system performance needed. OFDM is easy to combine with Multiple Input - Multiple Output (MIMO), opening doors to Spatial Multiplexing (SM) and Space Frequency Block Coding (SFBC), enhancing data rates exceeding the Shannon-Hartley capacity theorem. The capacity can be linearly increased, theoretically, if M = N antennas and the channel is ideal;

$$C \approx Mlog2(1 + SNR)[bit/sec/Hz] \tag{1.1}$$

This channel does not exist, and test results have shown an increase in a low mobility scheme that MIMO can provide up to 20% gain in spectral efficiency. [5].

1.1 Earlier Test results

The Cost2100 program [2] has performed lot of testing of MIMO systems, specifically in Work Group 2 and 3, but close to all testing is carried out focusing on handset performance, where multiple antenna systems faces the highest challenges, because of the size matter. Regarding antenna configuration of multiple antennas on the Evolved Node B (eNB) side, there is close to no tests at all, also leaving it up to the mobile system providers to find the best implementation.

1.2 Motivation

Telenor is highly interested in the aspects of using MIMO technology to invoke higher data rates. In Telenors LTE hardware MIMO implementation is, as for now, limited to SFBC (Transmission Mode 3), Open Loop SM (Transmission Mode 3), Closed Loop SM (Transmission Mode 4) and Rank 1 Precoding (Transmission Mode 6). Also, only 2x2 MIMO is implemented, though Telenor is interested in the MIMO gain by implementating of 4x2 and 4x4 MIMO. In this thesis, LTE is tested at 2.6GHZ on Telenors eNB at Oksenøya. Telenor wants to find out the best antenna configuration for MIMO at the eNB. LTE 800MHz will also be tested as a part of the same test runs, but will not be discussed in this thesis.

2 Background

This chapter is a short version of chapter 2 and 4 in [3], and will try to give some insight into relevant topics of the LTE system.

2.1 LTE

The LTE specifications are based on OFDM and Single-Carrier Frequency Division Multiple Access (SC-FDMA) technology, a spread spectrum technique dividing the whole band into several narrowband subcarriers which are orthogonal to each others. The most basic form of modulation applied to the subcarriers produces a frequency spectrum represented by a sinc function ($\frac{sin(x)}{x}$) convoluted around the subcarrier frequency [8]. The orthogonality is achieved by letting the subcarrier spacing be the inverse of the symbol length, as shown in equation 2.1 [7]:

$$\Delta f_{sc} = \frac{k}{T_{symbol}} \tag{2.1}$$

where Δf_{sc} is the subcarrier spacing, T_{symbol} is the symbol length and k is a positive integer. The standard LTE symbol length is 66,7 microseconds [7] which gives subcarrier spacing of:

$$\frac{1}{66,7 * 10^{-6} s} = 15kHz \tag{2.2}$$

Applying this, the peaks, and zeros lines up perfectly so that there is no interference between adjacent subcarriers, as can be seen in figure 2.1. Due to multipath propagation and Doppler, the orthogonality will to some extent be distorted.

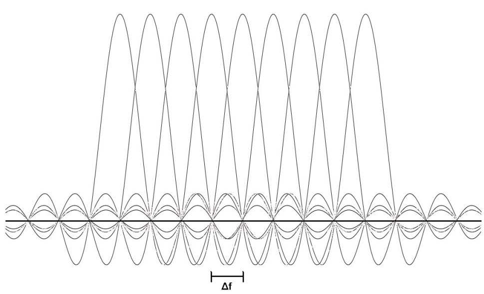


Figure 2.1: OFDM subcarriers frequency spectrum

There is also an optional subcarrier spacing of 7.5 kHz giving twice the symbol length (133,3 microseconds), primarily for long distance transmissions, i.e. very large cells.

2.1.1 Terminology

First some of the terminology used in LTE will be clarified.

- The *eNB* is the Base Station (BS) in LTE. It is more sophisticated than the Node B in HSDPA, operating more independent and handling more of the scheduling.
- A *Resource Element (RE)* is the smallest unit in LTE and is comprised of one subcarrier and one OFDM symbol.
- A *Resource Block (RB)* is the smallest unit that can be scheduled for transmission, and consists of one time-slot and either 12 subcarriers of 15 kHz or 24 subcarriers of 7.5 kHz. One time-slot is always 0.5 milliseconds, and varies in number of symbols from 3 to 7 [7], but for now the only implementation is 7 symbols.

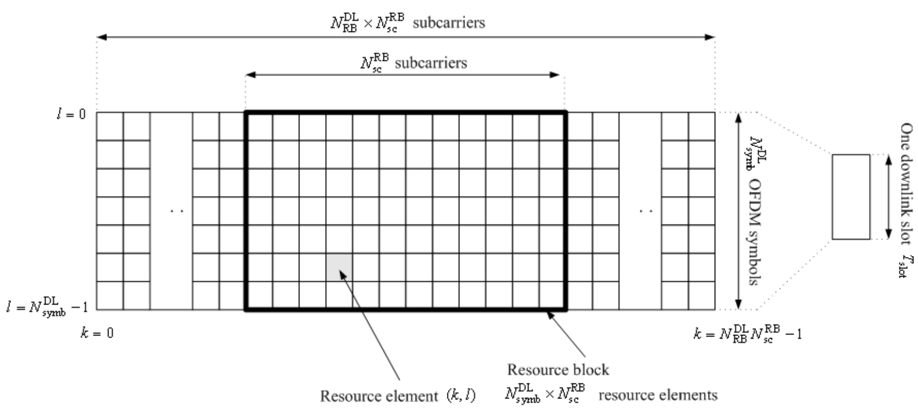


Figure 2.2: Resource Block in LTE Downlink. [4]

- A *Transmission Time Interval (TTI)* is the shortest time interval where changes to transmission can be made, and is 1 millisecond long, i.e. the duration of two RBs.
- A *Codeword* is a block of data and is the smallest possible data unit transmittable in LTE. A codeword corresponds to a *Transport Block.* [1][8].

- The codewords are mapped to *layers*, and there are maximum as many layers in use as there are antenna ports. The codewords can be mapped either directly to each separate layer, or mixed between the layers to create redundancy and decrease Bit Error Rate (BER). The mapping of codewords to layers are given in table 1.

	Codeword 1	Codeword 2
Rank 1	Layer 1	
Rank 2	Layer 1	Layer 2
Rank 3	Layer 1	Layer 2 and Layer 3
Rank 4	Layer 1 and Layer 2	Layer 3 and Layer 4

Table 1: Codeword-to-layer-mapping in LTE [8]

- The decorrelation between the layers is described by *Channel Rank*, and is a limiter to the number of layers that can possible be transmitted. E.g. if channel rank is 2, the maximum number of layers the channel can carry is 2. *Transmission Rank* is the number of layers actually transmitted, and will always be equal to or lower than the channel rank.

- *Rank Indicator (RI)* is computed at the User Equipment (UE) and describes channel rank, and reflects how many layers the channel is able to support, taking into consideration both the channel rank and the UE's capabilities [7].

- The *Reference Signal (RS)*, or *Reference Symbol's*, main task is to function as a training symbol for channel estimation, and is also used to estimate the channel matrix and channel rank in MIMO transmission modes, also known as non-blind technique. The RS is chosen not to be placed on each subcarrier due to the large overhead this would generate, but is placed on REs in certain intervals on certain subcarriers, as shown in figure 2.3. The channel estimation for the in between subcarriers are iterated from the subcarriers with RSs. The RSs are always transmitted without Power Control, e.g. the transmitted power is the same, regardless of other transmission properties. This gives a static power reference, and ensures an accurate Signal-to-Noise Ratio (SNR) calculation.

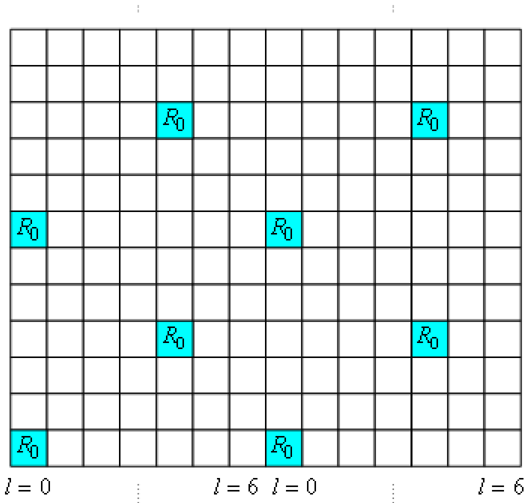


Figure 2.3: Reference Symbol arrangement in LTE Downlink for 1-antenna configuration. [4]

- *Channel Quality Indicator (CQI)* is computed at the UE and reflects the noise and interference level experienced by the receiver for a certain part of the channel. It can be seen as a sort of SINR (Signal-to-Noise-and-Interference-Ratio) feedback [7].
- The *Precoding Matrix Indicator (PMI)* is a suggestion from the UE of what matrix to be used chosen from a finite set of predefined matrices, known as the *Codebook*.
- *HARQ Indicator* is sent from the UE, and will give an indication of BER. Hybrid Automatic Repeat Request (HARQ) is similar to ARQ, except it is improved for low SNR conditions. The disadvantage is larger overhead and lower throughput than conventional ARQ in high SNR conditions [8].
- Received Signal Strength Indicator (RSI)

2.2 LTE Downlink

The LTE downlink system is built up of seven different transmission modes, each mode representing a different MIMO technology. The mode to be used are chosen by the eNB, which considers several factors to choose the preferred transmission mode, e.g. SNR and channel rank. The modes span from regular Single Input - Single Output (SISO) transmission to 4x4 SM.

Table 2 shows the 7 different fundamental transmission modes for Physical Downlink Shared CHannel (PDSCH) transmission in LTE.

Trans. mode 1	Transmission from a single eNodeB antenna port (SISO)
Trans. mode 2	Transmit Diversity (SFBC) (2.2.2)
Trans. mode 3	Open-loop SM (2.2.3)
Trans. mode 4	Closed-loop SM (2.2.4)
Trans. mode 5	Multi-user MIMO
Trans. mode 6	Closed loop rank-1 precoding
Trans. mode 7	Transmission using UE-specific reference signals

Table 2: Transmission modes in LTE [8]

Figure 2.4 shows an overview of the PDSCH processing.

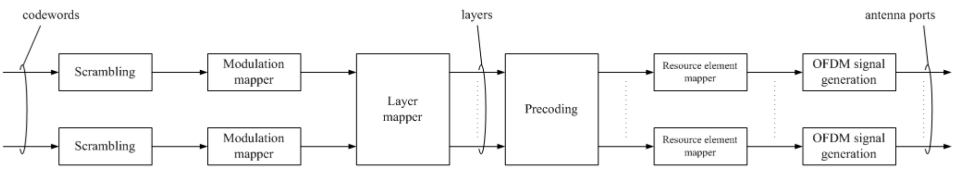


Figure 2.4: Overview of physical channel processing. [4]

2.2.1 Channel Precoding

Transmission mode 3 through 6 uses precoding from defined Precoding Matrix Codebooks. The codebooks consists of a number of different matrices (W) for mapping layers to antenna ports. There is one codebook corresponding to each antenna configuration, e.g. the number of antennas in use. Equation 2.3 is showing the matrices in the 2-antenna codebook.

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \text{ and } \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix} \text{ [8]} \tag{2.3}$$

2.2.2 Transmit Diversity

SFBC is the transmit diversity scheme chosen for LTE, and is generally an implementation of pure Alamouti-coding, but with Frequency diversity instead of time diversity, at least in a 2 transmit antenna setup. As seen in equation 2.4, the symbols on Antenna port 1 is straight forward, while on antenna port 2 the symbols are made orthogonal to the interfering stream on the other port. This keeps the SNR for each stream to a maximum, so that the layers can be received on a linear receiver [8].

Equation 2.4 shows 2-antenna layer to antenna-port and subcarrier mapping,

$$\begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} = \begin{bmatrix} y^{(1)}(1) & y^{(1)}(2) \\ y^{(2)}(1) & y^{(2)}(2) \end{bmatrix} \tag{2.4}$$

where $y^{(p)}(k)$ denotes the symbols transmitted from antenna port p on the k^{th} subcarrier.

For a 4-antenna setup, e.g 4x4, there exists no orthogonal codes so SFBC is combined with Frequency Switched Transmit Diversity (FSTD) like described in table 3, leaving the orthogonality intact, thus making the signal more robust against interference burst leaving a slight coding gain [8].

	Subcarrier 1	Subcarrier 2	Subcarrier 3	Subcarrier 4
Ant Port 1	x_1	x_2		
Ant Port 2			x_3	x_4
Ant Port 3	$-x_2^*$	x_1^*		
Ant Port 4			$-x_4^*$	x_3^*

Table 3: SFBC in combination with FSTD [8]

2.2.3 Open Loop Spatial Multiplexing

In open-loop SM, the only feedback from the UE is RI. If the transmission rank is larger than one, LTE will utilize Cyclic Delay Diversity (CDD) [8] as a diversity technique. CDD introduces delay between multi-antenna signals to reduce signal cancellation that occurs if the same signal is transmitted from multiple antennas and the channel is relatively flat [7]. This technique transmits all layers to all antennas introducing frequency dependent phase shift (see table 4) between the antenna ports. Since the phase shift is proportional to the subcarrier frequency, the different subcarriers will experience a different beamforming pattern when the components are added, leaving the peaks and nulls of each subcarrier to differ, as seen in figure 2.5. The diversity is achieved from the fact that the different subcarriers will propagate in different directions increasing frequency selectivity. Frequency selective fading will therefore only influence the individual subcarrier rather than the whole resource block. This can particularly be beneficial if the channel information at the transmitter is unreliable, for example due to the feedback being limited or the UE velocity being high [8].

Antennas #	Phase Shift	Delay
2	180°	$T_{symbol}/2$
3	120°	$T_{symbol}/3$
4	90°	$T_{symbol}/4$

Table 4: Cyclic Delay Shifts for eNB. [7]

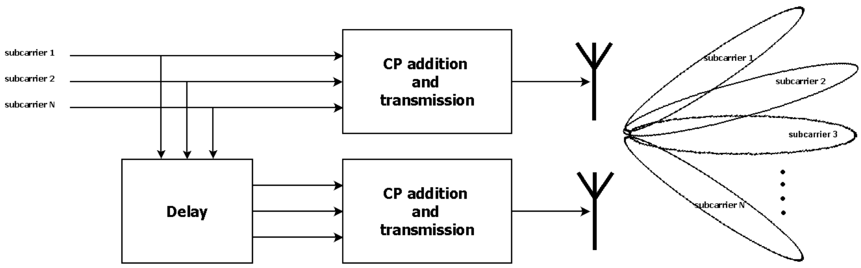


Figure 2.5: Principle of Cyclic Delay Diversity [8]

An example of a received symbol in a situation with two transmit antennas is shown in equation 2.5.

$$r = h_1 x + h_2 e^{-1} x \tag{2.5}$$

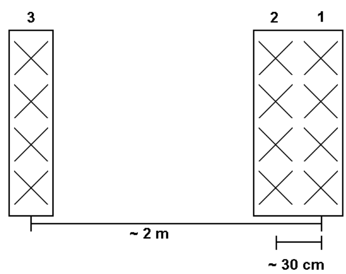
where $e^{j\phi}$ is the phase shift and h_i is the symbol transmitted at antenna i.

2.2.4 Closed-Loop Spatial Multiplexing

Closed loop operation is a high performance Spatial Multiplexing system utilizing all of the four different UE feedback indicators; RSSI, PMI, RI and HARQ Indicator, in addition to RI. The UE itself will estimate the four parameters, and send them to the eNB as a "suggestion", and then it is up to the (eNB) to choose Precoding Matrix and modulation scheme. This transmission mode utilize high feedback rate to optimize channel scheduling and MIMO configuration.

3 Data Acquisition

The MIMO testing was performed at Fornebu and as much as possible inside the 30 degree sector of the BS antenna mounted at the roof of the Telenor building, facing approximately straight north, 10 degrees to the east. The sector can be seen in figures 3.5 and 3.7. Figure 3.1a shows the antenna setup on the roof of the antenna . For X-polarized configuration only antenna 1 is used for co-localization, and antenna 1 and 3 for large distance (≈2 m). For the co-polarized configuration antenna 1 and 2 are used for short inter-antenna distance (≈30cm) and 1 and 3 for large distance (≈2 m).



(a) Antenna Configuration

(b) Antennas mounted on the roof of the Telenor Center

Figure 3.1: eNB antennas

(a) LTE Antennas

(b) GPS Antenna

Figure 3.2: Vehicle antennas

Figure 3.1b is a picture of the eNB antennas mounted on the roof of the Telenor Center. The right one is the double antenna with four antenna arrays while the left one is the single antenna with two antenna arrays. Figure 3.2 shows the vehicle mounted antennas. Figure 3.2a viewing the two LTE -antennas, mounted roughly one meter apart. It was important that the antennas was placed at the exact same place throughout all testing to avoid contamination of the results. The picture was used as a reference for antenna placement during testing. Figure 3.2b shows the GPS-antenna used for geo-spatial tracking. Figure 3.3 views the LTE test terminal provided, and the Probe Station, a laptop with a software tool providing test data. (The mounted screen in the picture is not in use.) In figure 3.4 you can see the topography of the sending direction, with Polhøgda on the right behind the building. The building is obviously obstructing Line of Sight (LOS) for a large part of the cell. The probe station will generate a CSV (Comma Separated Values)-file mediating data for 1000 TTIs at a time, i.e. one second.

(a) The LTE Terminal

(b) Probe Station

Figure 3.3: LTE Test Equipment

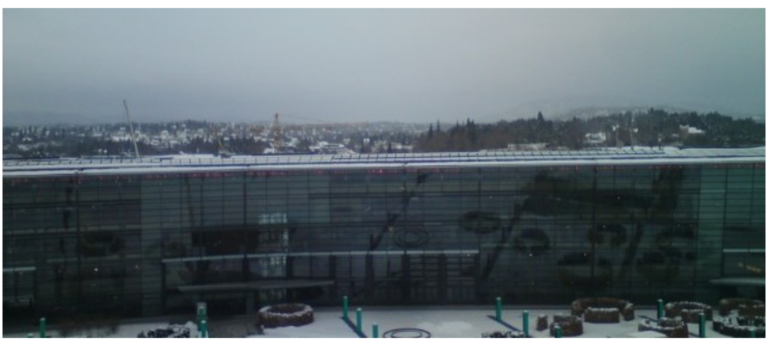


Figure 3.4: The Antenna sending Direction

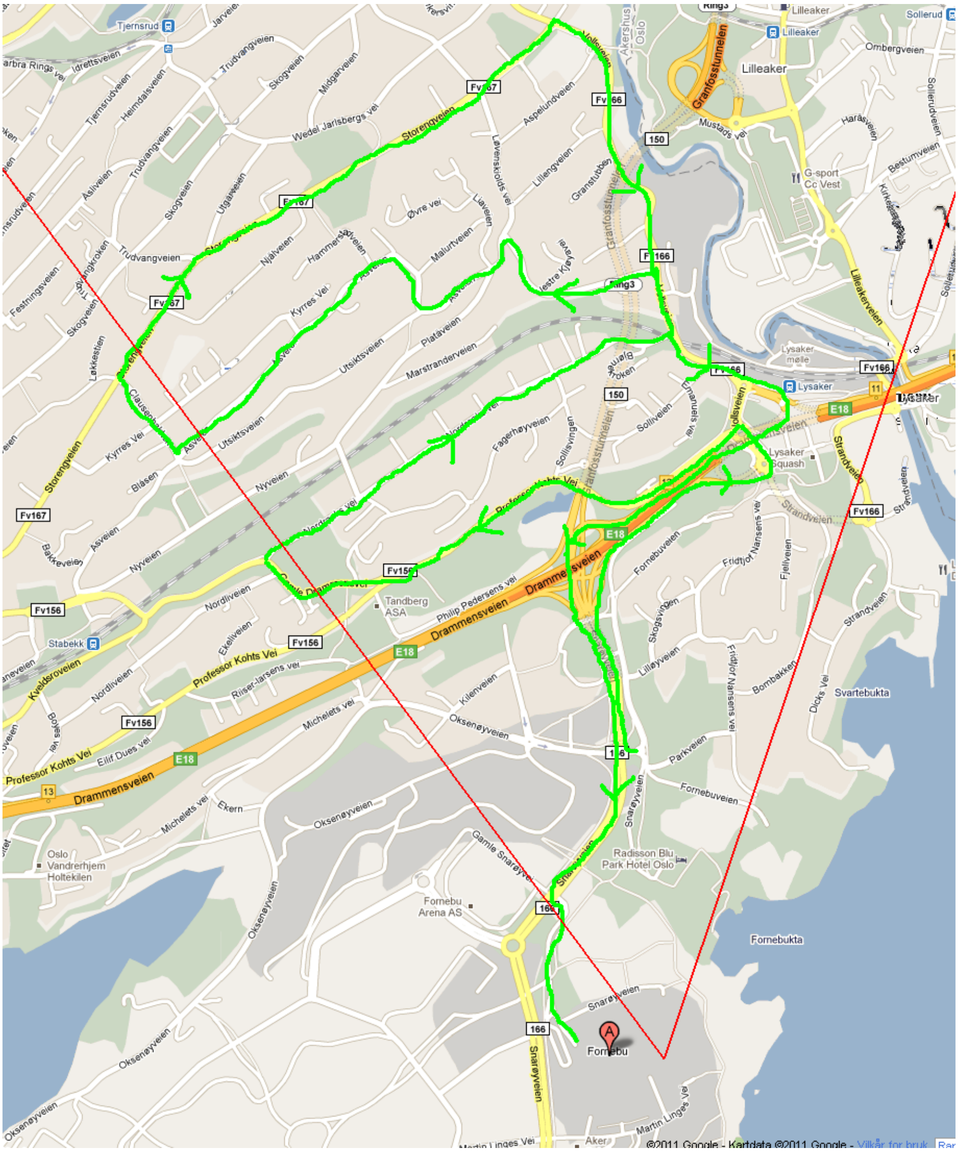
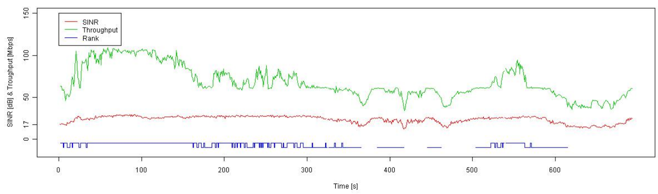


Figure 3.5: Preliminary test routes

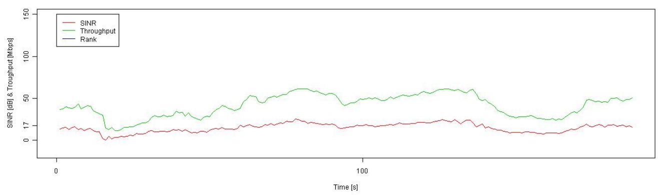
3.1 Preliminary Testing

The preliminary testing was done with regard to the geography in the cell sector. Both antennas were set to -45° in antenna 1 and 2 (See figure 3.1a), giving an antenna separation of approximately 2 wavelengths at 2,6 GHz. The testing was done in Transmission Mode 3, Open Loop SM, with automatic switching to Transmission Mode 2 (SFBC) when Channel Rank 1.

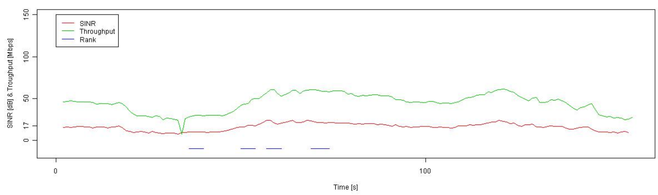
Figure 3.5 shows the routes driven and the cell sector, figure 3.6 shows Signal-to-Interference-plus-Noise-Ratio (SINR), rank and throughput for the whole route divided into six standalone measurements. Route 1 (3.6a) is performed inside Oksenøya, south of E18, while Route 2 through 6 (3.6b - 3.6f) is performed outside of Oksenøya, north of E18. The Cell-edge is anticipated to be around E18, and the data showing close to no MIMO performance north of E18.



(a) Route 1



(b) Route 2

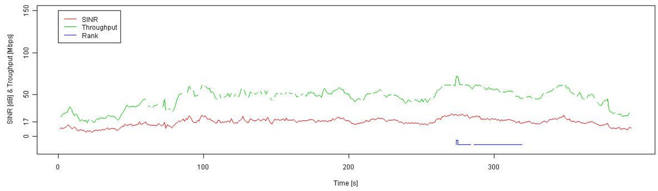


(c) Route 3

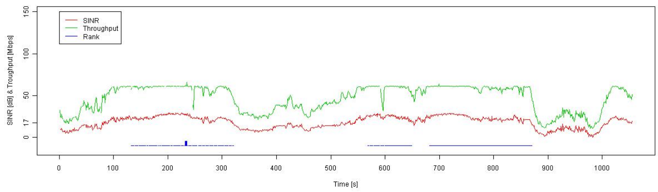
Figure 3.6: SINR vs DL vs Rank

3.2 MIMO testing

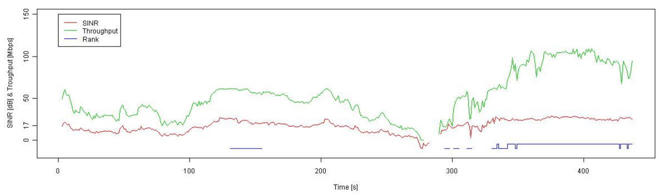
A route was derived from the initial testings, starting at the Telenor building driving north, and through small roads over Polhøgda and ending behind the Teleplan building. This can be seen in in figure 3.7. The speed was kept, as



(d) Route 4



(e) Route 5



(f) Route 6

Figure 3.6: SINR vs DL vs Rank

far as possibly, below 40 kmph, trying to remove the speed as a contributing factor to the test-results. Each configuration was tested twice, once driving the route one way, and once driving the same route back towards the Telenor building. The difference is believed to be minimal.

Table 5 shows the different file-names and a short explanation of the notation. The configuration factors varied are Transmission mode, Antenna Polarization, Inter-Antenna Distance and the direction of the Route.

The Transmission Modes are either Closed Loop Spatial Multiplexing (Transmission Mode 4) combined with Closed Loop Rank1 Precoding (Transmission Mode 6) and Open Loop Spatial Multiplexing (Transmission Mode 3) combined with SFBC (Transmission Mode 2). This is implementation restricted by the hardware manufacturer. All tests are performed with 2x2 glsmimo configuration. To narrow down number of figures, the data from

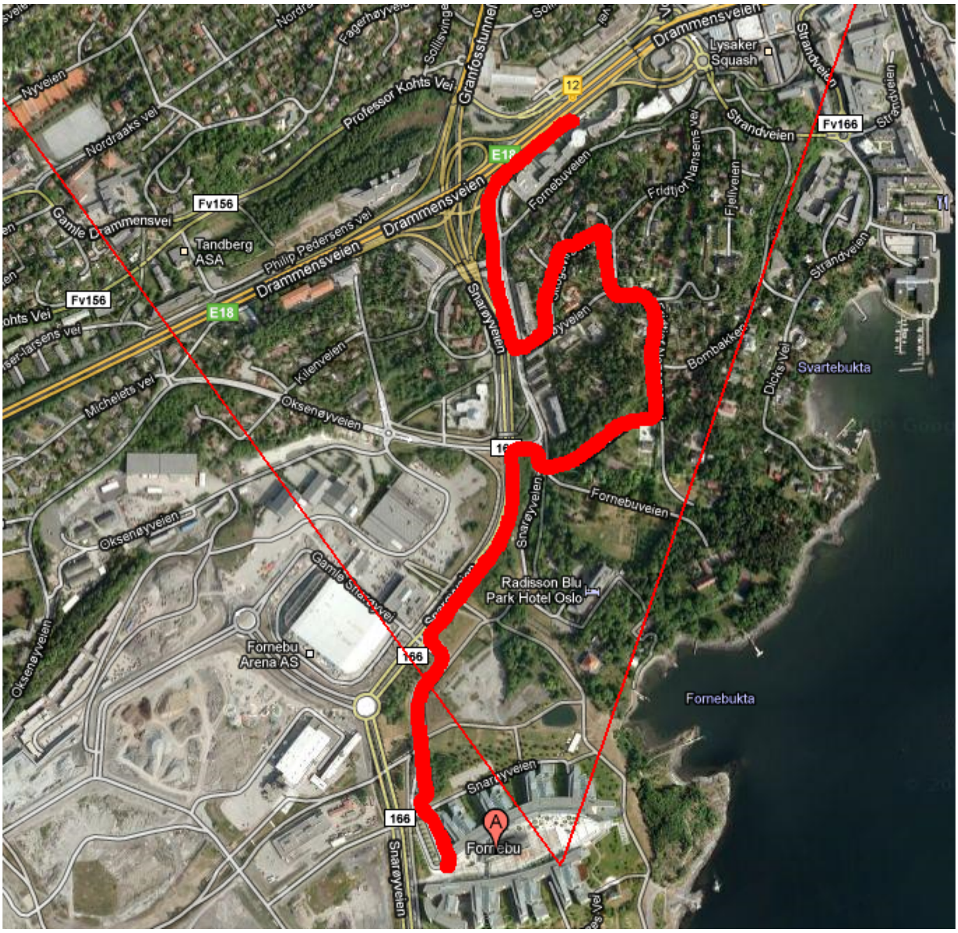


Figure 3.7: Test route

both directions has been put together.

3.3 Data Processing

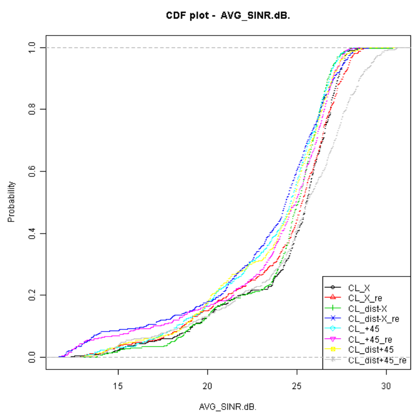
There are several issues connected to implementing MIMO while building an LTE system. The most important is cost/performance perspective, where increase in the inter antenna distance increase site-costs. The performance gain of the setup needs to be large enough to justify the increased implementation costs.

Telenor plans to utilize 4x4-MIMO systems when user equipment (and Base station equipment) will support it.

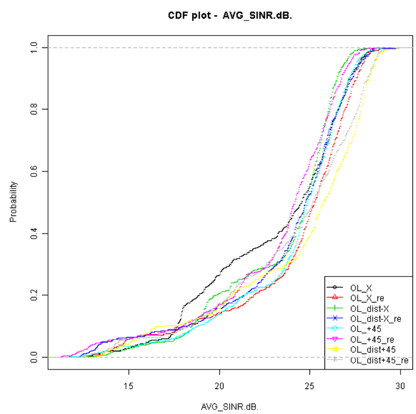
All data processing is performed with R-project statistics tool. "R is a

Filename	TM	Ant. Polarization	Ant. distance	Route
CL_45	Closed Loop	Both +45°	30 cm	North
CL_45_re	Closed Loop	Both +45°	30 cm	South
CL_dist45	Closed Loop	Both +45°	2 m	North
CL_dist45_re	Closed Loop	Both +45°	2 m	South
CL_X	Closed Loop	X-polarized	0	North
CL_X_re	Closed Loop	X-polarized	0	South
CL_distX	Closed Loop	X-polarized	2 m	North
CL_distX_re	Closed Loop	X-polarized	2 m	South
OL_45	Open Loop	Both +45°	30 cm	North
OL_45_re	Open Loop	Both +45°	30 cm	South
OL_dist45	Open Loop	Both +45°	2 m	North
OL_dist45_re	Open Loop	Both +45°	2 m	South
OL_X	Open Loop	X-polarized	0	North
OL_X_re	Open Loop	X-polarized	0	South
OL_distX	Open Loop	X-polarized	2 m	North
OL_distX_re	Open Loop	X-polarized	2 m	South

Table 5: CSV filenames syntax



(a) SINR Closed Loop



(b) SINR Open Loop

Figure 3.8: CDF of SINR [dB]

free software environment for statistical computing and graphics." [6]. Binning data is based on median values to remove faults caused by logarithmic values. Because of the large number of data, much of the graphs has been generated by scripts. The scripts is found in appendix C.

The values compared is the inter-antenna distance (table 6), the Transmission Mode (table 7) and the polarization (table 8). The interest is of course the antenna configuration.

1	2	3	4
CL_X	CL_dist-X	CL_+45	CL_dist+45
OL_X	CL_dist-X	OL_+45	OL_dist+45

Table 6: Inter-antenna Distance Compared Data

1	2	3	4
CL_X	OL_X	CL_+45	OL_+45
CL_dist-X	OL_dist-X	CL_dist+45	OL_dist+45

Table 7: Transmission Mode Data

1	2	3	4
CL_X	OL_X	CL_dist-X	OL_dist-X
CL_+45	OL_+45	CL_dist+45	OL_dist+45

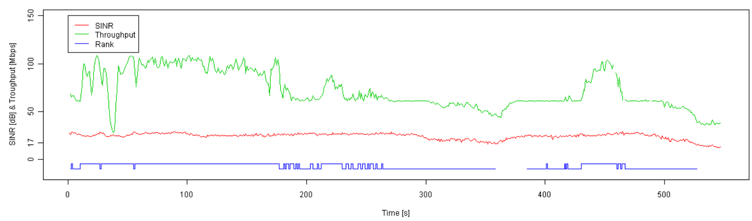
Table 8: Polarization Data

4 Results

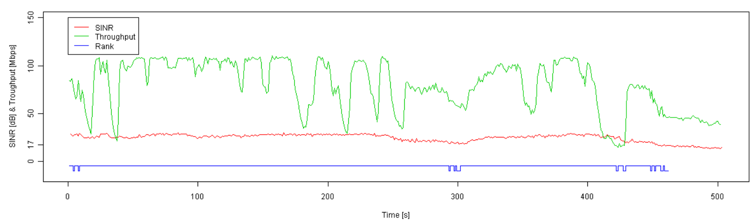
4.1 Cases Studied

This study focuses primarily on the antenna configurations on the eNB, and for simplicity four different configurations has been evaluated, cross-polarized antennas, Cross polarized antennas separated by approximately 2 meters, Co-polarized antennas both tilted +45 degrees and separated by approximately 30 centimeters and Co-polarized antennas tilted +45 degrees separated by approximately 2 meters.

Figure 4.1 is a real time comparison of SINR, Throughput and rank over time in seconds. The figure gives an indication that at approximately 16 to 17 dB, SM is applied, regardless of the rank. This is to some extent confirmed by figure 4.2. Corresponding plots for all antenna configurations can be found in Appendix B.



(a) Open Loop Co-Polarized Co-Located



(b) Open Loop Co-Polarized distance Separated

Figure 4.1: RANK vs. SINR vs. Throughput over Time, Case 1

Figure 4.2 shows a plot of for which SINR values Spatial Multiplexing is applied. This gives a clear indication of what is foreseen, that for SINR values lower than 16 - 17 dB SM is not applied. The reason for this is not known, but it has probably to do with the manufacturer finding SM to be difficult below this threshold. You can also see that for co-located antennas setup, SM is applied at much higher SINR values, giving an indication towards the co-located setup has poorer MIMO performance than the other setups. Especially co-located co-polarized antennas shows a much higher threshold for activating SM.

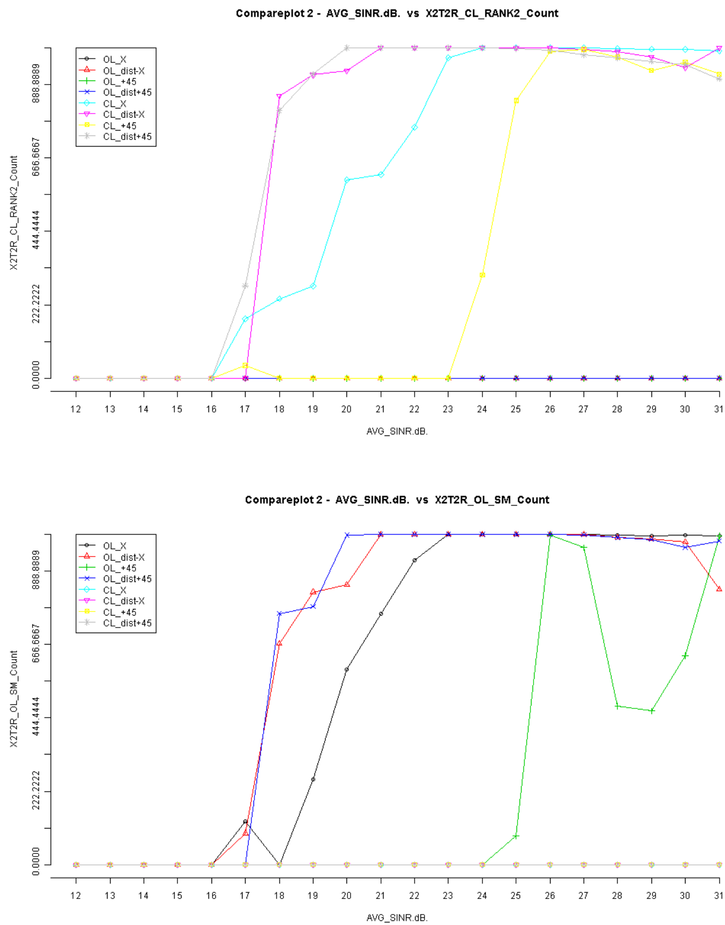


Figure 4.2: SINR [dB] vs. Spatial Multiplexing

Figure 4.3 shows the Throughput vs. SINR for all Transmission modes and antenna configurations, and is giving an indication that antenna separation will give some performance advantages compared to co-located antennas. Be advised that the 17 dB threshold for Spatial Multiplexing should give ignorable results below this value, although there is an consistency with most data above 15 dB. Thus lower values will not be taken into account. Above the threshold it is consistent that cross polarization combined with antenna distance has better performance, and that co-polarization co-located is performing worse, in accordance with the theory. Still the data fluctuates till some extent, but is considered a measurement related problem.

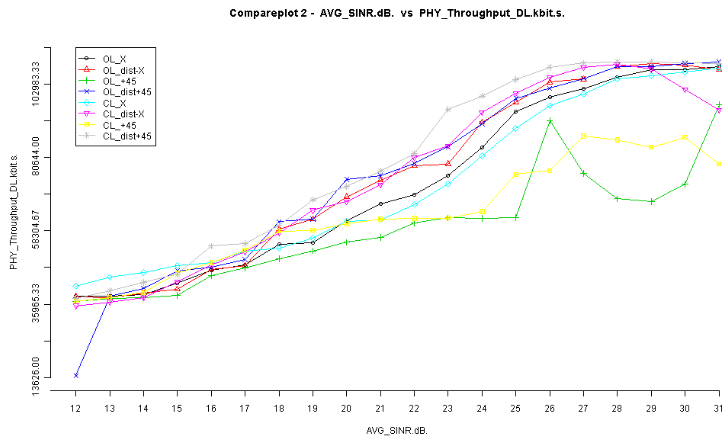
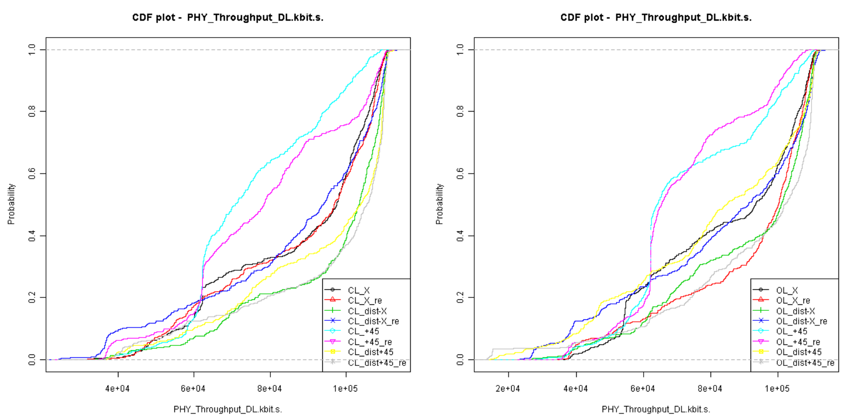


Figure 4.3: Throughput [kbps] vs. SINR [dB]

In accordance with what seen so far, figure 4.4 reveals that for 50% of the time, the colocated antennas setup gives approximately 70 Mbps in throughput, while other configurations performes between 90 to 110 Mbps.

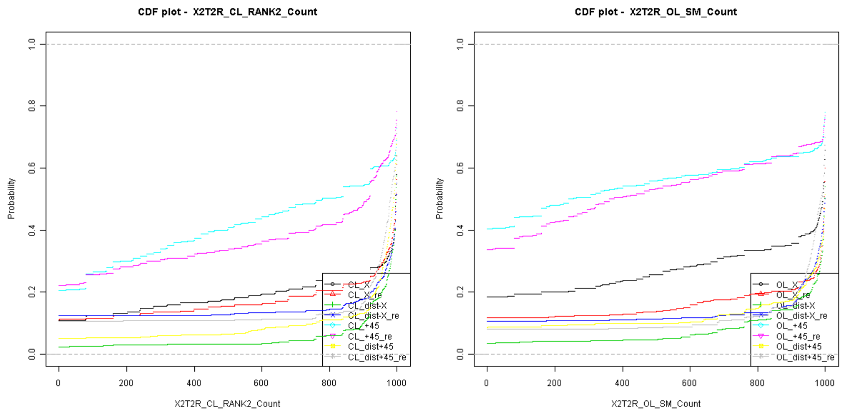


(a) Closed Loop

(b) Open Loop

Figure 4.4: CDF of Throughput

Trying to tie the above results to MIMO performance, figure 4.5 shows a plot of the cumulative distribution function for Closed Loop Rank 2 and Open Loop Spatial Multiplexing. What is clear is that Spatial Multiplexing is applied for much shorter time for co-located co-polar antennas, and some more time for Cross-polar co-located antennas. For both transmission modes distance separated cross-polar antennas will utilize SM more frequently. If this is related to channel rank or other parameters will be discussed later, but there is reason believe that higher average throughput is linked to MIMO performance.



(a) Closed Loop (b) Open Loop

Figure 4.5: CDF of Spatial Multiplexing

4.2 Transmission Mode Comparison

To be able to evaluate the impact of the antenna configuration, the impact of the chosen Transmission mode needs to be looked into. Also if the transmission mode is capable of suppressing negative influence from antenna configuration, it is possible that what is found to be bad antenna configurations may be of value. This chapter will see, for all of the antenna setups, if there is a significant difference in performance in favor of one transmission mode. In Appendix B you will find figures of SINR of all the comparisons, showing that the SINR is not of any significance.

The section will be divided into four cases illustrated in table 9

	Polarization	Ant. Distance
Case 1	Cross Polarized	Small
Case 2	Cross Polarized	Large
Case 3	Co-polarized	Small
Case 4	Co-polarized	Large

Table 9: TM Cases

4.2.1 Case 1: Cross-polarized Co-located Antennas

This Cross-polar configuration is obviously a better option than a co-polar configuration, and will probably be the preferred solution in a 2x2 MIMO system.

Figure 4.6 is a comparison of throughput through the route, binned geographically 20 x 20 meters, and reveals no evidence that Closed Loop is performing better than Open Loop for this specific antenna setup. This setup is expected to perform poor, but is not a worst case scenario.

Looking at figure 4.7, there seems to be no evidence of rank being better for any of the configurations, in accordance with the throughput being so similar for the two cases.

Figure 4.8 and 4.9 shows the throughput comparison of the two transmission modes for respectively SINR and distance to the base station. There is an obvious difference at low SINR levels and also close to the eNB. This is a contradiction, expecting high SINR levels closer to the transmitter, but since there may be differences between the two routes, there will not be drawn any conclusions from this. The tendency, considering a margin of error in the measurements, is that there is no difference between the Closed loop and Open loop transmission modes for this specific antenna configuration.

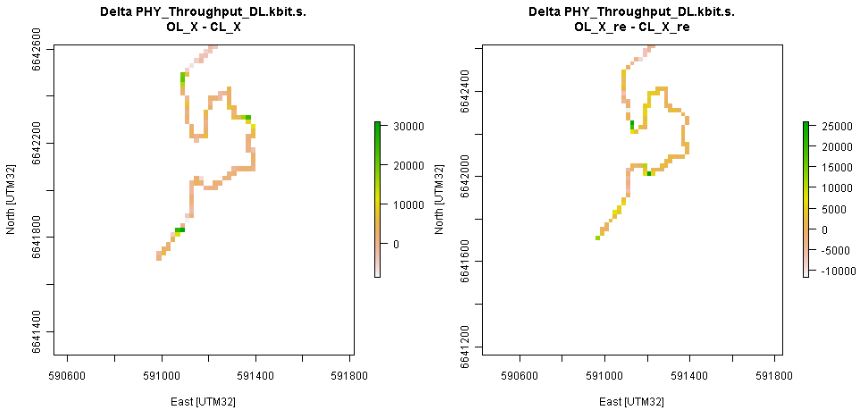


Figure 4.6: Case 1: Throughput

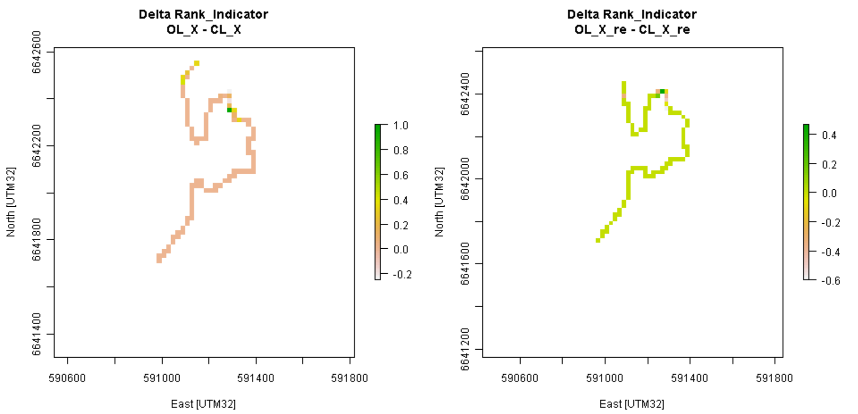


Figure 4.7: Case 1: Rank Indicator

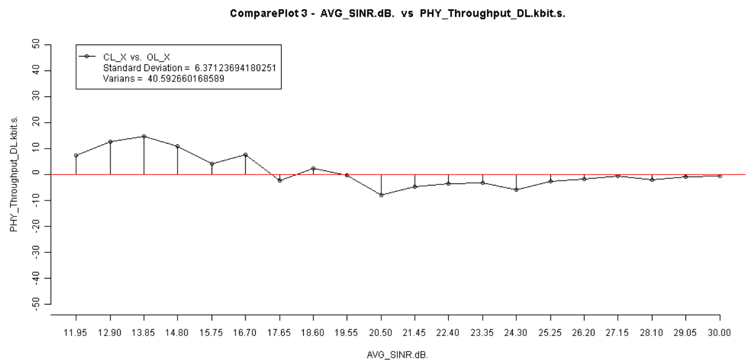


Figure 4.8: Case 1: SINR vs Throughput

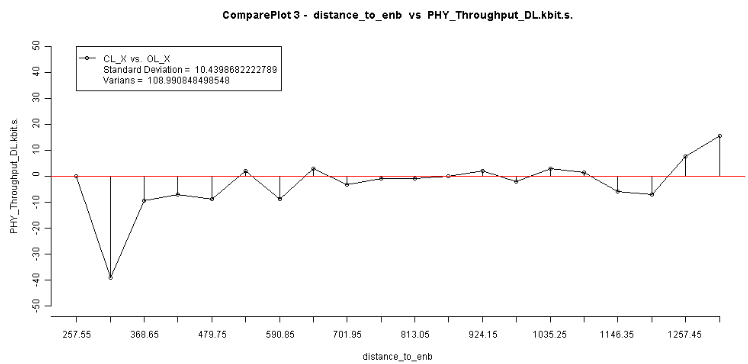


Figure 4.9: Case 1: Distance to eNB vs. Throughput

4.2.2 Case 2: Cross-polarized Distance Separated Antennas

To try to find out if Closed Loop has any advantages or disadvantages compared to Open Loop in a more ideal MIMO antenna setup, as in Case 1, figure 4.10 compares Throughput over the route, and finds that there may be a slight gain in favor of Closed Loop, even though it is not very stable, and large gain may only be found in certain areas. This areas has been found as problematic geographical areas where SINR levels are lower than other part of the route.

Figure 4.11 shows the rank indicator around the route, but reveals no tendency that may explain the lower throughput for Open loop found in figure 4.10. It seems that there are spots where Closed Loop seems to maintain rank 1 when Open loop does not, found around the problem areas mentioned earlier. This is not very frequent, and will not be considered a major gain

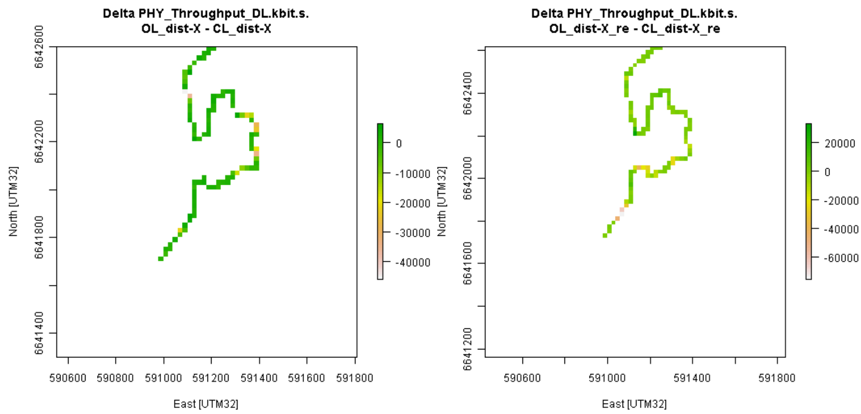


Figure 4.10: Case 2: Throughput

in a bigger picture.

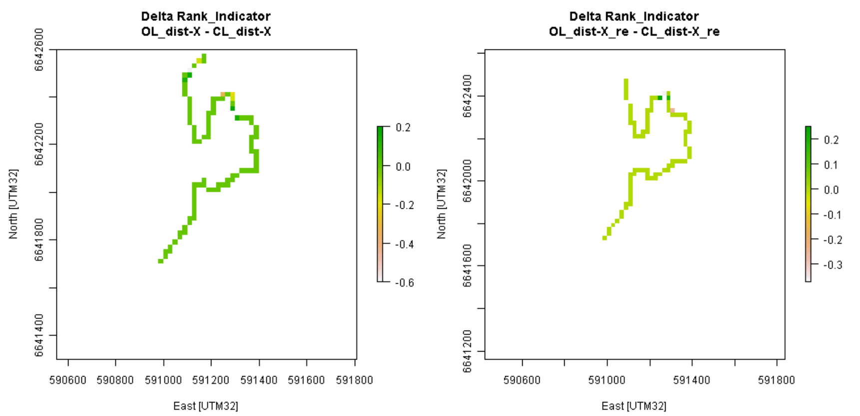


Figure 4.11: Case 2: Rank Indicator

4.2.3 Case 3: Co-polarized Co-located Antennas

It is more interesting to see if the Transmission mode can make any difference in what appears to be the weakest antenna setup, where both antennas are set to +45 degrees and co-located with approximately two wavelengths. What is known is that the antenna setup is performing worse than the other, in overall throughput and in Spatial Multiplexing access. What is seen in

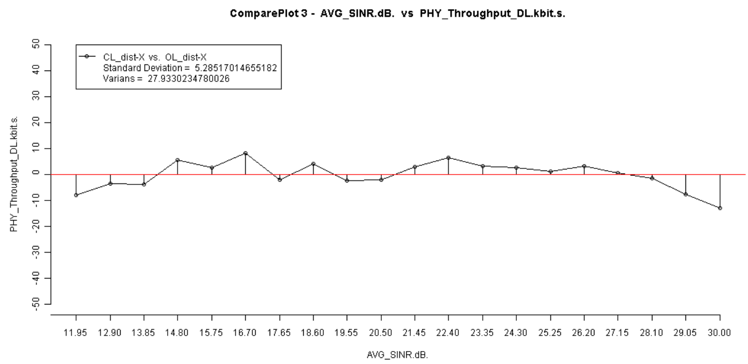


Figure 4.12: Case 2: SINR vs Throughput

figure 4.13 is that the throughput i fluctuating quite much, but if any Closed loop show a slight better performance.

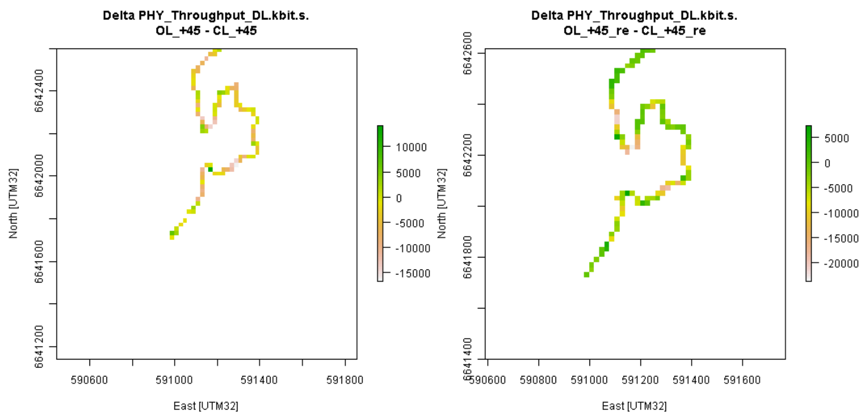


Figure 4.13: Case 3: Throughput

Figure 4.14 confirms that the channel is not good, seeing that the rank of both channels fluctuates, and not at the same time.

Figure 4.15 shows a clear tendency that Closed Loop is better for all SINR levels. Since we already know that this antenna configuration is performing worse, and that it is fluctuating, it is tempting to conclude than there may be some gain in utilizing Closed Loop.

Figure 4.16 will also confirm this suspicion, disregarding where it appears that Open Loop is performing better closer to transmitter, but this may have to do with a slight variation in the route close to the Telenor Center.

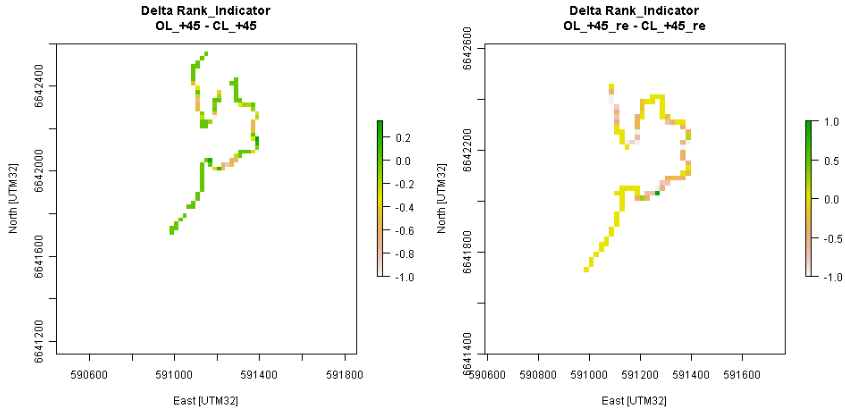


Figure 4.14: Case 3: Rank Indicator

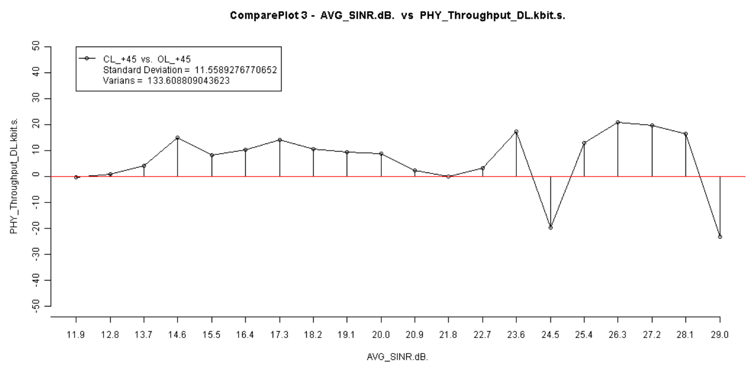


Figure 4.15: Case 3: SINR vs Throughput

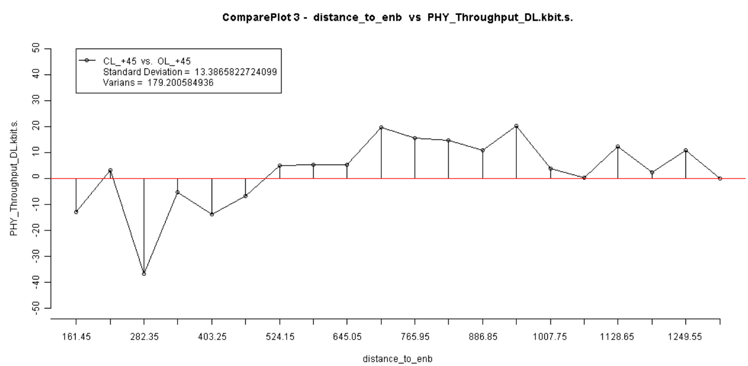


Figure 4.16: Case 3: distance to eNB vs Throughput

4.2.4 Case 4: Co-polarized Distance Separated Antennas

The last combination is where both antennas are +45 degrees polarized, but now placed two meters apart. This is a configuration of high interest since at 4x4 MIMO one is bound to have two pairs of co-located antennas. In figure 4.17 there seems to be pretty much the same as in case 3, Closed Loop is performing better at some places and sometimes up to 80 Mbps better. It is definite that closed loop is better, but the degree is not easy to establish since there is for most part of the route not much difference. In figure 4.18, there is no evidence of any difference in channel rank giving closed loop gain.

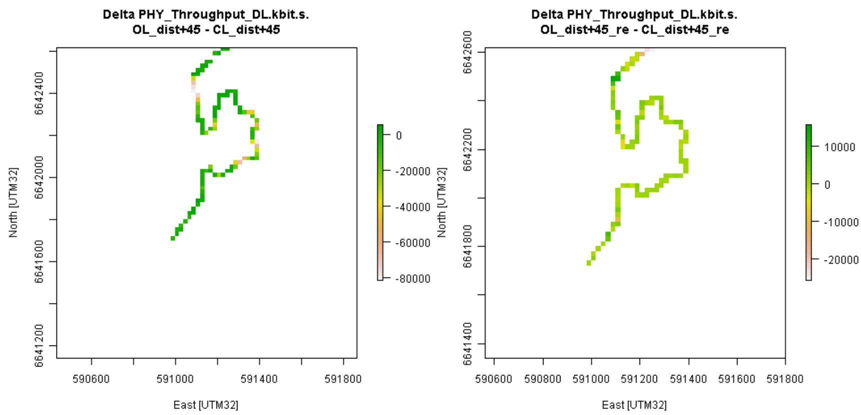


Figure 4.17: Case 4: Throughput

Figure 4.19 reveals what was found earlier, that closed loop has the tendency to perform better, but is not a large gain. In despite, figure 4.20 shows that there is almost no gain at all throughout the route, except very close to the eNB and is probably due to the measurement error described earlier.

4.2.5 Closed Loop vs. Open Loop

There is a tendency that closed loop will perform better than open loop, and especially where the channel conditions are worse, e.g. because of NLOS conditions or bad antenna configurations. On the other hand it is not definite, thus hard to conclude other than a slight performance gain in benefit of closed loop.

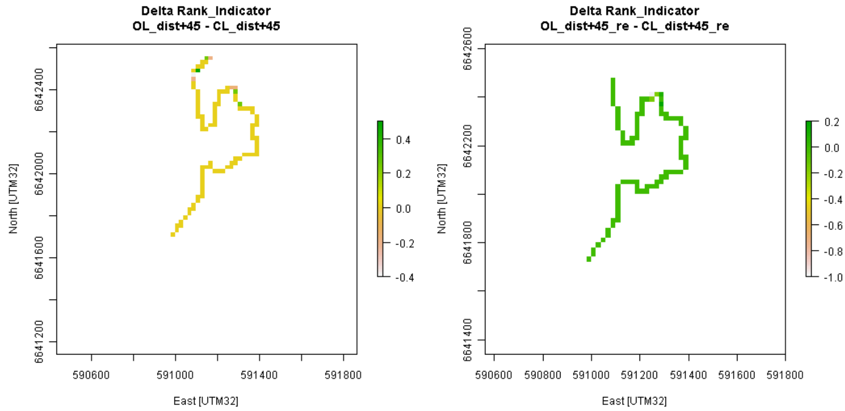


Figure 4.18: Case 4: Rank Indicator

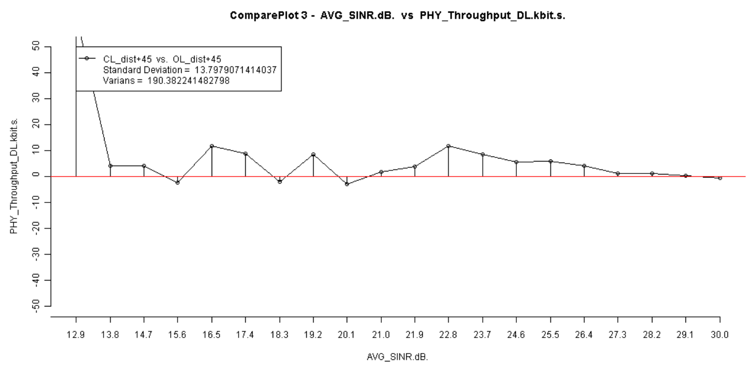


Figure 4.19: Case 4: SINR vs Throughput

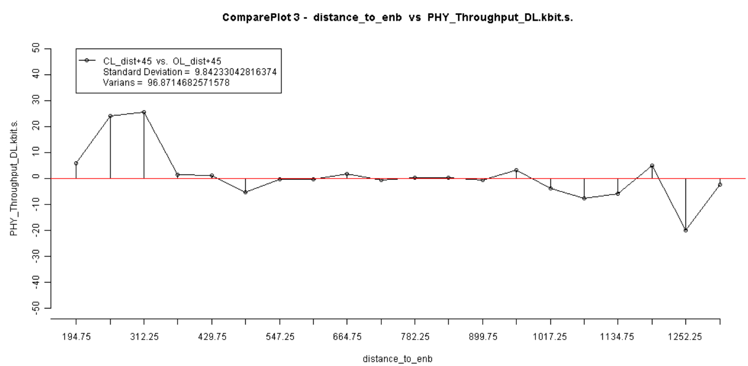


Figure 4.20: Case 4: Distance to eNB vs Throughput

4.3 Comparing Cases

Now, it is needed to compare the four cases. To eliminate drawing conclusions based on several parameters, only one parameter will be changed in each comparison. This leads to table 10. In this table only rows and columns will be compared, not diagonals.

	Co-located	Distance separated
Cross-Polar	Case 1	Case 2
Co-Polar	Case 3	Case 4

Table 10: Compared Cases

4.3.1 Polarization Comparison, Case 1 vs. Case 3

To see if there is a great difference between antenna polarity for MIMO performance, this section will try to see if there is any significant differences. Figure 4.21 shows the throughput for both open loop and closed loop is very close to each other, so that only open loop will be compared in this section.

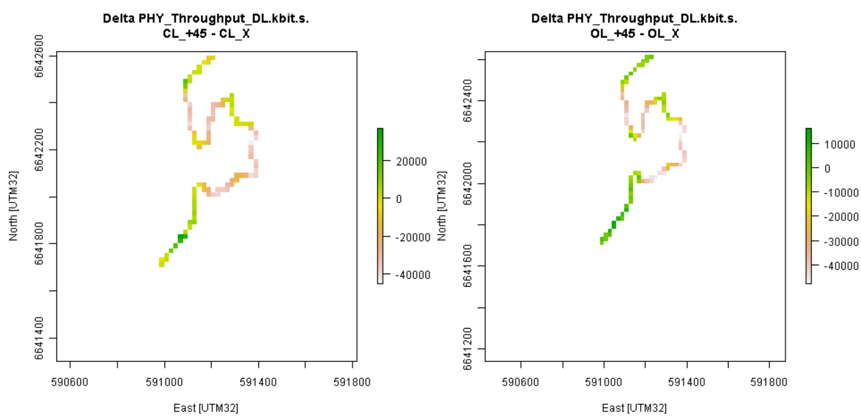


Figure 4.21: Case 1 vs 3: Throughput

Figure 4.22 also reveals that there are small differences between the two antenna configurations.

The two last figures 4.23 and 4.24 reveals no specific favor to any of the two, maybe a little towards distance separation if any.

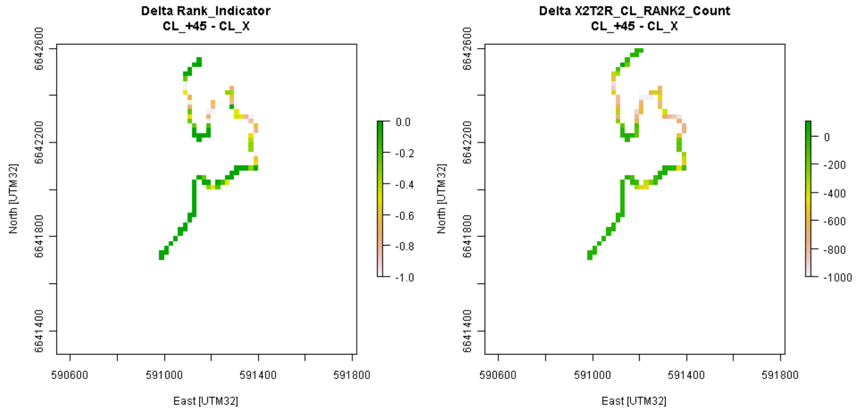


Figure 4.22: Case 1 vs 3: Rank Indicator and Spatial Multiplexing Count

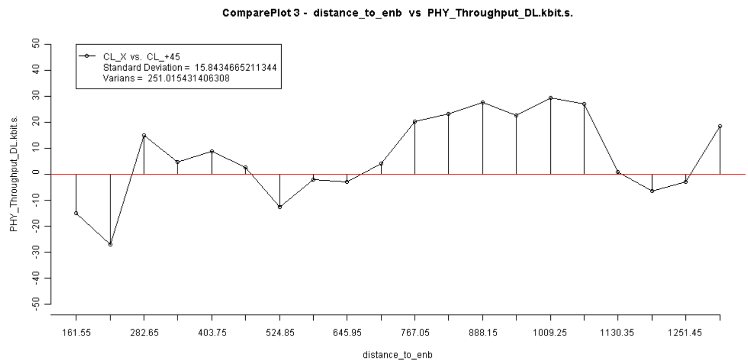


Figure 4.23: Case 1 vs 3: Throughput vs Distance to eNB, Closed Loop

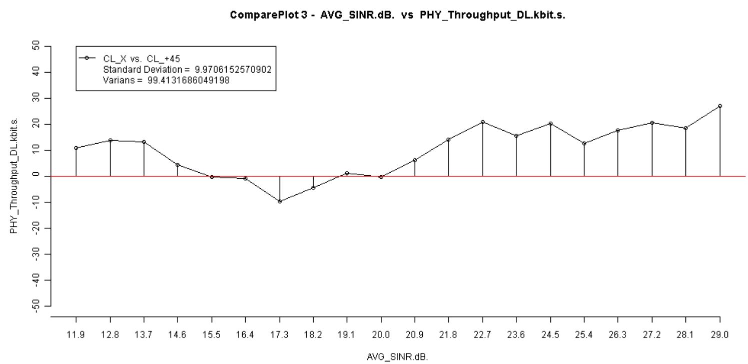


Figure 4.24: Case 1 vs 3: SINR vs Throughput, Closed Loop

4.3.2 Polarization Comparison, Case 2 vs. Case 4

To see if there is a great difference between antenna polarity for MIMO performance, this section will again try to see if there is any significant differences. Figure 4.25 shows the throughput for both open loop and closed loop is very close to each other, so that only open loop will be compared in this section.

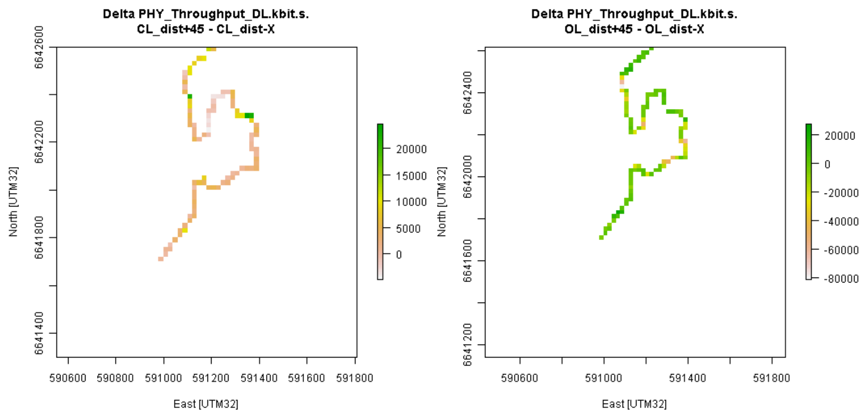


Figure 4.25: Case 1 vs 3: Throughput

Figure 4.26 like above can tell that there are no differences between the two antenna configurations in utilization of Spatial Multiplexing and the channel rank is the same for both.

The two last figures 4.27 and 4.28 is consistently in favor of co-polarization, which is not expected. Since the difference is so small, and it is actually the co-polarized antennas that has the slight gain, it is a fairly good reason to believe that the polarization, when antennas are distance separated by 2 meters, is of no influence.

4.4 Distance variance Comparison, Case 1 vs. Case 2

This will in effect be comparison of co-located and distance separated antenna configurations for cross polarized antennas. The prospect of this comparison is to find if there is any gain in moving the antennas away from each other, and if this gain is large enough to be of any value. Since closed loop has slightly better performance, only closed loop will be discussed in this comparison. Figures for open loop can be found in appendix B.

Figure 4.29 shows that there is not much difference between the two

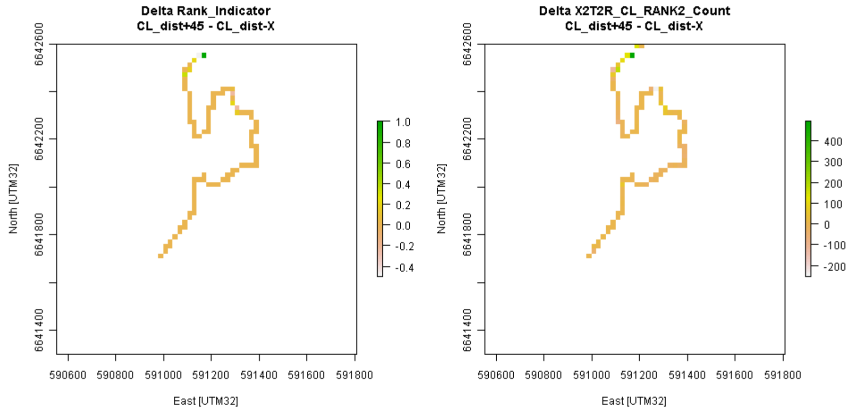


Figure 4.26: Case 1 vs 3: Rank Indicator and Spatial Multiplexing Count

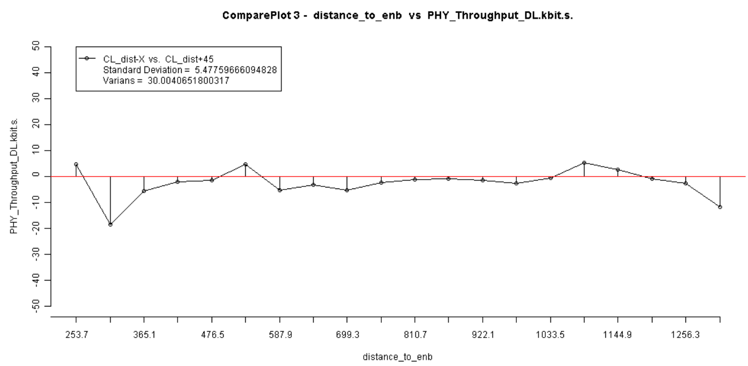


Figure 4.27: Case 1 vs 3: Throughput vs Distance to eNB, Closed Loop

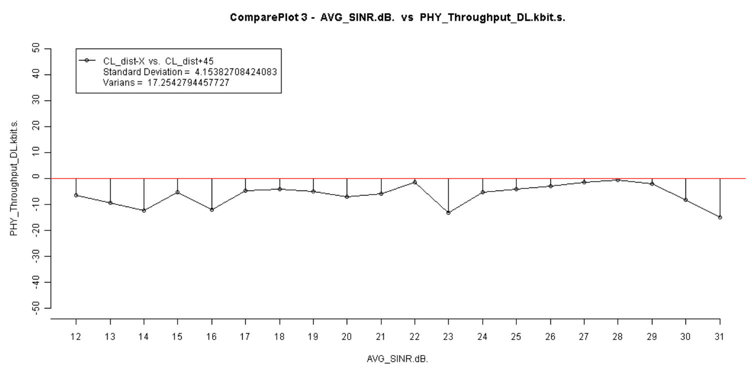


Figure 4.28: Case 1 vs 3: SINR vs Throughput, Closed Loop

antennas configurations. Only in the problem areas found earlier, there is a gain in using distance separation for cross polarized antennas.

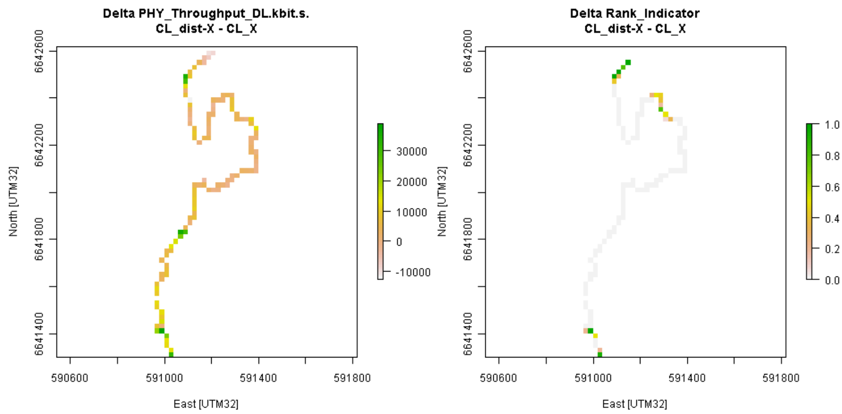


Figure 4.29: Case 1 vs 2: Throughput and Rank Indicator

In figure 4.30 it is evident that there is a slight throughput gain using distance separation, but in figure 4.31 it seems this occurs very close or very distant from the transmitter.

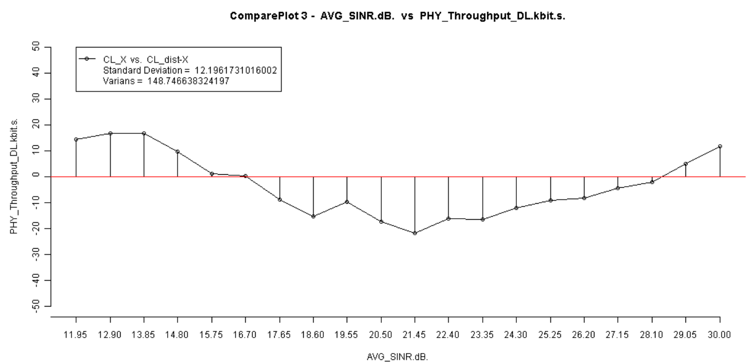


Figure 4.30: Case 1 vs 2: Throughput vs. SINR

4.4.1 Distance Variance Comparison: Case 3 vs. Case 4

This section will try to compare if it is possible to place four cross polarized antennas close to each other. This has not been possible to test due to the

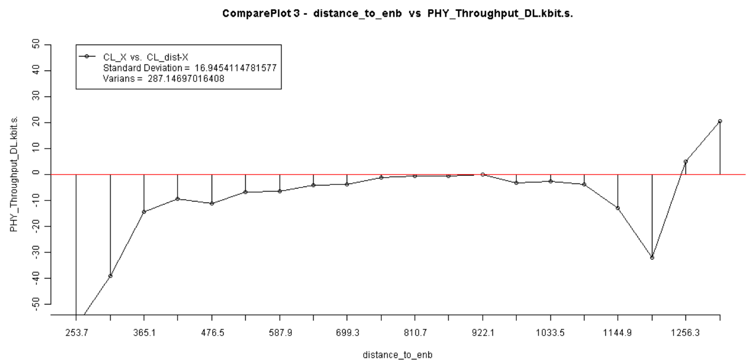


Figure 4.31: Case 3 vs 4: Thsoughput vs distance to eNB

fact that LTE is not yet supporting 4x4 MIMO, so therefore this approximation to the issue. To see if two co-polarized antennas will give good MIMO performance when placed close together will be of high interest to the LTE network constructor. Even though it is not obvious in figure 4.32, the distance separated configuration is performing at a steady 10Mbps better data rate than the co-located antenna configuration, and in the problem areas mentioned earlier, distance separation is peaking at plus 40 Mbps. Looking at the rank, in a sommewhat restrained SINR environment, the channel rank is quickly falling to 1, and explaining the poor data rate.

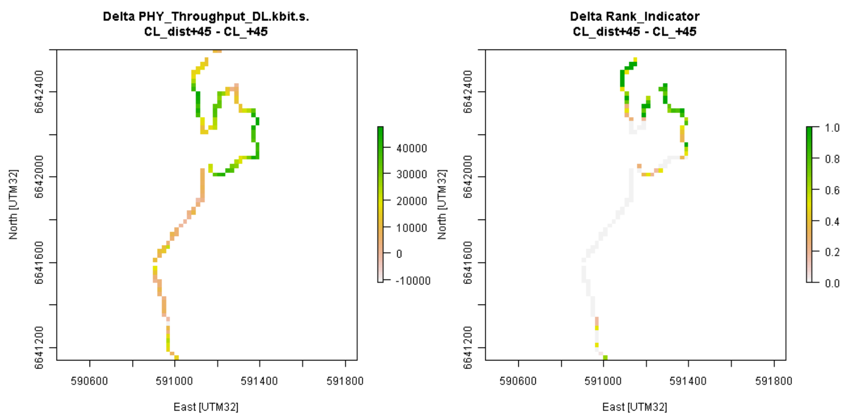


Figure 4.32: Case 2 vs 4: Throughput and Rank

Figure 4.33 shows that for around 20 dB and upwards, the distance separated configuration is performing much better than the co-located.

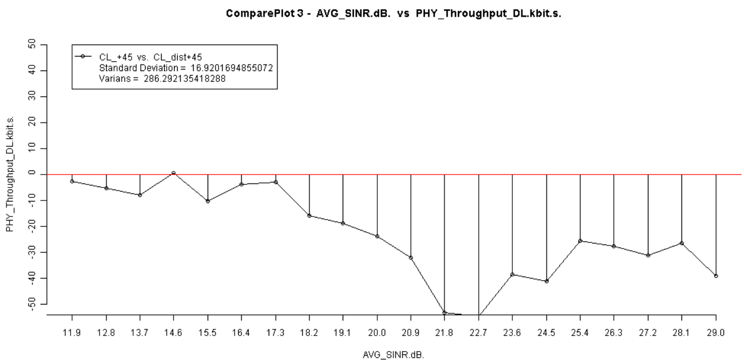


Figure 4.33: Case 2 vs 4: Throughput vs. SINR

5 Conclusions

What we set out to find in this thesis is the right antenna configuration MIMO in LTE. The reason for this is not only a question of MIMO efficiency, but also a question of how much gain it actually produces in a close to real test scenario. What needs to be taken into account is that this test did not suffer from any neighbor-cell interference or co-interference. Also the test as performed with only one terminal and one eNB, so that there was no handover-delay, and the whole bandwidth was preserved for the terminal.

What has been found in this thesis is not concluding, but what is clear is that for 2x2 MIMO there is no performance issues using cross polarized co-located antennas. This is from the collected data results very clear, or at least it is not contradicting. There has been found no restrictions in use of either co-polar or cross-polar antennas when they are distance separated by approximately 2 meters, but other distances has been been tested, so a more adequate inter antenna distance has not been found. Thus it is possible that there is an inter antenna distance that will fulfill the task better.

For co-polar antennas co-located, in this instance 30cm or about two wave lengths, the performance is found in this tests to be considerably worse than for other configurations. This was expected, but it was found that for most SINR levels, the performance was suffering. This will imply that to utilize the type of combination antenna tested in this thesis for 4x4 MIMO may not be recommended, unless another antenna with better spatial characteristics may enhance the MIMO performance. The setup will give two pairs of co-polarized antennas, and may perform like the co-located co-polarized antennas tested in this thesis, or the antennas may even degrade the signal further.

The conclusion will be that it seems, as foreseen, it is advisable to move the antennas some distance apart, but there will of course be other parameters constraining this. This is a cost/performance issue, the increased cost of mounting two antennas instead of a single one, is not only a question of the mounting itself, but also cite rental, maintenance and purchase price.

6 Further Work

Telenor has started to build new test networks at other locations, in the interest of doing more large scale testing. The impact of neighbor cell interference, co-frequency cell interference, handover, large numbers of user equipment on MIMO performance has not been explored in this thesis. Considering the flatness of the area tested, and that MIMO will occur differently at other places, there is still a job to do.

These test are performed at 2.6 GHz, and Telenor is also starting testing at 800MHz, leaving other factors to the equation, e.g. frequency combined antennas.

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A CSV File Indexes

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[2]	"Longitude"	Longitude
[3]	"Latitude"	Latitude
[4]	"CODE0_IBLER_."	Code 0 1st BLock ERror Rate ?
[5]	"CODE0_RBLER_."	
[6]	"CODE1_IBLER_."	
[7]	"CODE1_RBLER_."	
[8]	"Serving_Cell_PCI"	Serving Cell Physical Cell Identifier
[9]	"Serving_Cell_RSRP"	Reference Symbol Received Power
[10]	"Serving_Cell_RSRQ"	Reference Signal Received Quality
[11]	"Serving_Cell_RSSI"	Received Signal Strenght Indicator
[12]	"Listed_Cell_PCI"	Alternative cell PCI
[13]	"Listed_Cell_RSRP"	Alternative cell RSRP
[14]	"Listed_Cell_RSRQ"	Alternative cell RSRQ
[15]	"Listed_Cell_RSSI"	Alternative cell RSSI
[16]	"X1T1R_Count"	SISO Count
[17]	"X1T2R_Count"	1x2 Diversity Count
[18]	"X2T2R_SFBC_Count"	2x2 SFBC Sount
[19]	"X2T2R_OL_SM_Count"	2x2 Open Loop SM Count
[20]	"X2T2R_CL_RANK2_Count"	2x2 Closed−Loop SM Count

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[22] "X2T2R_CL_RANK1_Count"           2x2 Closed-Loop Rank-1 Precoding Count
[23] "SINGLE_PORT5_Count"             (Unused Transmission Mode)      ?
[24] "MAX_ReTx_Count"                 Max Retransmissions (Static Value)      ?

[26] "Rank2_Code0_Band_Wide"          Rank 2 CW1 Bandwith [MHz]       ?
[27] "Rank2_Code1_Band_Wide"          Rank 2 CW2 Bandwith [MHz]       ?
[28] "MAC_Throughput_UL.kbit.s."      MAC-layer Troughput UL [kbps]

[29] "MAC_Throughput_DL.kbit.s."      MAC-layer Troughput DL [kbps]
[30] "RLC_Throughput_UL.kbit.s."      Network Layer Throughput UL [kbps]
[31] "RLC_Throughput_DL.kbit.s."      Network Layer Throughput DL [kbps]
[32] "PDCP_Throughput_UL.kbit.s."     Transport Layer Troughput UL [kbps]

[33] "PDCP_Throughput_DL.kbit.s."     Transport Layer Troughput DL [kbps]
[34] "PHY_Throughput_UL.kbit.s."      Physical Layer Throughput UL [kbps]
[35] "PHY_Throughput_DL.kbit.s."      Physical Layer Throughput DL [kpbs]
[36] "Power_Headroom.dB."             Additional Return Power Available at the UE [
                                      dB]

[37] "AVG_SINR.dB."                   Average Signal to Interference and Noise
                                      Ratio [dB]
[38] "RANK1_SINR.dB."                 SISO SINR
[39] "RANK2_SINR.dB."                 SINR spatial Channel 1 [dB]
[40] "RANK2_SINR2.dB."                SINR Spatial Channel 2 [dB]

[41] "PUSCH_Power.dBm."               Physical Uplink Shared Channel Output Power [
                                      dBm]
[42] "UL_IBLER"                         ?
[43] "UL_SBLER"                         ?
[44] "UL_RBLER"                         ?

[45] "CGI"                            Cell Global Identifier
[46] "PCI"                            Physical Cell Identifier
[47] "PDCCH_UL_Grant_Count"           Physical Uplink Control Channel Grant Count (
                                      nr of TTI's Scheduled for user)
[48] "PDCCH_DL_Grant_Count"           Physical Downlink Control Channel Grant Count
                                       (nr of TTI's Scheduled for user)

[49] "Total_UL_MCS_Count"             Total UL Modulation- Coding Scheme Count
[50] "Total_UL_MCS_RBCount"           Total UL Modulation- Coding Scheme RB Count
[51] "Total_DL_MCS_Code0Count"        Total UL Modulation- Coding Scheme Code 0
                                      Count
[52] "Total_DL_MCS_Code0RBCount"      Total DL Modulation- Coding Scheme Code 0 RB
                                      Count

[53] "Total_DL_MCS_Code1Count"        Total DL Modulation- Coding Scheme Code 1
                                      Count
[54] "Total_DL_MCS_Code1RBCount"      Total DL Modulation- Coding Scheme Code 1 RB
                                      Count
[55] "Rank_Indicator"                 Rank Indicator (RI)
[56] "PUCCH_Power"                    Physical Uplink Control Channel Transmit
                                      Power [dBm]

[57] "seconds"                        Ellapsed Time [s]
[58] "distance_to_enb"                Distance to basestation [m]
[59] "speed"                          User Equipment (UE) Velocity [kmph]
[60] "distance_traveled"              Distance Traveled [m]

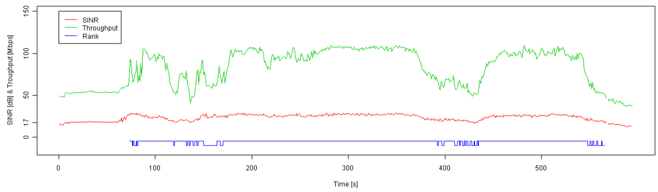
[61] "utm_north"                      Universal Transverse Mercator (32V) North
[62] "utm_east"                       Universal Transverse Mercator (32V) East
[63] "PMI0_Count"                     Precoding Matrix 0 Count
[64] "PMI1_Count"                     Precoding Matrix 1 Count

[65] "PMI2_Count"                     Precoding Matrix 2 Count
[66] "PMI3_Count"                     Precoding Matrix 3 Count
```

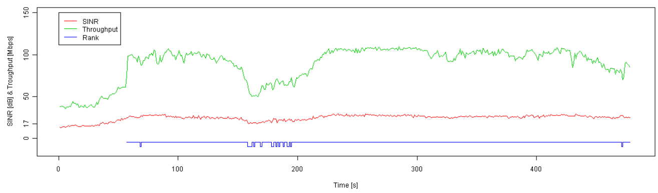
B Figures

B.1 MIMO - plots

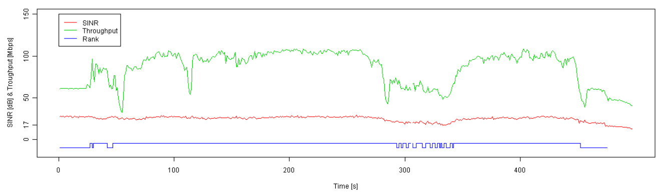
This plots are comparing Rank, SINR and Throughput, to see if the dependency between the parameters. They also gives a good visual impression of the performance of the transmission mode and antenna setup configuration.



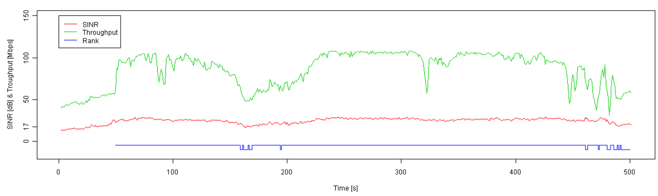
(a) Open Loop Cross polarized Co-located



(b) Open loop Cross Polarized Co-Located Return

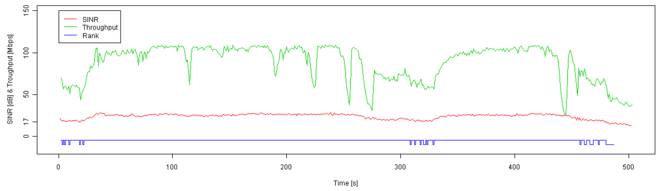


(c) Closed Loop Cross Polarized Co-Located

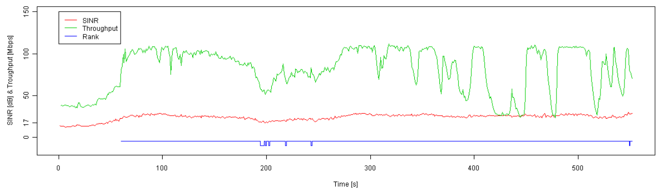


(d) Closed Loop Cross Polarized Co-Located Return

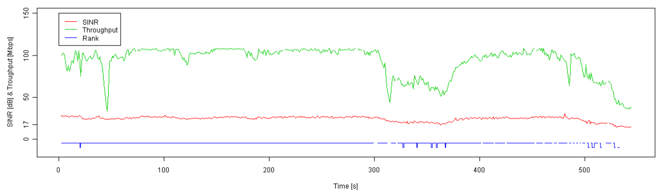
Figure B.1: RANK vs. SINR vs. Throughput over Time, Case 1



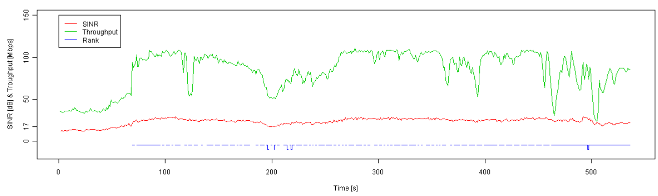
(a) Open Loop Cross Polarized Distance Separated



(b) Open Loop Cross Polarized Distance Separated Return

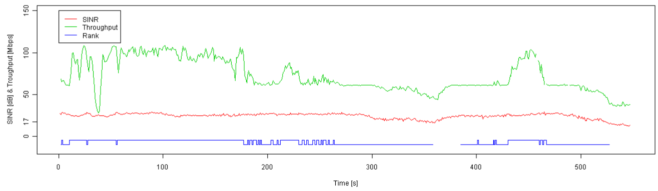


(c) Closed Loop Cross Polarized Distance Separated

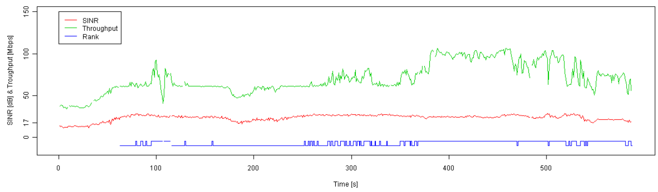


(d) Closed Loop Cross Polarized Distance separated

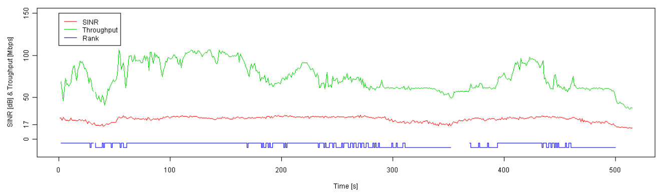
Figure B.2: RANK vs. SINR vs. Throughput over Time, Case 2



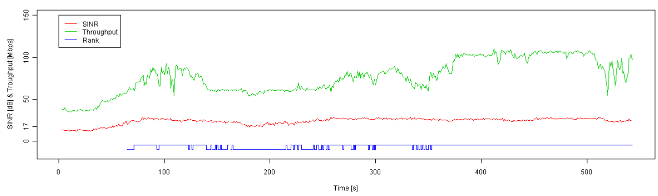
(a) Open Loop Co-Polarized Co-Located



(b) Open Loop Co-Polarized Co-Located Return

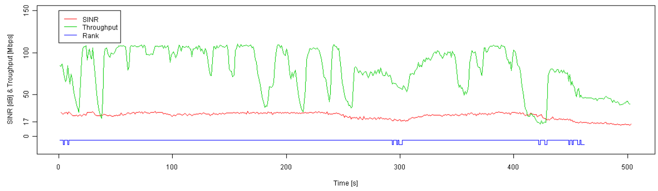


(c) Closed Loop Co-Polarized Co-Located

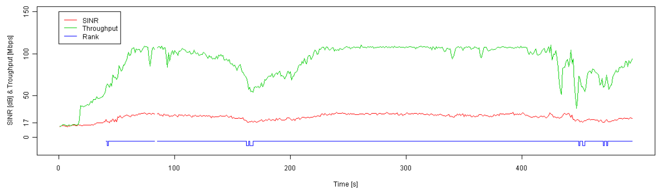


(d) Closed Loop Co-Polarized Co-Located Return

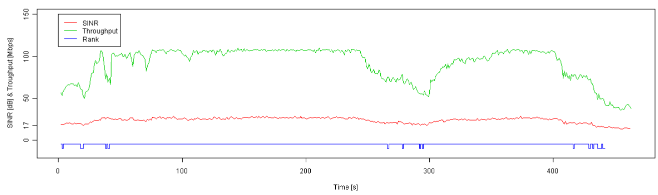
Figure B.3: RANK vs. SINR vs. Throughput over Time, Case 3



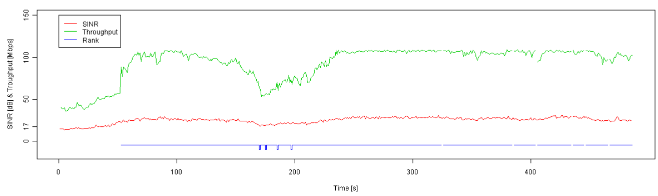
(a) Open Loop Co-Polarized distance Separated



(b) Open Loop Co-Polarized Distance Separated Return



(c) Closed Loop Co-Polarized Distance separated



(d) Closed Loop Co-Polarized Distance Separated Return

Figure B.4: RANK vs. SINR vs. Throughput over Time, Case 4

B.2 Comparison Plots

The plots here is a supplement to chapter 4.

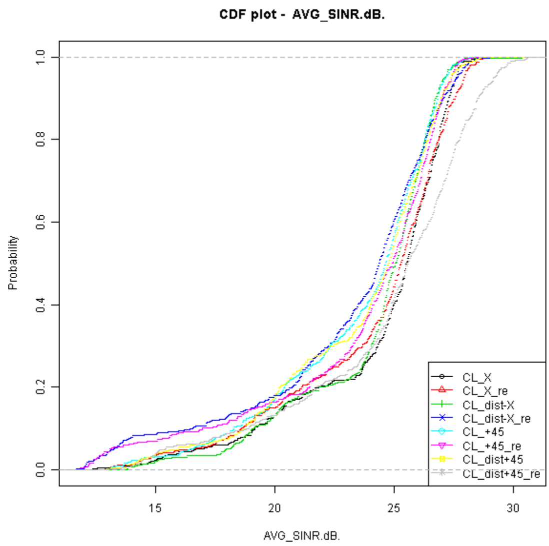


Figure B.5: CDF of SINR for Closed Loop Mode

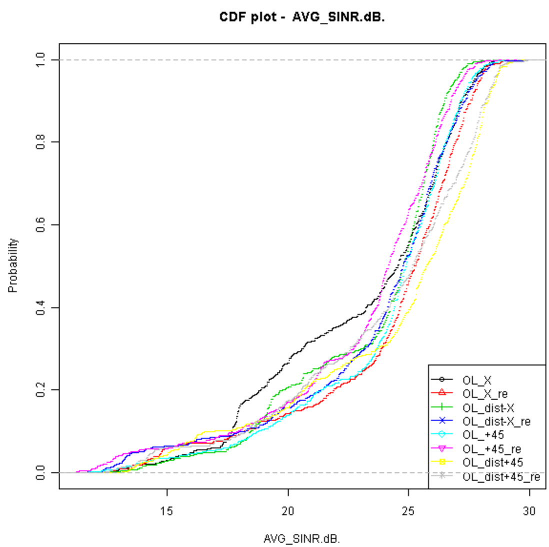


Figure B.6: Plotted CDF of SINR for open Loop Mode

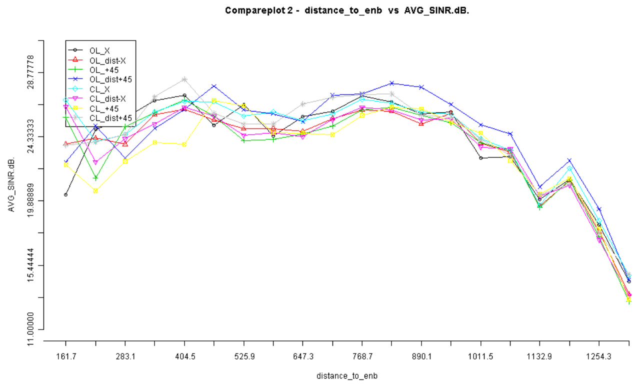


Figure B.7: SINR [dB] vs Distance to Base Station [m] (eNB)

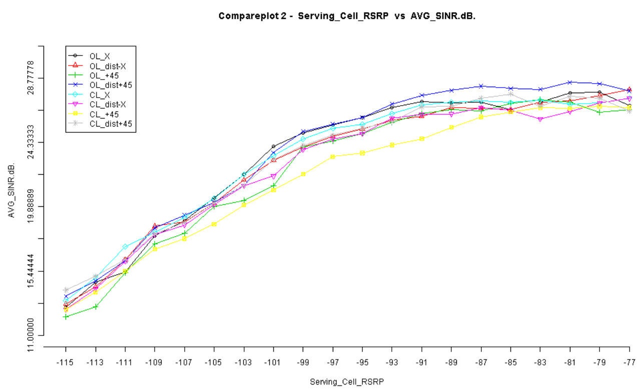


Figure B.8: Average SINR [dB] RSRP

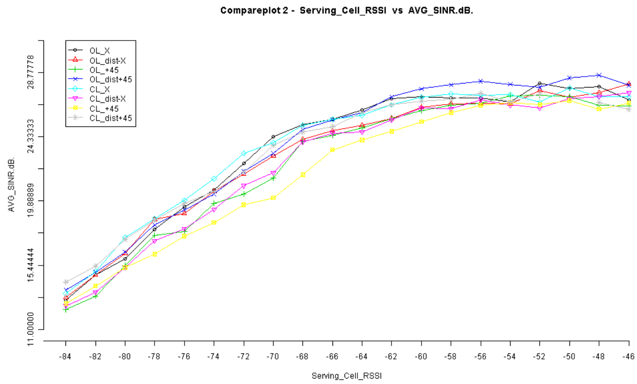


Figure B.9: Average SINR [dB] vs RSSI

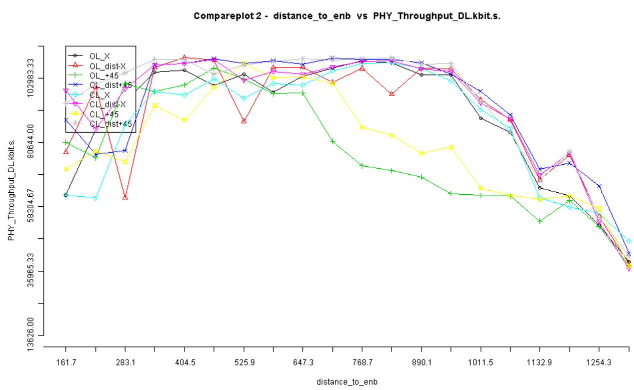


Figure B.10: Throughput [kbps] vs Distance to Base Station

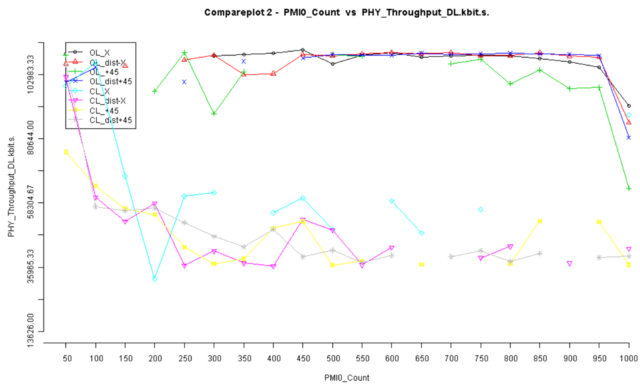


Figure B.11: Throughput [kbps] vs Precoding Matrix 0

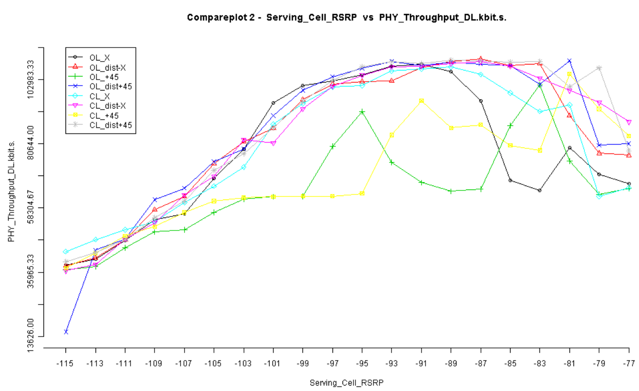


Figure B.12: Throughput [kbps] vs RSRP

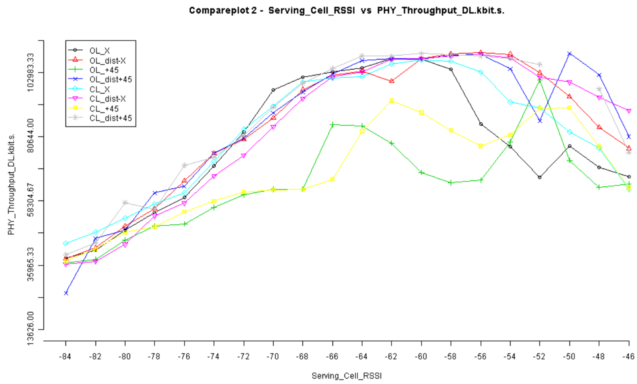


Figure B.13: Throughput [kbps] vs RSSI

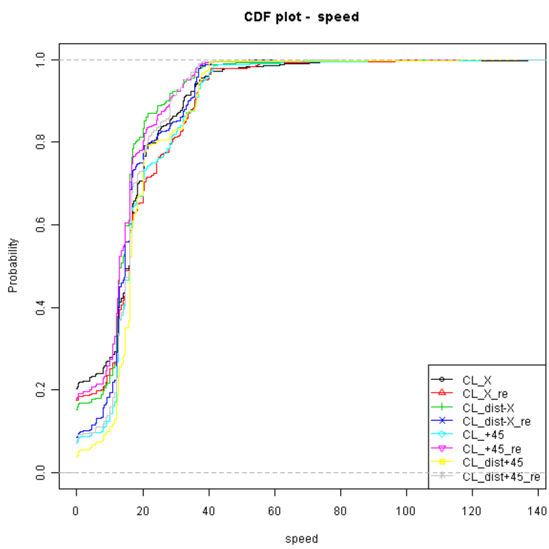


Figure B.14: Plotted CDF of traveling Speed for Closed Loop Mode

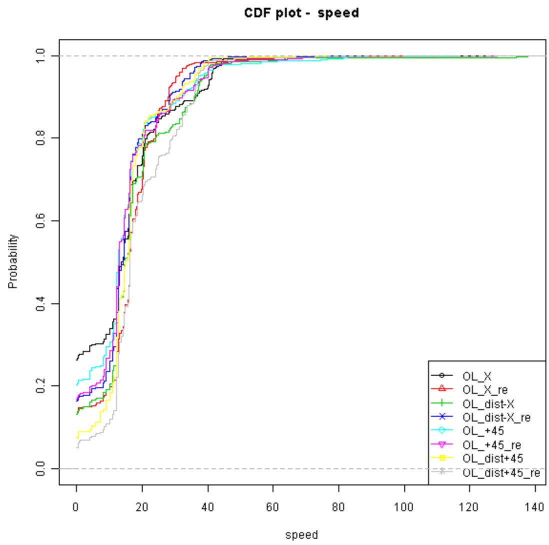


Figure B.15: Plotted CDF of traveling speed for Open Loop Mode

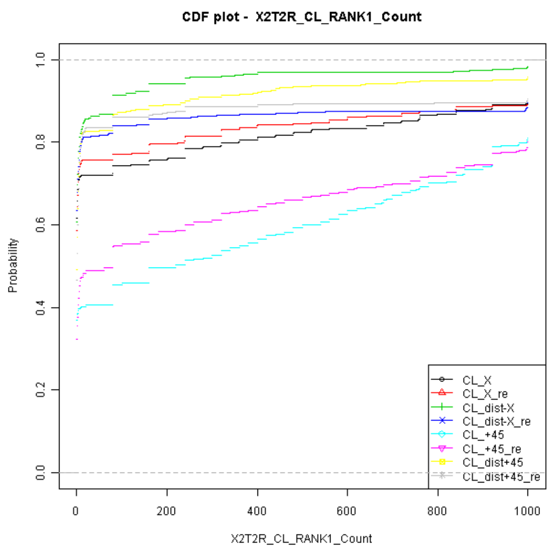


Figure B.16: Plotted CDF of Closed Loop Rank1 Precoding Count [0-1000]

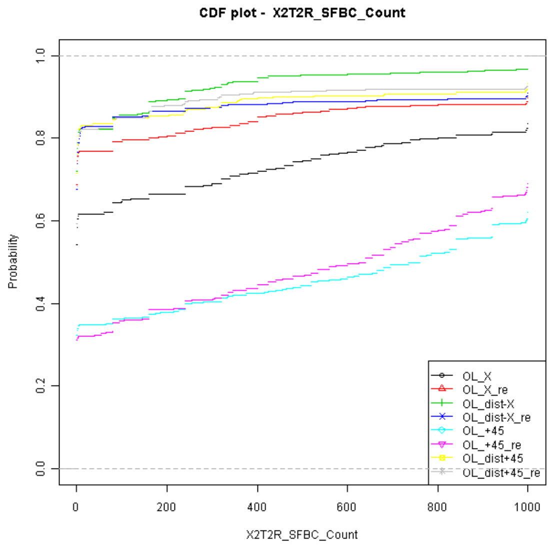
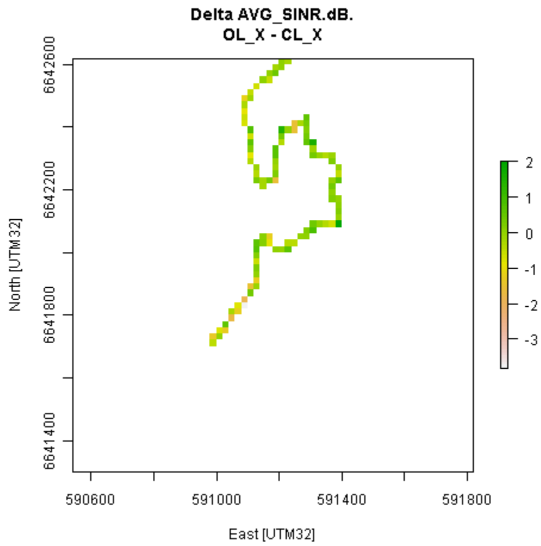
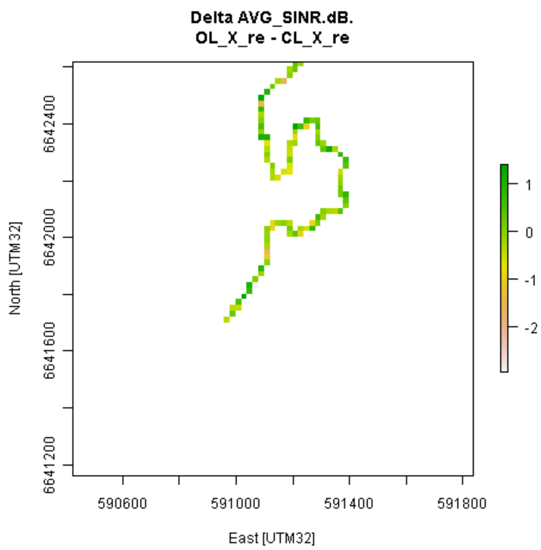


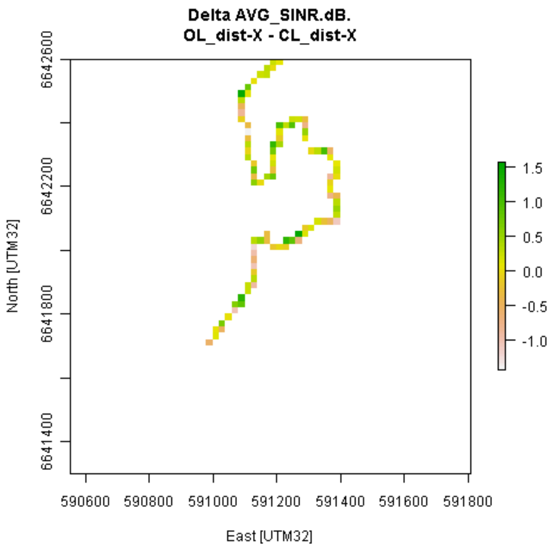
Figure B.17: Plotted CDF of SFBC Count Open Loop Mode

Case 1

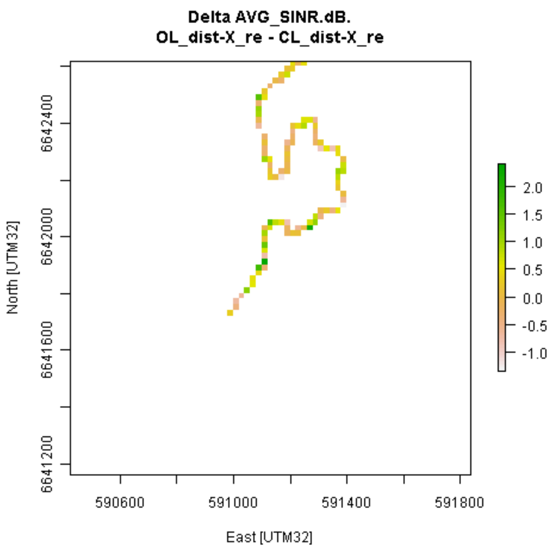

Delta AVG_SINR.dB.
OL_X - CL_X
North [UTM32]
East [UTM32]
6641400
6641800
6642200
6642600
590600
591000
591400
591800
2
1
0
-1
-2
-3


Delta AVG_SINR.dB.
OL_X_re - CL_X_re
North [UTM32]
East [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
1
0
-1
-2

Case 2



Delta AVG_SINR.dB.
OL_dist-X - CL_dist-X
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
591800
East [UTM32]
1.5
1.0
0.5
0.0
-0.5
-1.0



Delta AVG_SINR.dB.
OL_dist-X_re - CL_dist-X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0

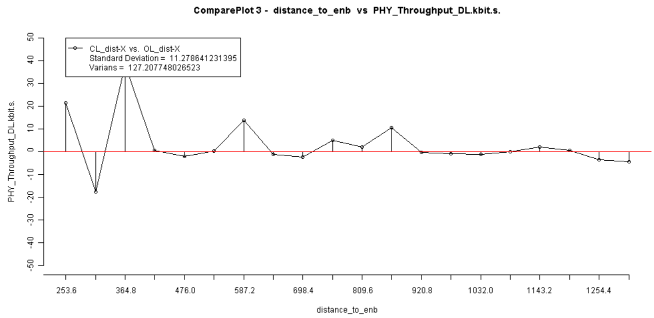
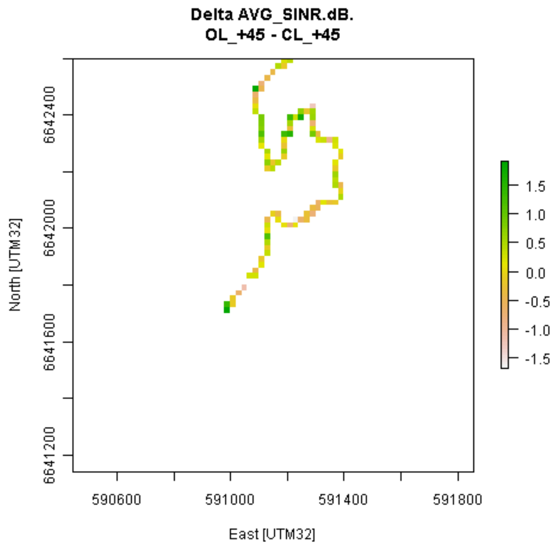
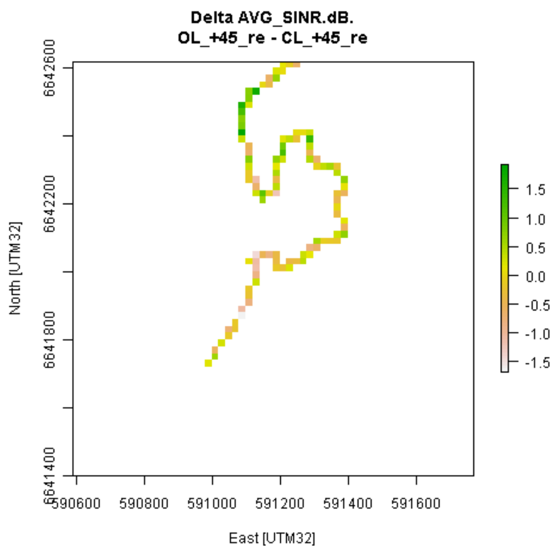


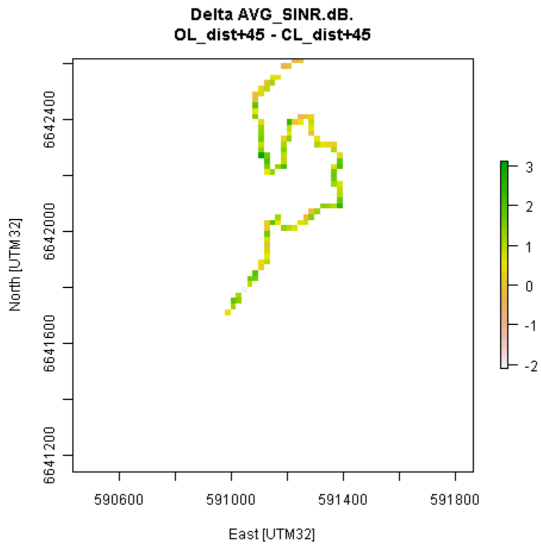
Figure B.18: Throughput vs distance to eNB

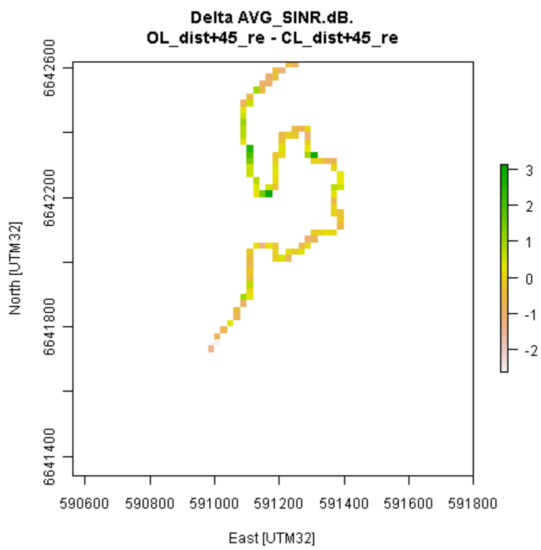
Case 3


Delta AVG_SINR.dB.
OL_+45 - CL_+45
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5


Delta AVG_SINR.dB.
OL_+45_re - CL_+45_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
East [UTM32]
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5

Case 4


Delta AVG_SINR.dB.
OL_dist+45 - CL_dist+45
North [UTM32]
6641200
6641600
6642000
6642400
East [UTM32]
590600
591000
591400
591800
3
2
1
0
-1
-2


Delta AVG_SINR.dB.
OL_dist+45_re - CL_dist+45_re
North [UTM32]
6641400
6641800
6642200
6642600
East [UTM32]
590600
590800
591000
591200
591400
591600
591800
3
2
1
0
-1
-2

Case 1 vs 2

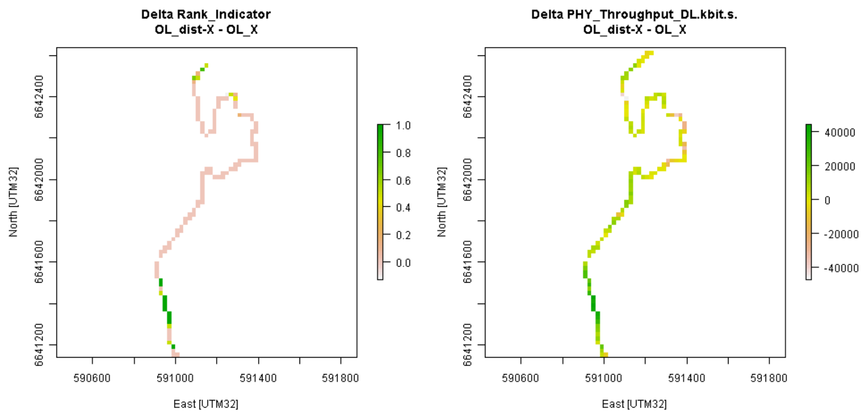


Figure B.19: Cross Polarization: Rank Indicator

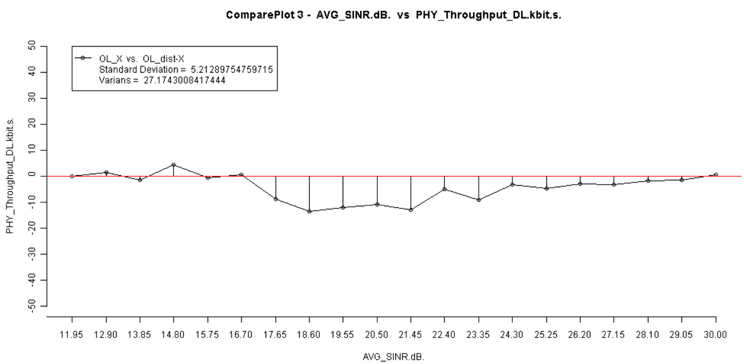


Figure B.20

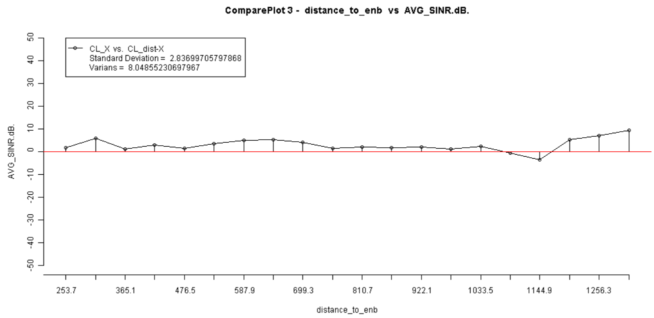


Figure B.21: SINR [dB] vs. Distance to Base Station

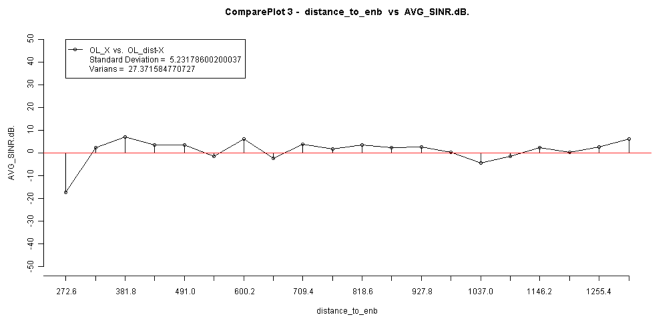


Figure B.22: SINR [dB] vs. Distance to Base Station

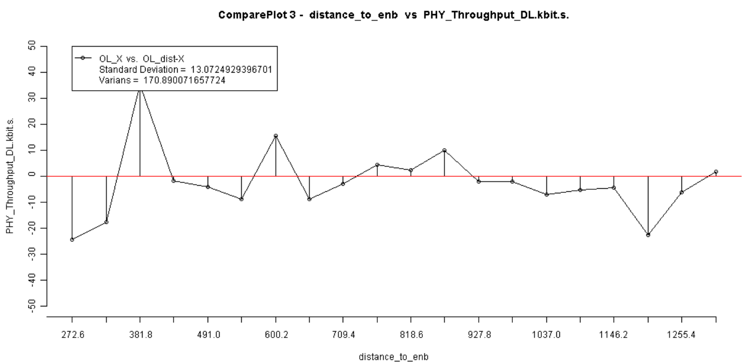
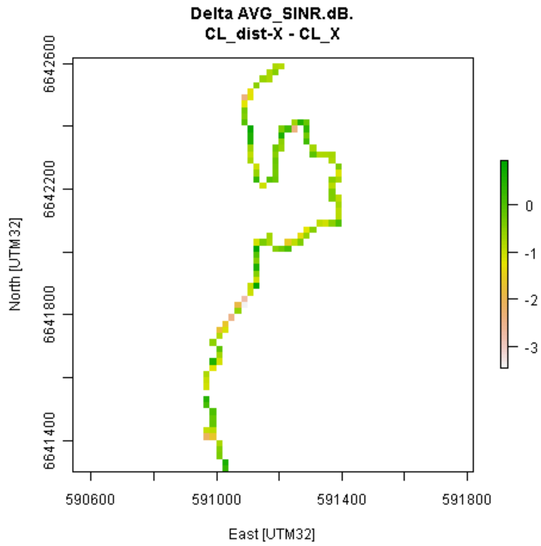
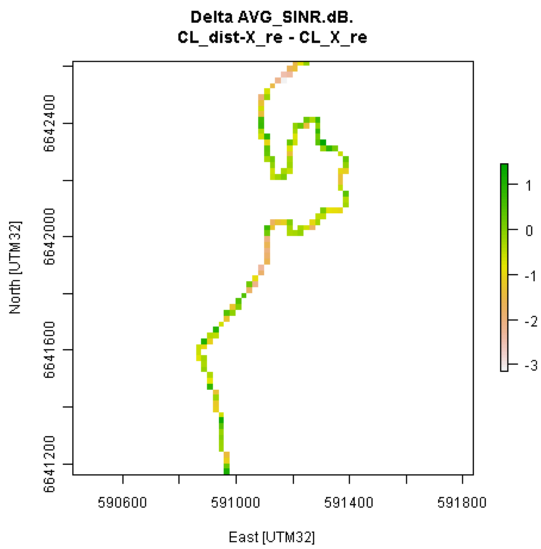
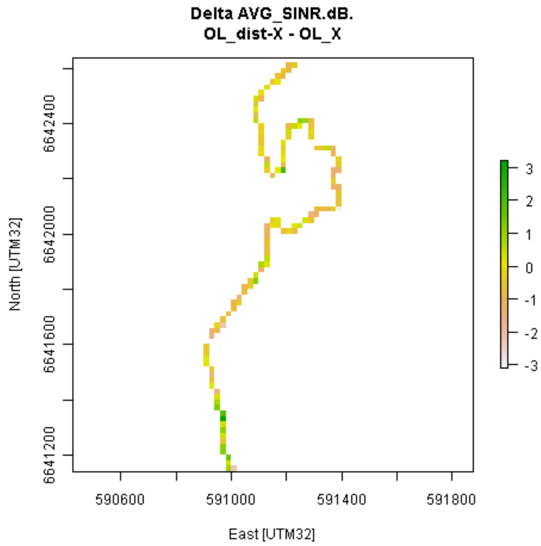
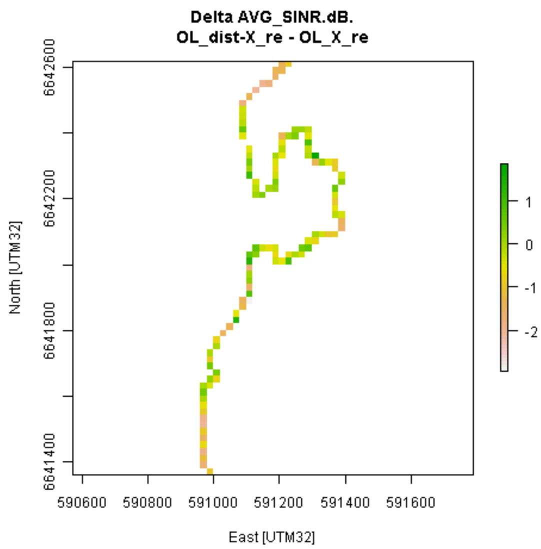


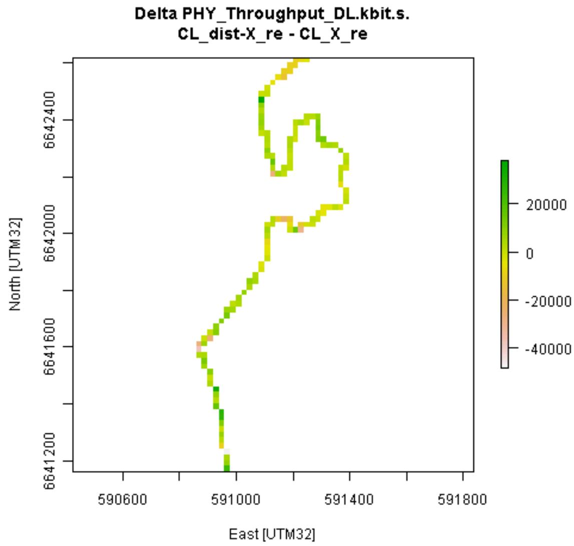
Figure B.23


Delta AVG_SINR.dB.
CL_dist-X - CL_X
North [UTM32]
6642600
6642200
6641800
6641400
East [UTM32]
590600
591000
591400
591800
0
-1
-2
-3

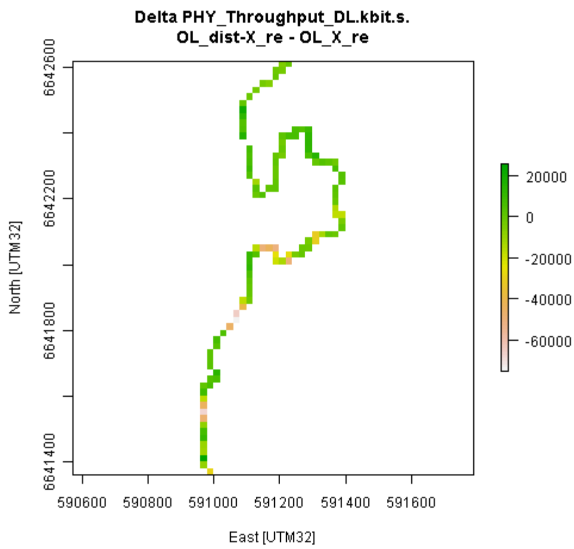

Delta AVG_SINR.dB.
CL_dist-X_re - CL_X_re
North [UTM32]
6642400
6642000
6641600
6641200
East [UTM32]
590600
591000
591400
591800
1
0
-1
-2
-3


Delta AVG_SINR.dB.
OL_dist-X - OL_X
6642400
6642000
6641600
6641200
North [UTM32]
590600
591000
591400
591800
East [UTM32]
3
2
1
0
-1
-2
-3

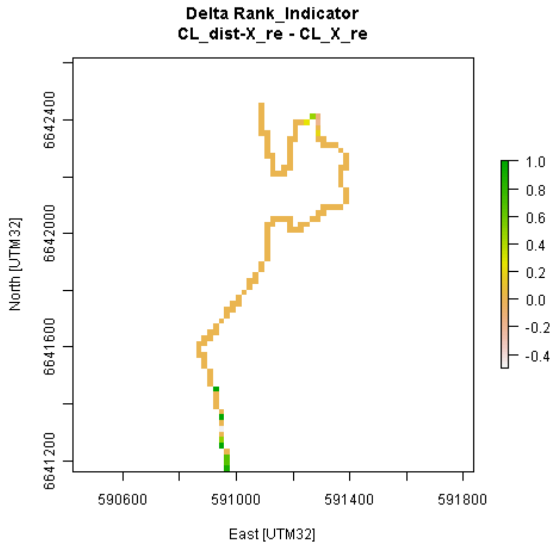

Delta AVG_SINR.dB.
OL_dist-X_re - OL_X_re
6642600
6642200
6641800
6641400
North [UTM32]
590600
590800
591000
591200
591400
591600
East [UTM32]
1
0
-1
-2

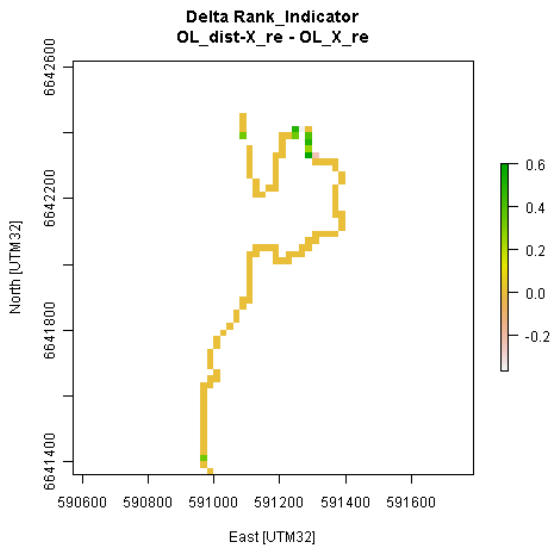


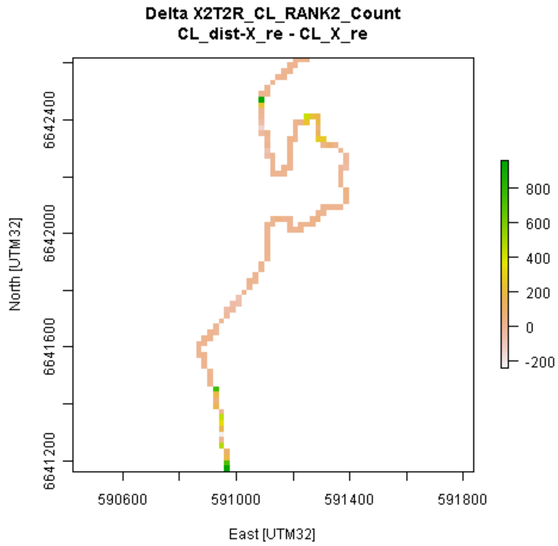
Delta PHY_Throughput_DL.kbit.s.
CL_dist-X_re - CL_X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
20000
0
-20000
-40000

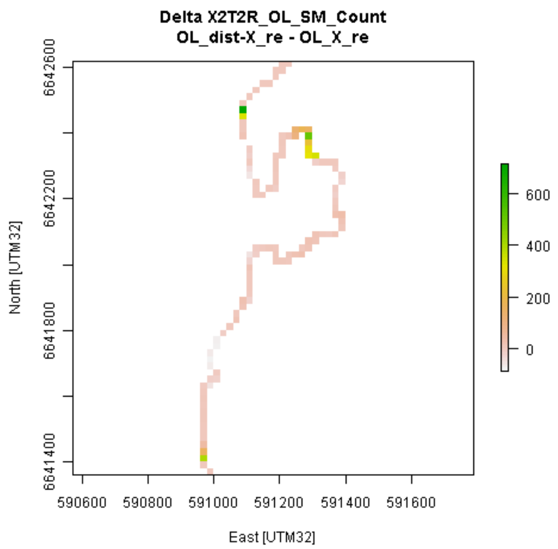


Delta PHY_Throughput_DL.kbit.s.
OL_dist-X_re - OL_X_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
East [UTM32]
20000
0
-20000
-40000
-60000


Delta Rank_Indicator
CL_dist-X_re - CL_X_re
North [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
East [UTM32]
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4


Delta Rank_Indicator
OL_dist-X_re - OL_X_re
North [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
East [UTM32]
0.6
0.4
0.2
0.0
-0.2


Delta X2T2R_CL_RANK2_Count
CL_dist-X_re - CL_X_re
6642400
6642000
6641600
6641200
North [UTM32]
590600
591000
591400
591800
East [UTM32]
800
600
400
200
0
-200


Delta X2T2R_OL_SM_Count
OL_dist-X_re - OL_X_re
6642600
6642200
6641800
6641400
North [UTM32]
590600
590800
591000
591200
591400
591600
East [UTM32]
600
400
200
0

Case 1 vs 3

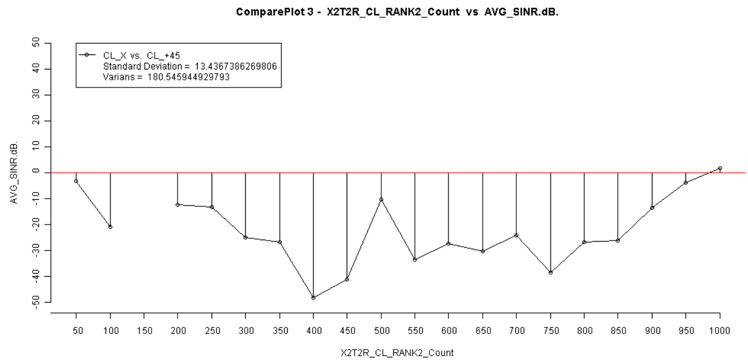


Figure B.24: SINR vs SM count, Closed Loop

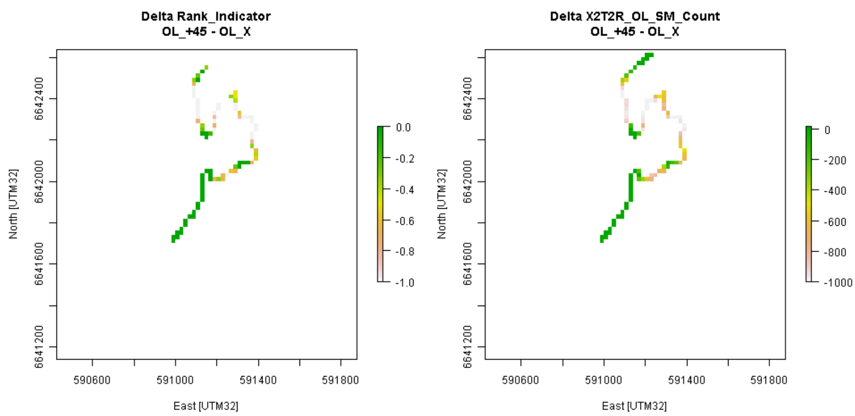


Figure B.25: Case 1 vs 3: Spatial Multiplexing Count

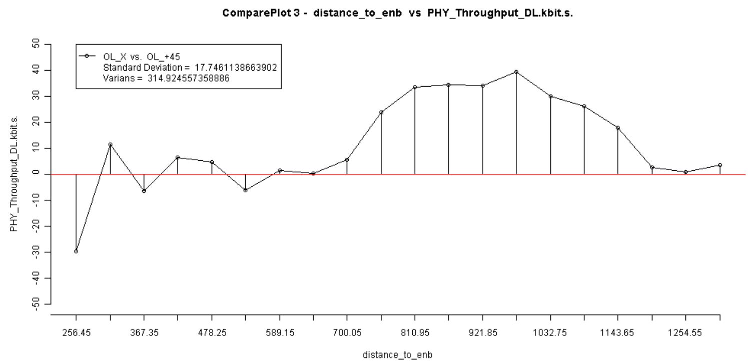


Figure B.26: Case 1 vs 3: Throughput vs Distance to eNB, Open Loop

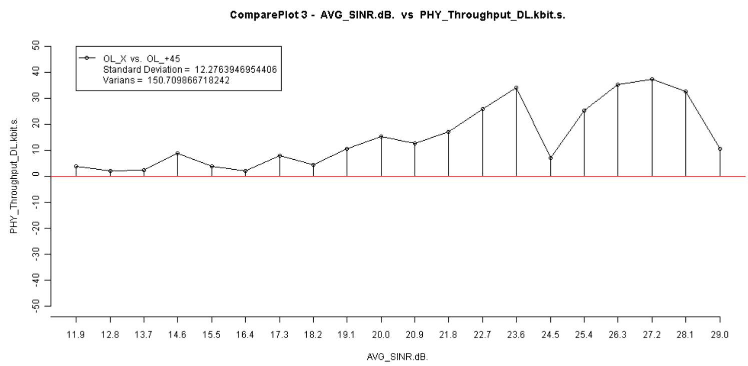


Figure B.27: Case 1 vs 3: SINR vs Throughput, Open Loop

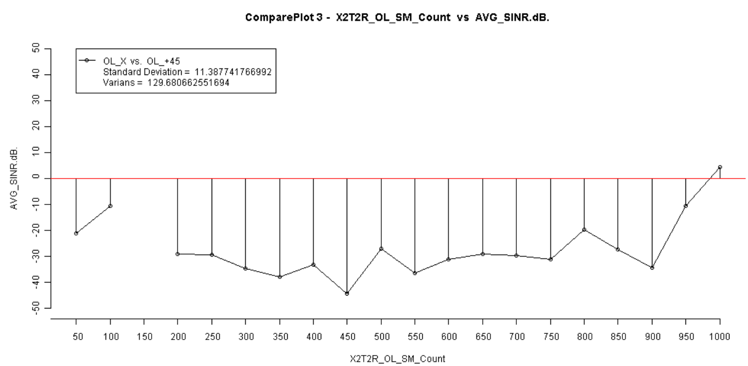
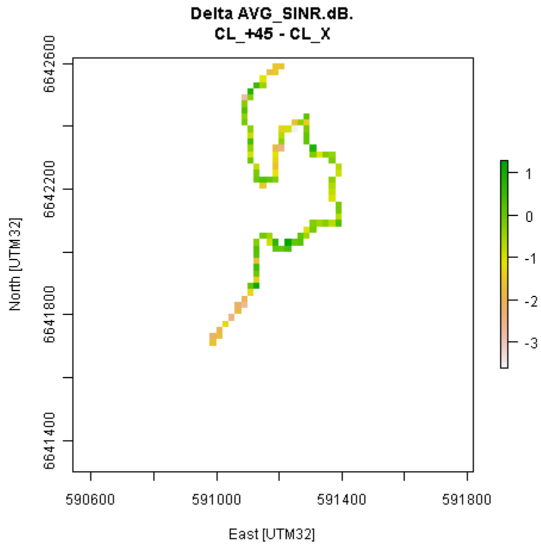
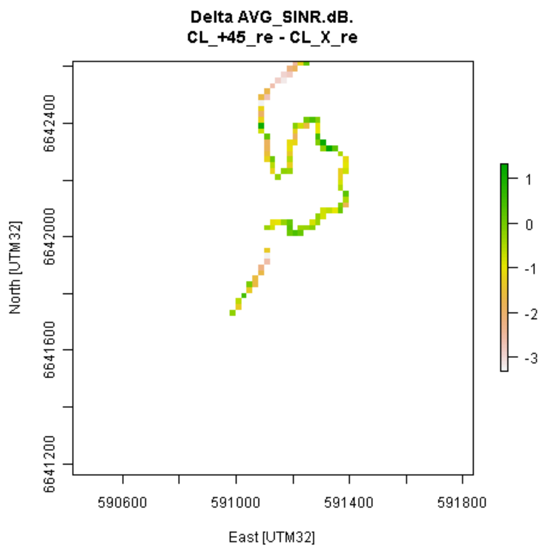
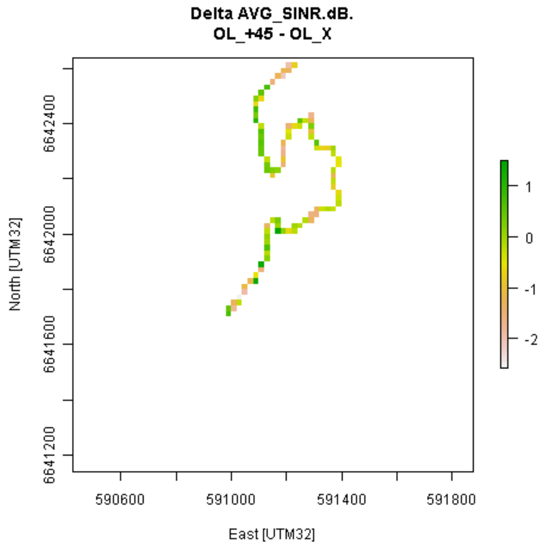
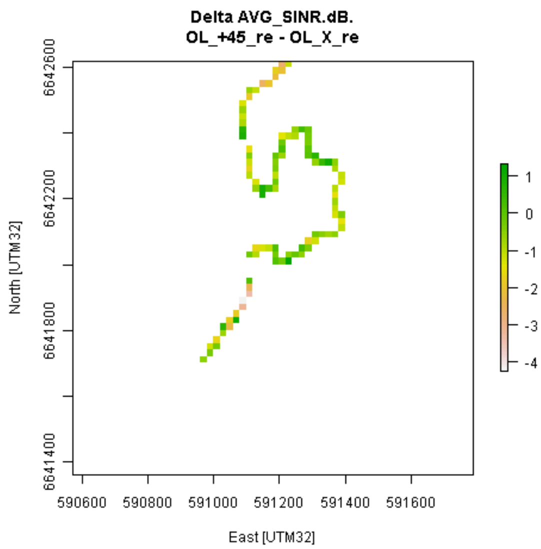


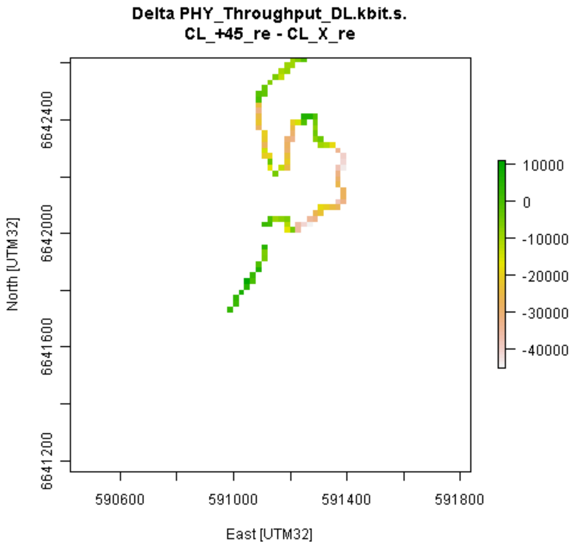
Figure B.28: Case 1 vs 3: SINR vs Throughput, Open Loop

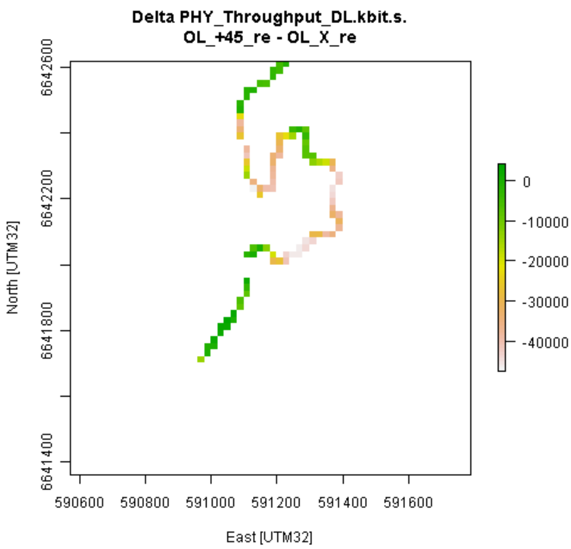

Delta AVG_SINR.dB.
CL_+45 - CL_X
North [UTM32]
6642600
6642200
6641800
6641400
590600
591000
591400
591800
East [UTM32]
1
0
-1
-2
-3

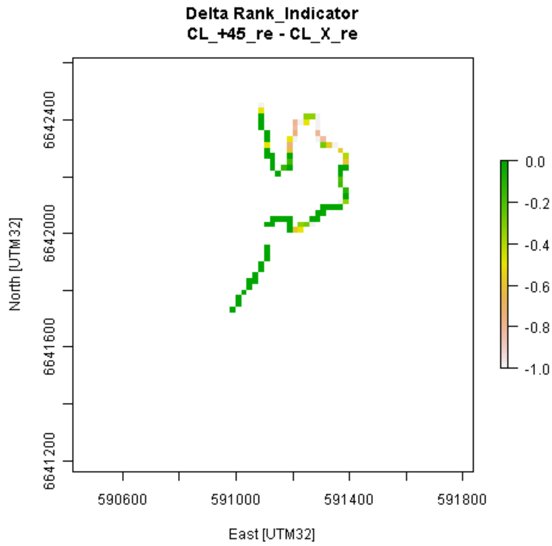

Delta AVG_SINR.dB.
CL_+45_re - CL_X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
1
0
-1
-2
-3

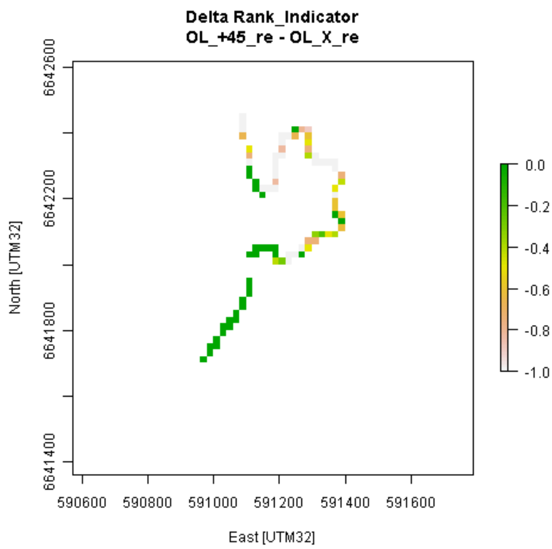

Delta AVG_SINR.dB.
OL_+45 - OL_X
North [UTM32]
6641200
6641600
6642000
6642400
East [UTM32]
590600
591000
591400
591800
1
0
-1
-2

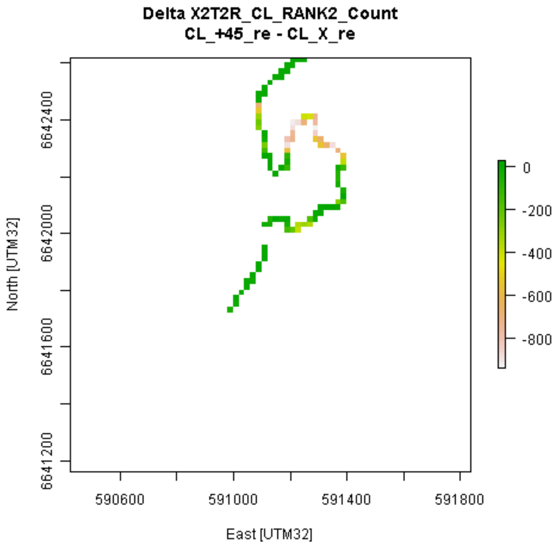

Delta AVG_SINR.dB.
OL_+45_re - OL_X_re
North [UTM32]
6641400
6641800
6642200
6642600
East [UTM32]
590600
590800
591000
591200
591400
591600
1
0
-1
-2
-3
-4

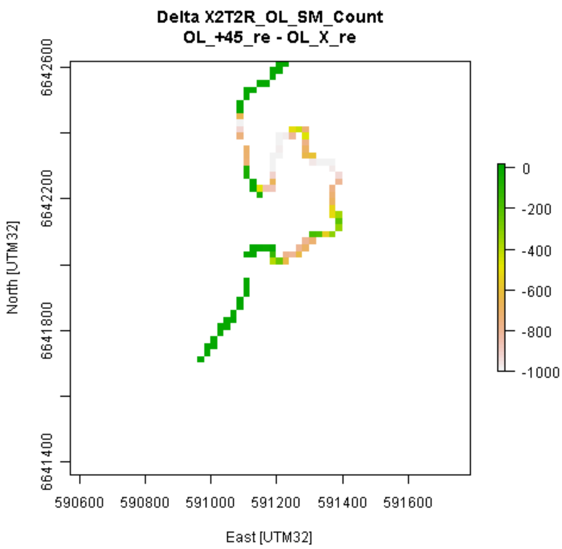

Delta PHY_Throughput_DL.kbit.s.
CL_+45_re - CL_X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
10000
0
-10000
-20000
-30000
-40000


Delta PHY_Throughput_DL.kbit.s.
OL_+45_re - OL_X_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
East [UTM32]
0
-10000
-20000
-30000
-40000

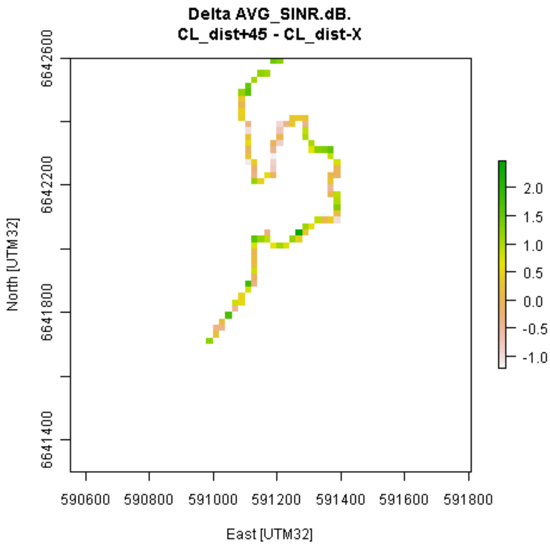

Delta Rank_Indicator
CL_+45_re - CL_X_re
North [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
East [UTM32]
0.0
-0.2
-0.4
-0.6
-0.8
-1.0

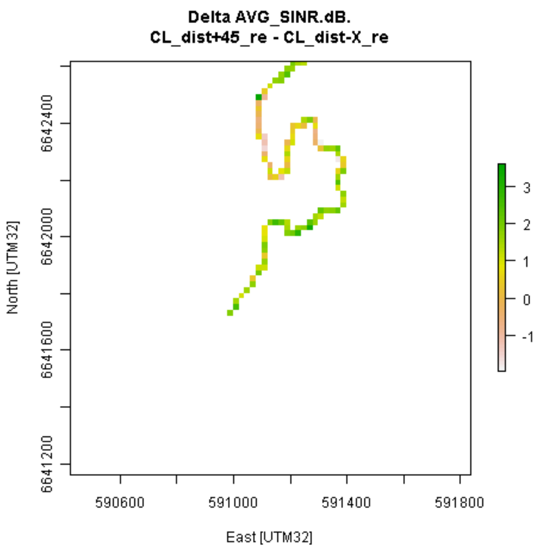

Delta Rank_Indicator
OL_+45_re - OL_X_re
North [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
East [UTM32]
0.0
-0.2
-0.4
-0.6
-0.8
-1.0

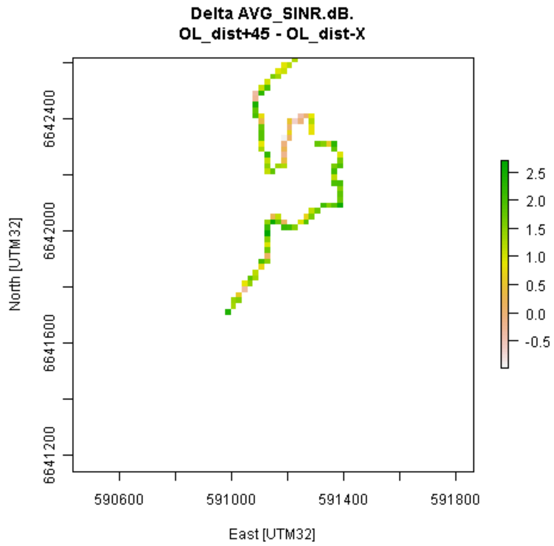

Delta X2T2R_CL_RANK2_Count
CL_+45_re - CL_X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
0
-200
-400
-600
-800

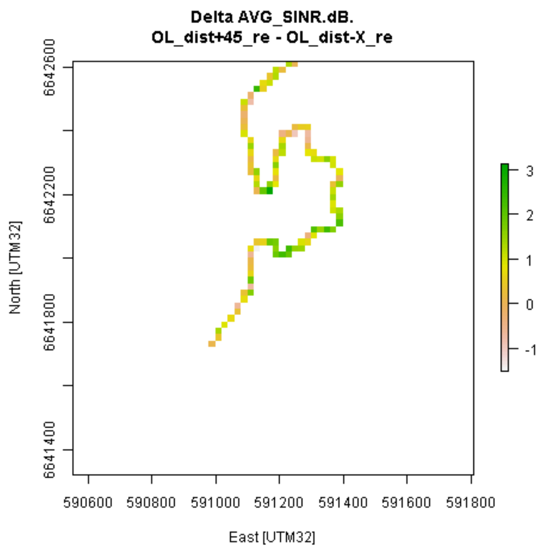

Delta X2T2R_OL_SM_Count
OL_+45_re - OL_X_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
East [UTM32]
0
-200
-400
-600
-800
-1000

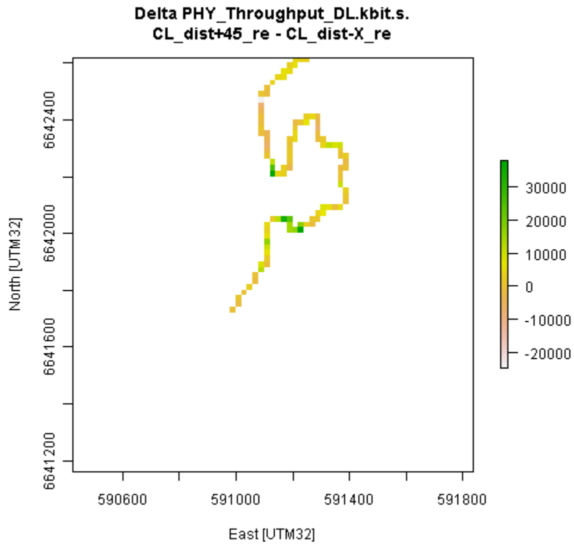
Case 2 vs Case 4

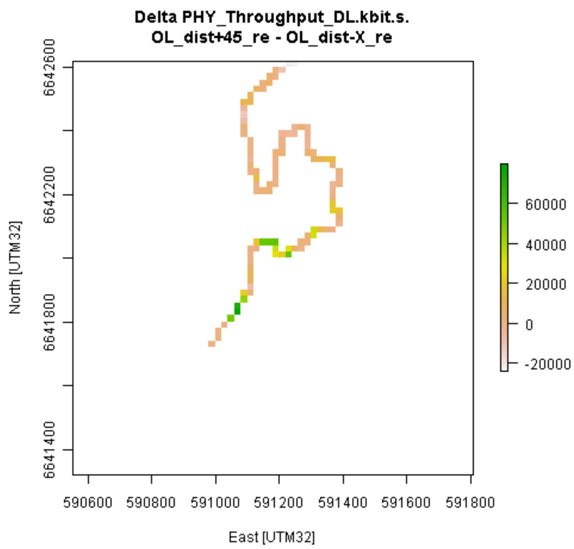


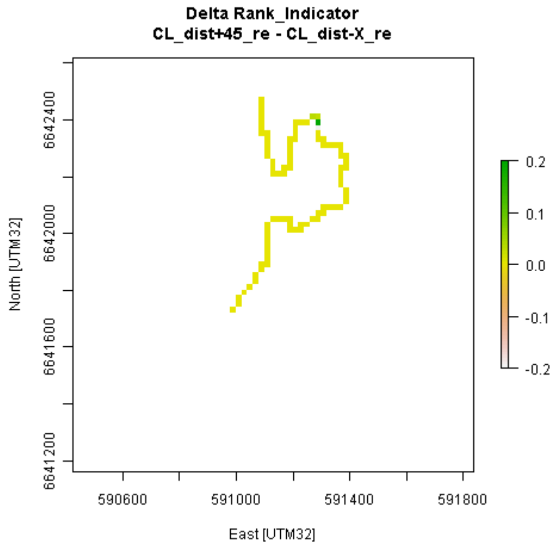



Delta AVG_SINR.dB.
OL_dist+45 - OL_dist-X
North [UTM32]
East [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
2.5
2.0
1.5
1.0
0.5
0.0
-0.5

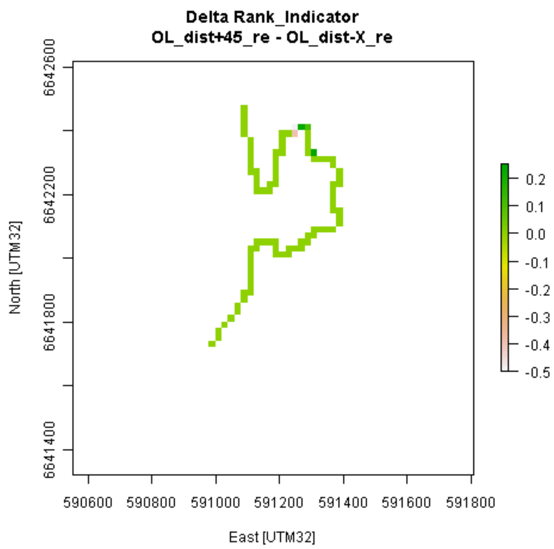

Delta AVG_SINR.dB.
OL_dist+45_re - OL_dist-X_re
North [UTM32]
East [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
591800
3
2
1
0
-1


Delta PHY_Throughput_DL.kbit.s.
CL_dist+45_re - CL_dist-X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
30000
20000
10000
0
-10000
-20000

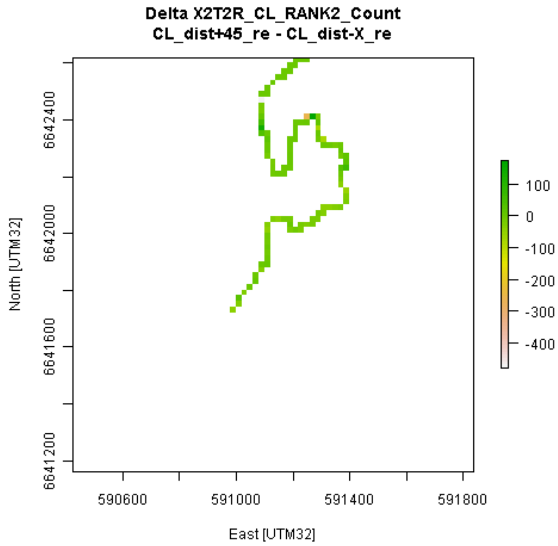

Delta PHY_Throughput_DL.kbit.s.
OL_dist+45_re - OL_dist-X_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
591800
East [UTM32]
60000
40000
20000
0
-20000

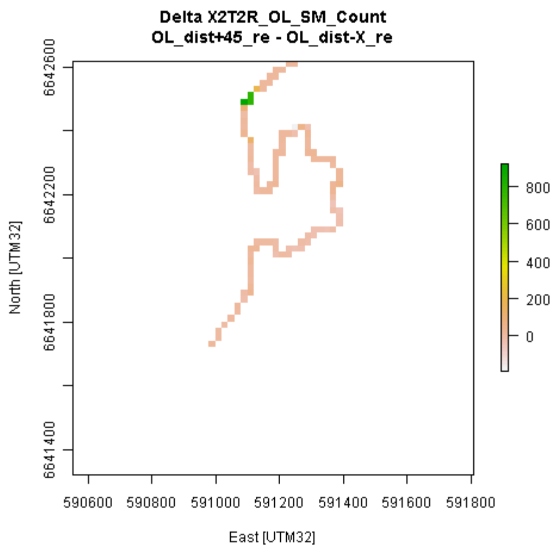


Delta Rank_Indicator
CL_dist+45_re - CL_dist-X_re
North [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
East [UTM32]
0.2
0.1
0.0
-0.1
-0.2



Delta Rank_Indicator
OL_dist+45_re - OL_dist-X_re
North [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
591800
East [UTM32]
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5


Delta X2T2R_CL_RANK2_Count
CL_dist+45_re - CL_dist-X_re
North [UTM32]
6642400
6642000
6641600
6641200
590600
591000
591400
591800
East [UTM32]
100
0
-100
-200
-300
-400


Delta X2T2R_OL_SM_Count
OL_dist+45_re - OL_dist-X_re
North [UTM32]
6642600
6642200
6641800
6641400
590600
590800
591000
591200
591400
591600
591800
East [UTM32]
800
600
400
200
0

Case 3 vs 4

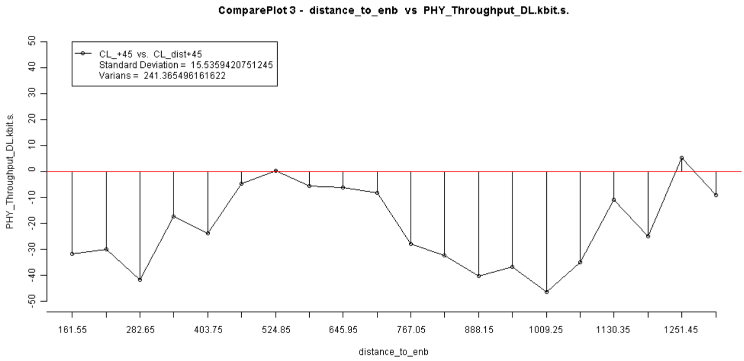
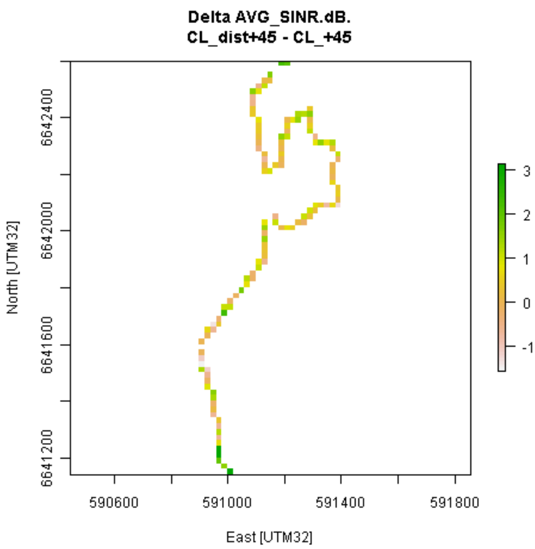
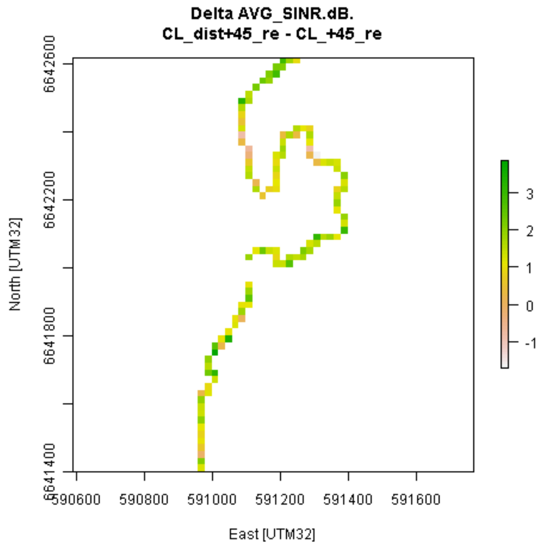
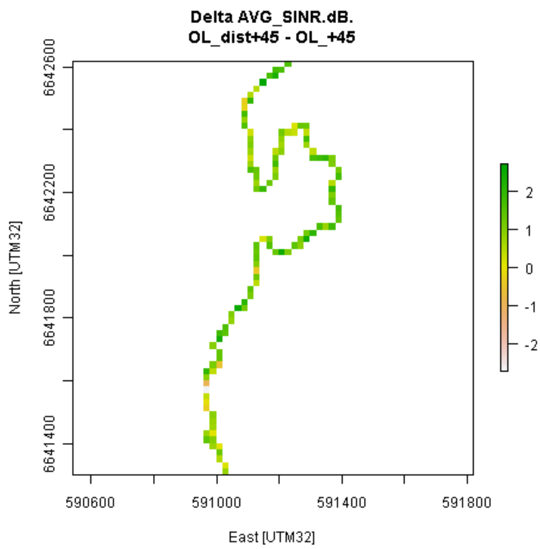
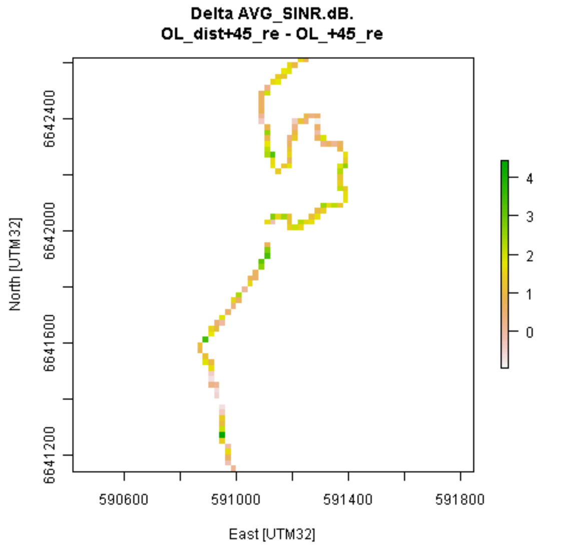


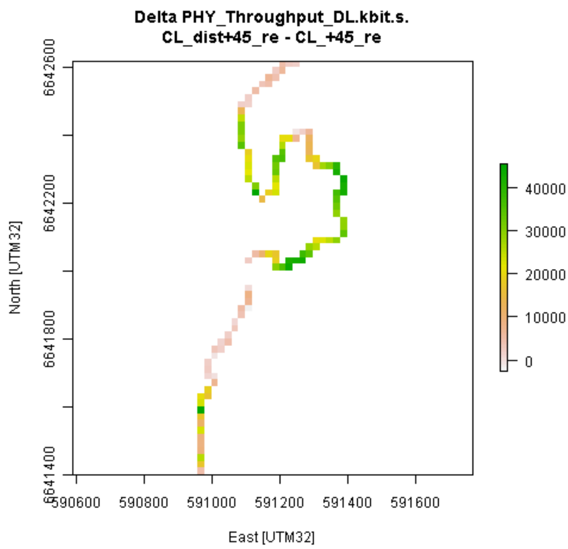
Figure B.29

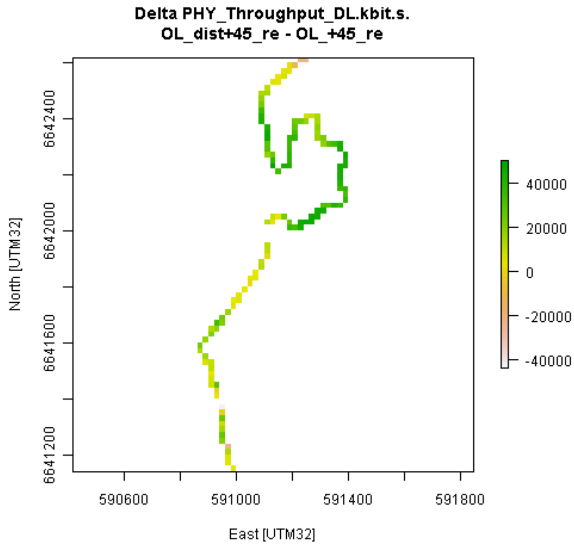



Delta AVG_SINR.dB.
CL_dist+45_re - CL_+45_re
North [UTM32]
East [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
3
2
1
0
-1

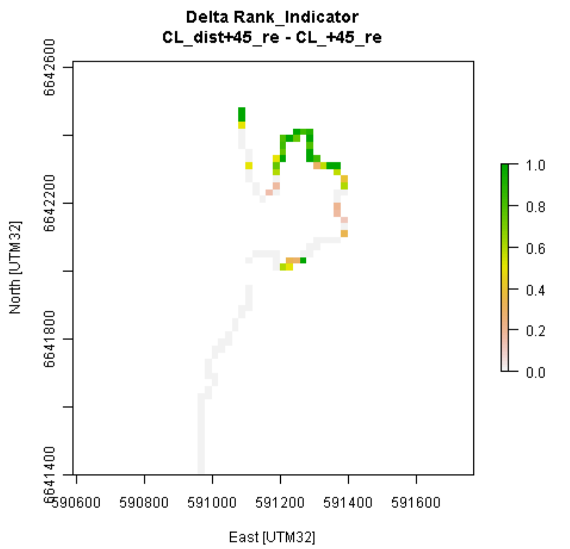

Delta AVG_SINR.dB.
OL_dist+45 - OL_+45
North [UTM32]
East [UTM32]
6641400
6641800
6642200
6642600
590600
591000
591400
591800
2
1
0
-1
-2


Delta AVG_SINR.dB.
OL_dist+45_re - OL_+45_re
North [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
East [UTM32]
4
3
2
1
0

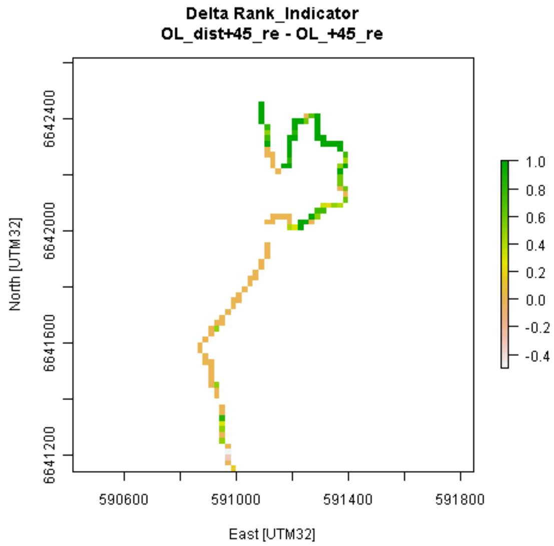

Delta PHY_Throughput_DL.kbit.s.
CL_dist+45_re - CL_+45_re
North [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
East [UTM32]
40000
30000
20000
10000
0

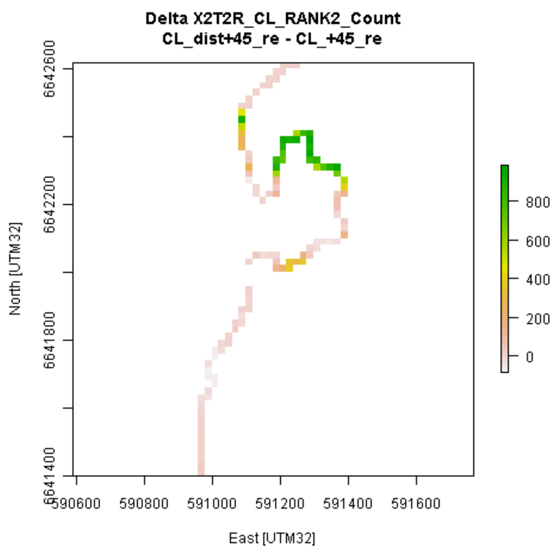


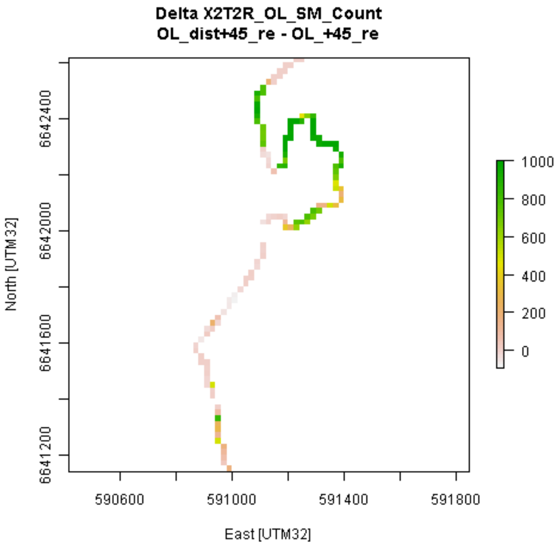
Delta PHY_Throughput_DL.kbit.s.
OL_dist+45_re - OL_+45_re
North [UTM32]
East [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
40000
20000
0
-20000
-40000



Delta Rank_Indicator
CL_dist+45_re - CL_+45_re
North [UTM32]
East [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
1.0
0.8
0.6
0.4
0.2
0.0


Delta Rank_Indicator
OL_dist+45_re - OL_+45_re
North [UTM32]
6641200
6641600
6642000
6642400
590600
591000
591400
591800
East [UTM32]
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4


Delta X2T2R_CL_RANK2_Count
CL_dist+45_re - CL_+45_re
North [UTM32]
6641400
6641800
6642200
6642600
590600
590800
591000
591200
591400
591600
East [UTM32]
800
600
400
200
0


Delta X2T2R_OL_SM_Count
OL_dist+45_re - OL_+45_re
North [UTM32]
6641200
6641600
6642000
6642400
East [UTM32]
590600
591000
591400
591800
1000
800
600
400
200
0

C Source Code, R-project

```
ComparePlot2 = function(files,parX,parY,type,bins,case)
{
#library(splines)
# parX="AVG_SINR.dB."
# parY="PHY_Throughput_DL.kbit.s."
# parX="PMI1_Count"
# parX="Rank_Indicator"
# type="b"
# bins=20
# folder="test"
# name="TEST"
  avg=median

  name= paste("Plots/",case,"/[",case,",",parY,",",parX,"][",paste(files,collapse
                                          =","),"]_2.png",sep="")

  if(case=="All")
  {
    name=paste("Plots/",case,"/[",case,",",parY,",",parX,"][All]_2.png",sep="")
  }

  L1=0; L2=0; L3=0; L4=0; L5=0; L6=0; L7=0; L8=0;
  while(T)
  {
    if(parY==parX){print(paste("Not Applicable",name,sep=" - ")); break;}
    for(i in 1:length(files))
    {
      temp1 = read.csv(paste(files[i],".csv",sep=""),sep=";")
      temp2 = read.csv(paste(files[i],"_re.csv",sep=""),sep=";")
      temp  = merge(temp1,temp2,by=names(temp1),all=T)
      if(i==1)
      {
        minX <- floor(  min(temp[,parX],na.rm=T))
        maxX <- ceiling(  max(temp[,parX],na.rm=T))
        minY <- floor(  min(temp[,parY],na.rm=T))
        maxY <- ceiling(  max(temp[,parY],na.rm=T))
      }
      if(all(temp[,parX] == 0,na.rm=T)){next} # print(paste("break",i,sep=" - "))
                                           ; next}

      if(i==1){ L1 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==2){ L2 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==3){ L3 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==4){ L4 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==5){ L5 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==6){ L6 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==7){ L7 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }
      if(i==8){ L8 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.
                                           rm=T) }

      if(minX > floor(   min(temp[,parX],na.rm=T))){  minX=floor( min(temp[,parX
                                           ],na.rm=T)) }
      if(maxX < ceiling( max(temp[,parX],na.rm=T))){  maxX=ceiling( max(temp[,
                                           parX],na.rm=T)) }
      if(minY > floor(   min(temp[,parY],na.rm=T))){  minY=floor( min(temp[,parY
                                           ],na.rm=T)) }
      if(maxY < ceiling( max(temp[,parY],na.rm=T))){  maxY=ceiling( max(temp[,
                                           parY],na.rm=T)) }

    }

    if(all(c(L1,L2,L3,L4,L4,L5,L6,L7,L8)==0,na.rm=T)){print(paste("Not Applicable
                                           ",name,sep=" - ")); break;}
    ticksX<- seq(minX,maxX,((maxX-minX)/bins))
    ticksY<- seq(minY,maxY,((maxY-minY)/9))
```

```
    dir.create(paste("Plots/",sep=""), showWarning=F)
    dir.create(paste("Plots/",case,sep=""), showWarning=F)


    png(name,width=1000,height=600);
      plot(L1,type=type,col=1,pch=1,
        main=paste("Compareplot 2 - ",parX," vs ",parY),cex=1,axes=F,
        xlab=parX,ylab=parY,
        ylim=c(minY,maxY))#,xlim=c(minX,maxX))
#     print("1")
      axis(1, at=seq(0,bins,1), labels=format(ticksX, scientific=F))
      axis(2, at=ticksY,labels=format(ticksY, scientific=F))
      legend(x=1,y=maxY,
         legend = files, col=1:length(files) ,lty=1,pch=1:length(files));

      for(i in 2:length(files))
      {
        if(i==2){ points(L2,type=type,col=2,pch=2);}# print("2") }
        if(i==3){ points(L3,type=type,col=3,pch=3);}# print("3") }
        if(i==4){ points(L4,type=type,col=4,pch=4);}# print("4") }
        if(i==5){ points(L5,type=type,col=5,pch=5);}# print("5") }
        if(i==6){ points(L6,type=type,col=6,pch=6);}# print("6") }
        if(i==7){ points(L7,type=type,col=7,pch=7);}# print("7") }
        if(i==8){ points(L8,type=type,col=8,pch=8);}# print("8") }
      }
    print(dev.cur())
    dev.off();
    break;
  }
}


# files <- c("CL_X","OL_X")
# ComparePlot2(files,"PMI1_Count","PHY_Throughput_DL.kbit.s.","o",30,"  ")

ComparePlot3 = function(files,parX,parY,type,bins,case)
{

#library(splines)
# files=c("CL_X","CL_dist-X")
# parX="AVG_SINR.dB."
# parY="PHY_Throughput_DL.kbit.s."
# parX="speed"
# type="h"
# bins=40
# folder="test"

  avg=median
  name= paste("Plots/",case,"/[",case,",",parY,",",parX,"][",paste(files,collapse
                                          =","),"]_3.png",sep="")
  if(case=="All")
  {
    name= paste("Plots/",case,"/[",case,",",parY,",",parX,"][All]_2.png",sep="")
  }
  L1=0;L2=0;
  while(T)
  {
    if(parY==parX){print(paste("Not Applicable",name,sep=" - ")); break;}
    temp1 = read.csv(paste(files[1],".csv",sep=""),sep=";")
    temp2 = read.csv(paste(files[1],"_re.csv",sep=""),sep=";")
    temp  = merge(temp1,temp2,by=names(temp1),all=T)
    if(all(temp[,parX] == 0,na.rm=T)){print(paste("Not Applicable",name,sep=" - "
                                           )); break}

    L1 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.rm=T)
    minX <- floor(  min(temp[,parX],na.rm=T))
    maxX <- ceiling(  max(temp[,parX],na.rm=T))


    temp1 = read.csv(paste(files[2],".csv",sep=""),sep=";")
    temp2 = read.csv(paste(files[2],"_re.csv",sep=""),sep=";")
    temp  = merge(temp1,temp2,by=names(temp1),all=T)
    if(all(temp[,parX] == 0,na.rm=T)){print(paste("Not Applicable",name,sep=" - "
                                           )); break}

    L2 = tapply( temp[,parY], cut(temp[,parX], breaks=bins), avg, na.rm=T)
```

```
    if(minX > floor(   min(temp[,parX],na.rm=T))){  minX=floor(  min(temp[,parX],
                                              na.rm=T))  }
    if(maxX > ceiling( max(temp[,parX],na.rm=T))){  maxX=ceiling(max(temp[,parX],
                                              na.rm=T))  }

    L <- (L1-L2)/L1*100
    ticksX<- seq(minX,maxX,((maxX-minX)/bins))

    dir.create(paste("Plots/",sep=""), showWarning=F)
    dir.create(paste("Plots/",case,sep=""), showWarning=F)


    png(name,width=1000,height=500);
      plot(L,type=type,col=1,pch=1,
        main=paste("ComparePlot 3 - ",parX," vs ",parY),cex=1,axes=F,
        xlab=parX,ylab=parY,
        ylim=c(-50,50))
      if(type=="h"){ points(L,type="o") }

      axis(1, at=seq(0,bins,1), labels=format(ticksX, scientific=F))          #X
                                                axis
      axis(2, at=seq(-50,50,10),labels=format(seq(-50,50,10), scientific=F))
                                                  #Y axis
      abline(h=0,col=2)

      legend(x=1,y=50,
        legend = c(paste(files[1]," vs. ",files[2]),
              paste("Standard Deviation = ",sd(L,na.rm=T)),
              paste("Varians = ",var(L,na.rm=T))),
        lty=1,col=c(1,0,0),pch=1);


#     abline(lm(ticksX[1:length(ticksX)-1] ~ L[]), col="4")
#     lines(lowess(L[],ticksX[1:length(ticksX)-1]), col="blue")
#     text(0, -35, paste("Standard Deviation = ",sd(L,na.rm=T)),adj=c(0,0))
#     text(0, -45, paste("Varians = ",var(L,na.rm=T)),adj=c(0,0))

    print(dev.cur())
    dev.off()
    break;
  }
}

#files <- c("CL_+45","CL_dist+45")
#ComparePlot3(files,"PMI0_Count","PHY_Throughput_DL.kbit.s.","h",40,"Pol")


Run = function(parX,parY,bins)
{
  make = function(files,case)
  {
    if(parX!="Raster")
    {
      if(parY=="Raster")
      {
        rastercomp(files[1],files[2],parX,bins,case)
        rastercomp(paste(files[1],"_re",sep=""),paste(files[2],"_re",sep=""),parX
                                                  ,bins,case)
      }
      else{
        ComparePlot3(files,parX,parY,"h",bins,case)
      }
    }
  }

  #Compare Transmission Mode

  make(c("CL_X","OL_X"),"Case1")          #Case 1
  make(c("CL_dist-X","OL_dist-X"),"Case2")     #Case 2
  make(c("CL_+45","OL_+45"),"Case3")         #Case 3
  make(c("CL_dist+45","OL_dist+45"),"Case4")     #Case 4


  #Compare Antenna Distance

  make(c("CL_X","CL_dist-X"),"Case1v2")       #Case 1 vs Case 2
  make(c("OL_X","OL_dist-X"),"Case1v2")        #Case 1 vs Case 2
```

```
  make(c("CL_+45","CL_dist+45"),"Case3v4")      #Case 3 vs Case 4
  make(c("OL_+45","OL_dist+45"),"Case3v4")      #Case 3 vs Case 4


  #Compare Polarity

  make(c("CL_X","CL_+45"),"Case1v3")         #Case 1 vs Case 3
  make(c("OL_X","OL_+45"),"Case1v3")         #Case 1 vs Case 3
  make(c("CL_dist-X","CL_dist+45"),"Case2v4")     #Case 2 vs Case 4
  make(c("OL_dist-X","OL_dist+45"),"Case2v4")     #Case 2 vs Case 4

  #Compare ALL
  files <- c("OL_X","OL_dist-X","OL_+45","OL_dist+45","CL_X","CL_dist-X","CL_+45"
                                         ,"CL_dist+45")
  if(parY!="Raster"){ComparePlot2(files,parX,parY,"o",bins,"All")}
}

PARAM<- c(
# "Raster",
# "PMI0_Count",
# "PMI1_Count",
# "PMI2_Count",
# "PMI3_Count",
  "distance_to_enb",
  "AVG_SINR.dB.",
# "Serving_Cell_RSSI",
# "Serving_Cell_RSRP",
# "distance_traveled",
  "speed",
  "PHY_Throughput_DL.kbit.s.",
# "X2T2R_SFBC_Count",
  "X2T2R_OL_SM_Count",
  "X2T2R_CL_RANK2_Count"
# "X2T2R_CL_RANK1_Count"
  )

runALL = function(parY,bins)
{
  for(i in 1:length(PARAM))
  {
    Run(PARAM[i],parY,bins)
#    if(PARAM[i]!="Raster")
#    {
#      CDFplot(c("CL_X","CL_X_re","CL_dist-X","CL_dist-X_re","CL_+45","CL_+45_re
                                         ","CL_dist+45","CL_dist+45_re"),PARAM[i],"CL
                                         ")
#      CDFplot(c("OL_X","OL_X_re","OL_dist-X","OL_dist-X_re","OL_+45","OL_+45_re
                                         ","OL_dist+45","OL_dist+45_re"),PARAM[i],"OL
                                         ")
#    }
  }
  dev.cur()
}
runALL2 = function(bins)
{
  for(i in 1:length(PARAM))
  {
    runALL(PARAM[i],bins)

  }
}
runALL3 = function()
{
  runALL2(20)
  runALL2(30)
  runALL2(40)

}
#Run("AVG_SINR.dB.","PHY_Throughput_DL.kbit.s.",20)
#runALL("PHY_Throughput_DL.kbit.s.",20)
#runALL2(20)
#runALL3()
```

```r
MimoPlot= function (file)
{

  library(ggplot2);library(rgdal);

  dir.create(file, showWarning=F)
  x <- read.csv(paste(file,".csv",sep=""),sep=";")

  png(paste(file,"/",file,"_Mimoplot.png",sep=""), width=1200, height=400);

  plot(x$AVG_SINR.dB.,col=2,type="l",ylim=c(-15,150),axes=F,frame.plot=T,xlab="
                                          Time [s]",ylab="SINR [dB] & Troughput [Mbps
                                          ]");
    axis(2,at=c(0,17,50,100,150));
    axis(1,at=seq(0,length(x[,1]),100));
    legend(x=0,y=150,legend =c("SINR","Throughput","Rank"), col=2:4,lty=1);
  # abline(h=17,col=2)r;
    points(x$PHY_Throughput_DL.kbit.s./1024, pch=11, col=3,type="l")
    points((x$Rank_Indicator*5)-10, pch=0, col=4,type="S")
  dev.off()

}


rastercomp = function (file1,file2,parameter,resolution,case)
{
  library(sp)
  library(raster)
  f1 = read.csv(paste(file1,".csv",sep=""), sep=";")
  f1 = subset(f1, Latitude > 0)
  f1 = subset(f1, Longitude > 0)

  f2 = read.csv(paste(file2,".csv",sep=""), sep=";")
  f2 = subset(f2, Latitude > 0)
  f2 = subset(f2, Longitude > 0)

  x1 = resolution*floor(min(f1$utm_east/resolution))
  x2 = resolution*ceiling(max(f1$utm_east/resolution))
  y1 = resolution*floor(min(f1$utm_north/resolution))
  y2 = resolution*ceiling(max(f1$utm_north/resolution))

  numx = (x2-x1) /resolution
  numy = (y2-y1) /resolution

  r1 = raster(ncols = numx, nrows= numy, xmn = x1, xmx = x2, ymn=y1, ymx=y2)
  r2 = raster(ncols = numx, nrows= numy, xmn = x1, xmx = x2, ymn=y1, ymx=y2)

  coord1 <- SpatialPoints(f1[, c("utm_east","utm_north")])
  f1_sp = SpatialPointsDataFrame(coord1, f1)
  r1 = pointsToRaster(r1, f1_sp, f1_sp@data[,parameter], fun=mean)

  coord2 <- SpatialPoints(f2[, c("utm_east","utm_north")])
  f2_sp = SpatialPointsDataFrame(coord2, f2)
  r2 = pointsToRaster(r2, f2_sp, f2_sp@data[,parameter], fun=mean)

  r3 = r2 - r1


  dir.create(paste("Plots/",sep=""), showWarning=F)
  dir.create(paste("Plots/",case,sep=""), showWarning=F)



#  png(paste("Plots/",case,"/[",case,",",parameter,"][",file1,"]_Raster.png", sep
                                          =""))
#  plot(r1, xlab="East [UTM32]", ylab="North [UTM32]", main=paste(parameter,"\n",
                                          basename(file1),sep=""))
#  print(dev.cur())
#  dev.off()

#  png(paste("Plots/",case,"/[",case,",",parameter,"][",file2,"]_Raster.png", sep
                                          =""))
#  plot(r2, xlab="East [UTM32]", ylab="North [UTM32]", main=paste(parameter,"\n",
                                          basename(file2),sep=""))
#  print(dev.cur())
```

```
#  dev.off()

  png(paste("Plots/",case,"/[",case,",",parameter,"][",file1,",",file2,"]_Raster.
                                          png", sep=""))
  plot(r3, xlab="East [UTM32]", ylab="North [UTM32]", main=paste("Delta ",
                                          parameter,"\n",basename(file2)," - ",
                                          basename(file1),sep=""))
  print(dev.cur())
  dev.off()
}

#rastercomp("CL_+45","CL_dist45","PHY_Throughput_DL.kbit.s.",20,"TEST")


CDFplot = function(files,parX,type)
{
  library(Hmisc)

  name= paste("ComparePlots/","CDF/CDFplot[",parX,",",type,"].png",sep="")

  L1=0; L2=0; L3=0; L4=0; L5=0; L6=0; L7=0; L8=0;
  range=0;
  while(T)
  {
    dir.create("ComparePlots", showWarning=F)
    dir.create("ComparePlots/CDF", showWarning=F)
    for(i in 1:length(files))
    {
#     temp1 = read.csv(paste(files[i],".csv",sep=""),sep=";")
#     temp2 = read.csv(paste(files[i],"_re.csv",sep=""),sep=";")
#     temp  = merge(temp1,temp2,by=names(temp1), all=T)
      temp  = read.csv(paste(files[i],".csv",sep=""),sep=";")

      if(all(temp[,parX] == 0,na.rm=T)){next} # print(paste("break",i,sep=" - "))
                                            ; next}

      if(i==1){ L1 = temp[,parX]; range=range(L1,na.rm=T)}
      if(i==2){ L2 = temp[,parX]; range=range(L1,L2,na.rm=T)}
      if(i==3){ L3 = temp[,parX]; range=range(L1,L2,L3,na.rm=T)}
      if(i==4){ L4 = temp[,parX]; range=range(L1,L2,L3,L4,na.rm=T)}
      if(i==5){ L5 = temp[,parX]; range=range(L1,L2,L3,L4,L5,na.rm=T)}
      if(i==6){ L6 = temp[,parX]; range=range(L1,L2,L3,L4,L5,L6,na.rm=T)}
      if(i==7){ L7 = temp[,parX]; range=range(L1,L2,L3,L4,L5,L6,L7,na.rm=T)}
      if(i==8){ L8 = temp[,parX]; range=range(L1,L2,L3,L4,L5,L6,L7,L8,na.rm=T)}
    }
    if(all(c(L1,L2,L3,L4,L4,L5,L6,L7,L8)==0)){print(paste("Not Applicable",name,
                                          sep=" - ")); break;}

    png(name,width=600,height=600);
      plot(ecdf(L1),do.points=F,col=1,xlim=range,pch=1,main=paste("CDF plot - ",
                                            parX),
        xlab=parX,ylab="Probability")
      legend("bottomright",legend = files, col=1:length(files) ,lty=1,pch=1:
                                            length(files));

    for(i in 2:length(files))
    {
      if(i==2){ plot(ecdf(L2),do.points=F,col=i,add=T) }
      if(i==3){ plot(ecdf(L3),do.points=F,col=i,add=T) }
      if(i==4){ plot(ecdf(L4),do.points=F,col=i,add=T) }
      if(i==5){ plot(ecdf(L5),do.points=F,col=i,add=T) }
      if(i==6){ plot(ecdf(L6),do.points=F,col=i,add=T) }
      if(i==7){ plot(ecdf(L7),do.points=F,col=i,add=T) }
      if(i==8){ plot(ecdf(L8),do.points=F,col=i,add=T) }
    }
    print(dev.cur())
    dev.off();
    break;
  }
}


# files <- c("CL_X","OL_X","CL_X_re","OL_X_re")
# CDFplot(files,"AVG_SINR.dB.")
```

Glossary

4G Term often used to denote future broadband mobile communications systems or standards with high mobility and bit rates beyond 100 Mb/s to follow 3G. Previously often referred to as "systems beyond 3G" (B3G). The most advanced coming standards are 3GPP's LTE-Advanced and the IEEE 802.16m.. 1

HSDPA Enhancement of the 3G standard UMTS in order to provide higher bit rates on the downlink. The theoretical data rate can reach 14.4 Mb/s. Together with Enhanced Uplink (EUL/HSUPA) the term HSPA is often used.. 1

LTE Name of 3GPP's Work Item for standardising the access technology of their 4G mobile broadband standard, Evolved UTRA and UTRAN (E-UTRA(N)). Often used as name of the new system itself. E-UTRA is based on OFDMA technology combined with MIMO to provide end-user peak bitrates up to 200 Mb/s. First tests were performed late 2007 and the first products appeared early 2010.. 1

MIMO MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed. MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SIMO (single input, multiple output). MIMO technology has aroused interest because of its possible applications in digital television (DTV), wireless local area networks (WLANs), metropolitan area networks (MANs), and mobile communications.. 1

SFBC Method of using MIMO technology for transmit diversity, resembles STBC.. 1

SM Multiple antenna technique where different uncorrelated sub-channels are used to increase the overall link capacity of a wireless link. It is a MIMO technique where multiple antennas are employed both at transmitter and receiver in order to span out several sub-channels.. 1