IEE 572 - FALL 2016

OPTIMIZATION OF WIRELESS INTERNET EXPERIENCE

DESIGN OF ENGINEERING EXPERIMENT

INSTRUCTOR: PROF. DOUGLAS C MONTGOMERY

TAPAN DOSHI	9:00 A.M. -10:15 A.M.
MITHUN MURALIDHAR	9:00 A.M. -10:15 A.M.
BHARATH HEBBAR	9:00 A.M. -10:15 A.M.

TABLE OF CONTENTS

	Introduction	....	1
1.	Recognition of and statement of the problem	....	1
2.	Choice of factors, levels and ranges	....	1
3.	Selection of response variable	....	5
4.	Experimental setup & Procedure	....	5
5.	Choice of experimental design	....	5
6.	Experimental design matrix	....	6
7.	Results and analysis	....	
	(i) R squared	....	7
	(ii) ANOVA table	....	8
	(iii) Normal Plots	....	9
	(iv) Residual Analysis	....	10
	(v) Residual vs Each Factor	....	14
	(vi) Interaction plots	....	16
8.	Conclusions	....	21
9.	References	....	21

INTRODUCTION

The focus of this experiment is to design and perform an experiment adhering to the fundamentals of Experimental Designs. The experiment titled ***Optimization of Wireless Internet Experience*** is designed to obtain best internet experience from the possible conditions. The experiment is scrutinized with the statistical approach and computing tools like JMP and Design Expert. The statistical analysis provides strong conclusions with reference to the best Signal Strength experienced from a router when subjected to varying operation conditions.

1. RECOGNITION OF AND STATEMENT OF THE PROBLEM

In the modern day it is almost impossible to live without internet. Or in other words we are so addicted to Internet in our daily life, that we find it hard to manage without it even for a single day. It is also important to get the good signal strength to obtain best internet experience. The experiment ***Optimization of Wireless Internet Experience*** is aimed to determine the best Internet experience for the users. During the experiment, we intend to check how the different factors affect the Signal strength.

2. CHOICE OF FACTORS, LEVELS AND RANGES

After analyzing the reasons which can affect the usage of wireless internet experience for the users, we came across three important factors influencing the process.

Distance: Signal strength varies with the distance between router and the device connected. Several runs are performed varying the distances of the device connected to Wi-Fi with respect to the router and observing the signal strength. The project was conducted in an apartment and the levels for distance were taken accordingly.

Two levels for this factor includes:

- At the distance of 2 meter
- At the distance of 8 meter

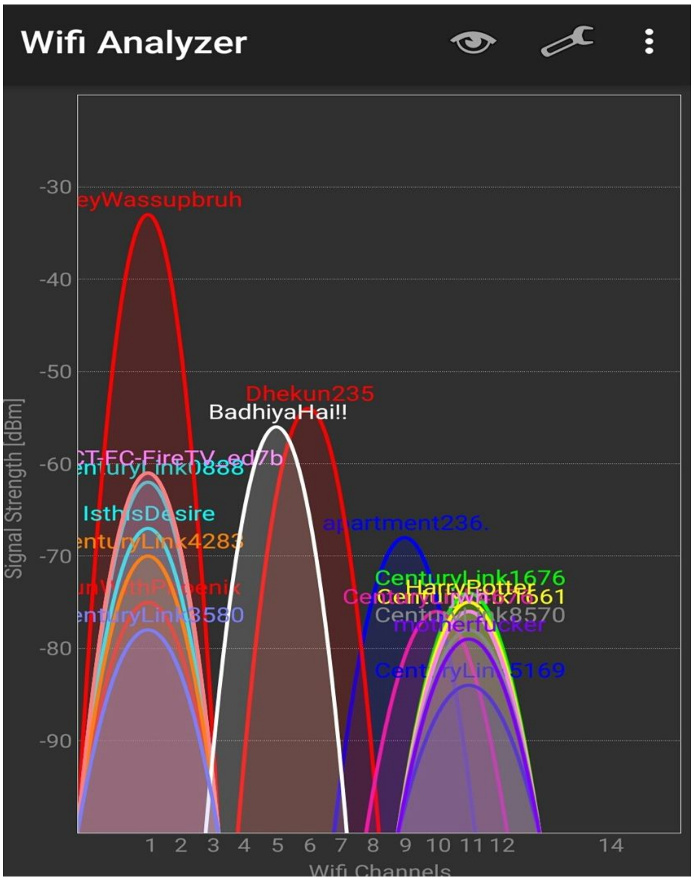
Channel: Co-Channel interference is a major problem as there are too many Wi-Fi devices on the same channel. Adjacent-Channel interference on the other hand is where we run into problems and channel selection becomes critical. Luckily, these channel related interferences can be reduced or eliminated by selecting the proper Wi-Fi channel for your network.

Two levels for this factor include:

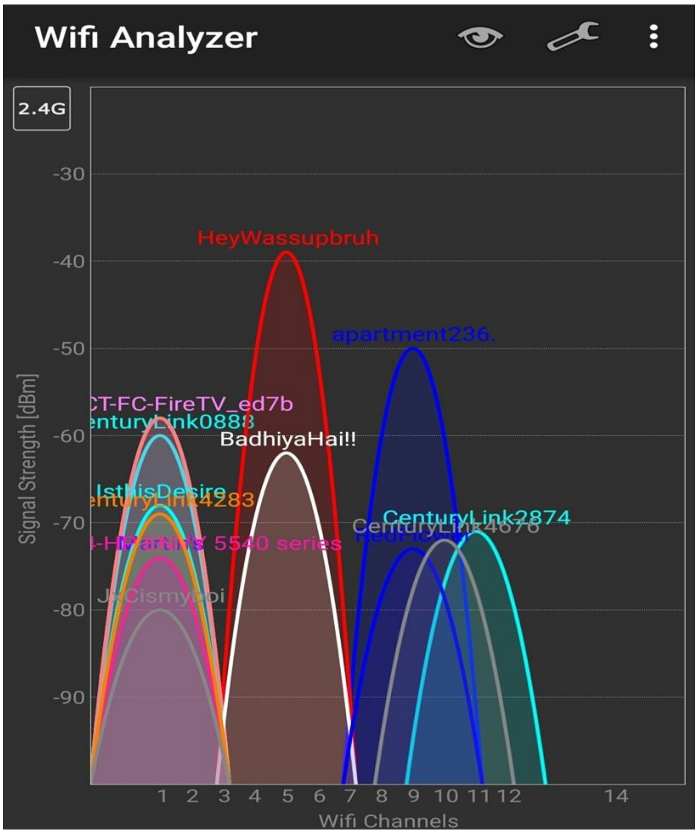
- Channel 5
- Channel 1

Interference pattern and the selection of channel is shown in the images below where the plotting for Channel VS Signal strength is done.

For Channel 1:



For Channel 5:

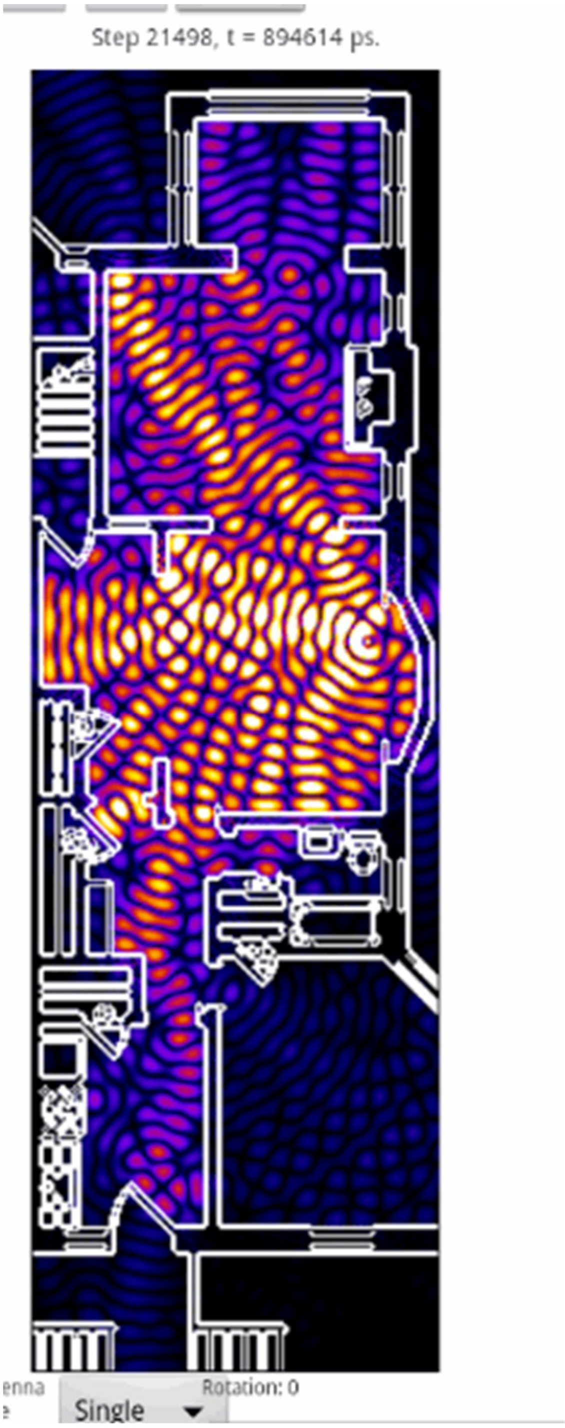


Each channel on the 2.4 GHz spectrum is 20 MHz wide. The channel centers are separated by 5 MHz, and the entire spectrum is only 100 MHz wide total. This means that the 11 channels have to squeeze into the 100 MHz available, and in the end, overlap.

As we can see from the Signal analyzer there are more overlapping signals on Channel 1 as compare to Channel 5. As a potential factor we have expected selection of Channel as significantly affecting factor for getting Wi-Fi signal strength.

<u>Physical Obstruction:</u> Wireless signals can have trouble penetrating solid objects which can be any numbers of things such as hills, buildings, single walls or even people. The more obstructions you have between the transmitter and receiver, the more chance there is that the signal strength will be affected.

However, it’s important to understand the impact that physical obstructions can have on your wireless performance. Materials such as concrete and wired mesh in thicker walls are particularly problematic.



As we can see from the image that the signal distribution is hindered by the physical obstruction like wall. We have taken two levels for the physical obstruction to measure its significance.

Levels for the Physical Obstruction factor:

- With Obstruction
- Without Obstruction

3. SELECTION OF RESPONSE VARIABLE.

Signal strength will be the response variable through which we can determine which combination of factors will give the best signal strength and hence the best Internet experience for the user. Signal strength is measured in decibel- milliwatts (dBm). Source of measuring the Signal strength is running an application which measures and compares the signal strength. It also helps us to find a less crowded channel for the wireless router.

NUISANCE FACTOR:

Since our experiment was performed indoors, it is quite possible that varying types of electromagnetic interference may affect our wireless signal strength. Also the signals from the neighboring Wi-Fi routers which may affect the signal strength of our router is a nuisance factor as it is uncontrollable and unavoidable.

4. EXPERIMENTAL SETUP & PROCEDURE

The experimental setup consists of measuring the output of signal strength from the application *Wi-Fi Analyzer*. The signal strength will be measured through the mobile device with varying operating conditions and factors. The output would be recorded against the run-order. Entire experiment was performed in randomized order. The whole experiment was performed in a single stretch with the same conditions so that the interference from the other Wi-Fi networks remains almost same for all runs of the experiment.

5. CHOICE OF EXPERIMENTAL DESIGN:

To perform this experiment, we assign two levels to each factor as shown in Table Each of the factor has high and low levels. Distance is a quantitative factor whereas the other two factors are categorical. Since the experiment design involves three factors at two levels each, we will follow 2^3 factorial design. Each trial will be replicated 3 times, so the total design matrix will have sample size of $2^3 * 3 = 24$ runs.

Factor	Type of Factor	Low-level	High-level
Distance	Continuous	2	8
Channel	Categorical	1	5
Physical Obstruction	Categorical	With	Without

Table 1: List of factors and their corresponding levels

6. EXPERIMENTAL DESIGN MATRIX

Select	Std	Run	Factor 1 A:Distance	Factor 2 B:Physical O...	Factor 3 C:Channel	Response 1 Signal strength dBm
	5	1	8	with	1	-63
	1	2	2	with	1	-50
	6	3	8	with	1	-61.5
	3	4	2	with	1	-52
	21	5	2	without	5	-28
	16	6	8	with	5	-47
	11	7	8	without	1	-44.5
	22	8	8	without	5	-33
	2	9	2	with	1	-51
	12	10	8	without	1	-47
	9	11	2	without	1	-42.5
	4	12	8	with	1	-61
	14	13	2	with	5	-38
	13	14	2	with	5	-36
	17	15	8	with	5	-47.5
	23	16	8	without	5	-32
	15	17	2	with	5	-34
	19	18	2	without	5	-29
	18	19	8	with	5	-49
	8	20	2	without	1	-40
	24	21	8	without	5	-33
	20	22	2	without	5	-27
	10	23	8	without	1	-46
	7	24	2	without	1	-41

The design matrix with 24 run order in a randomized order is as shown in the table above and the response variable readings are incorporated in the last column of the table.

7. RESULTS AND ANALYSIS

7.1 R-SQUARED

Various R squared values are as shown below :

Std. Dev.	1.19	R-Squared	0.9894
Mean	-43.04	Adj R-Squared	0.9872
C.V. %	2.76	Pred R-Square	0.9831
PRESS	42.68	Adeq Precisior	62.933
-2 Log Likeliho	70.71	BIC	86.60
		AICc	84.05

The value of R-squared is 0.9894 which shows that the percentage of the variability explained by the model is 98.94 and thus the design is a good fit to the model. Also Pred R-square is in reasonable agreement with Adj R-squared.

The effect estimates are shown in the table below.

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-43.04167	0.241057	-178.6	<.0001*
Distance(2,8)	-4	0.241057	-16.59	<.0001*
Physical Obstruction[With]	-6.125	0.241057	-25.41	<.0001*
Channel(1,5)	6.9166667	0.241057	28.69	<.0001*
Distance*Physical Obstruction[With]	-1.666667	0.241057	-6.91	<.0001*
Distance*Channel	-0.125	0.241057	-0.52	0.6108
Physical Obstruction[With]*Channel	0.3333333	0.241057	1.38	0.1846

Based on the parameter estimates generated by JMP, taking P-value into consideration, it is evident that Factors A, B, C and AB are significant model terms. Once the p-value goes below a certain value determined from the t-table and degrees of freedom, the factors can be declared as being significant.

7.2 ANOVA FOR SELECTED FACTORIAL MODEL:

Response 1 Signal strength

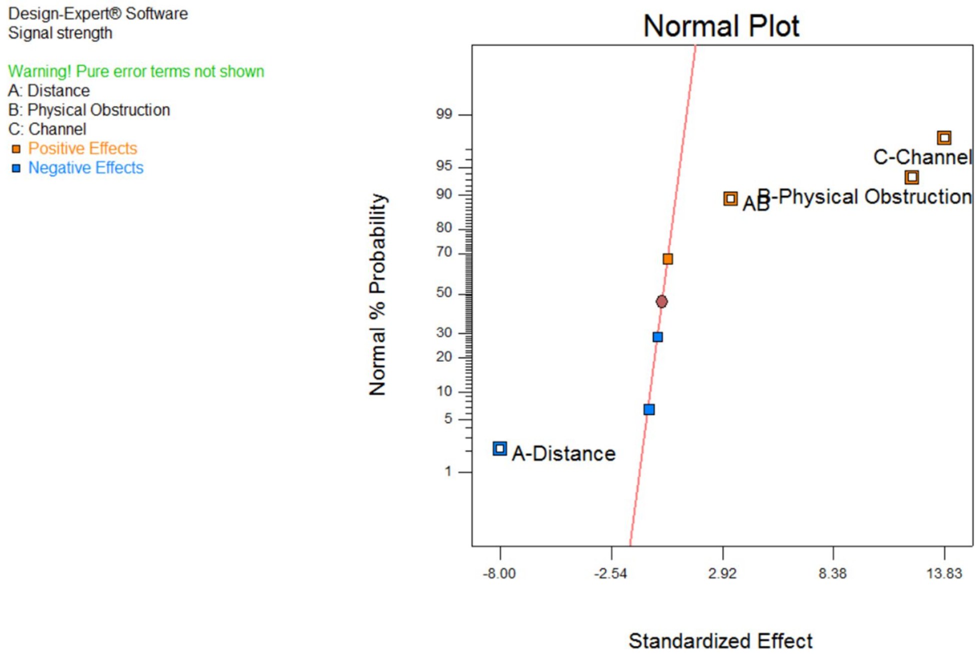
ANOVA for selected factorial model

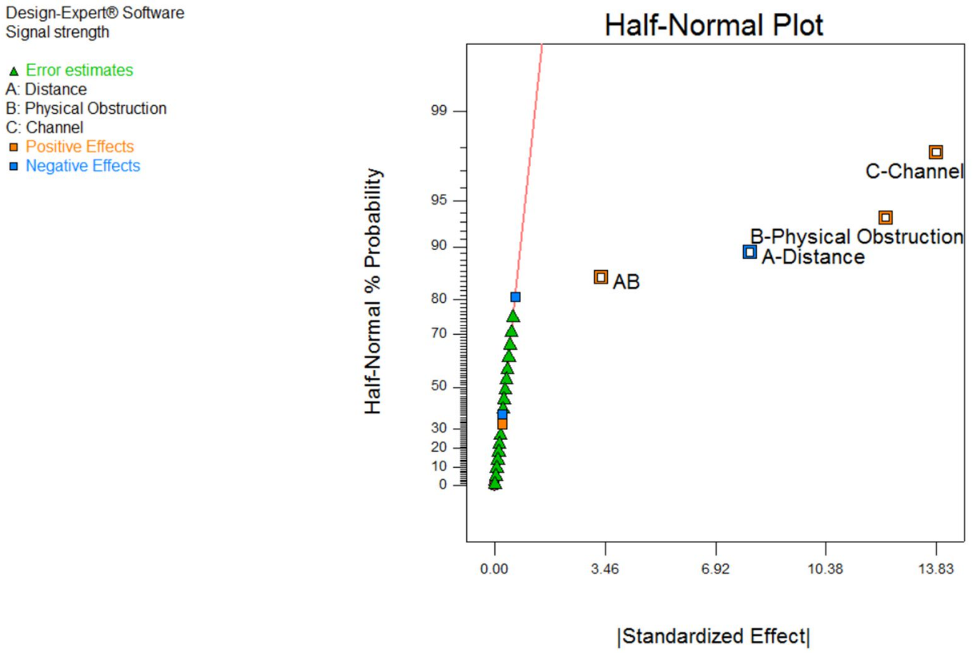
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2499.21	4	624.80	443.78	< 0.0001	significant
A-Distance	384.00	1	384.00	272.75	< 0.0001	
B-Physical C	900.38	1	900.38	639.52	< 0.0001	
C-Channel	1148.17	1	1148.17	815.52	< 0.0001	
AB	66.67	1	66.67	47.35	< 0.0001	
Residual	26.75	19	1.41			
Lack of Fit	3.42	3	1.14	0.78	0.5217	not significant
Pure Error	23.33	16	1.46			
Cor Total	2525.96	23				

The results are further corroborated by running the analysis in Design Expert and from the F-values, the same factors can be seen as significant. However factor AB is comparatively less significant than main factors. The F-statistic is calculated by taking the proportion of the mean square of the factor by the mean square of the residual. Thus, higher the value of mean square, more significant the factor can be seen to be. In this case, it appears that the main effect channel has the highest mean square and perhaps is the most significant factor.

7.3 NORMAL PLOTS





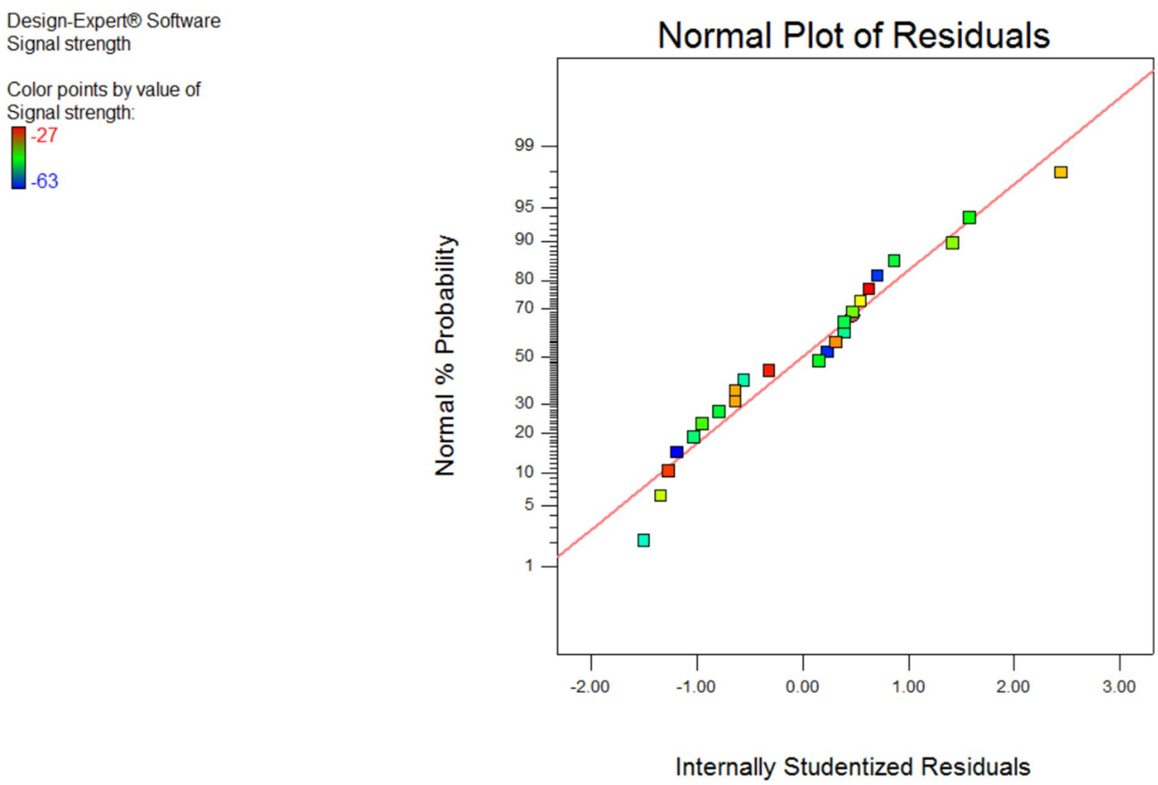
The half normal plot is used to identify which factors are significant in an experiment visually. It is a graph of Estimates against their normal quantile in a cumulative manner. The effects which are significant can be seen far away from the line. In this model, all the 3 factors and the Distance/Physical Obstruction interaction are significant, however the interaction effect is minimal when compared with main factors. The percentage contribution of which is as shown in the table below.

Term	Stdized Effect	Sum of Squares	% Contribution
Intercept			
A-Distance	-8.00	384.00	15.20
B-Physical Obstruction	12.25	900.38	35.64
C-Channel	13.83	1148.17	45.45
AB	3.33	66.67	2.64
AC	-0.25	0.38	0.015
BC	-0.67	2.67	0.11
ABC	0.25	0.38	0.015
Lack of Fit		0.000	0.000
Pure Error		23.33	0.92
Lenth's ME	2.44		
Lenth's SME	3.51		

Percentage contribution of the factors

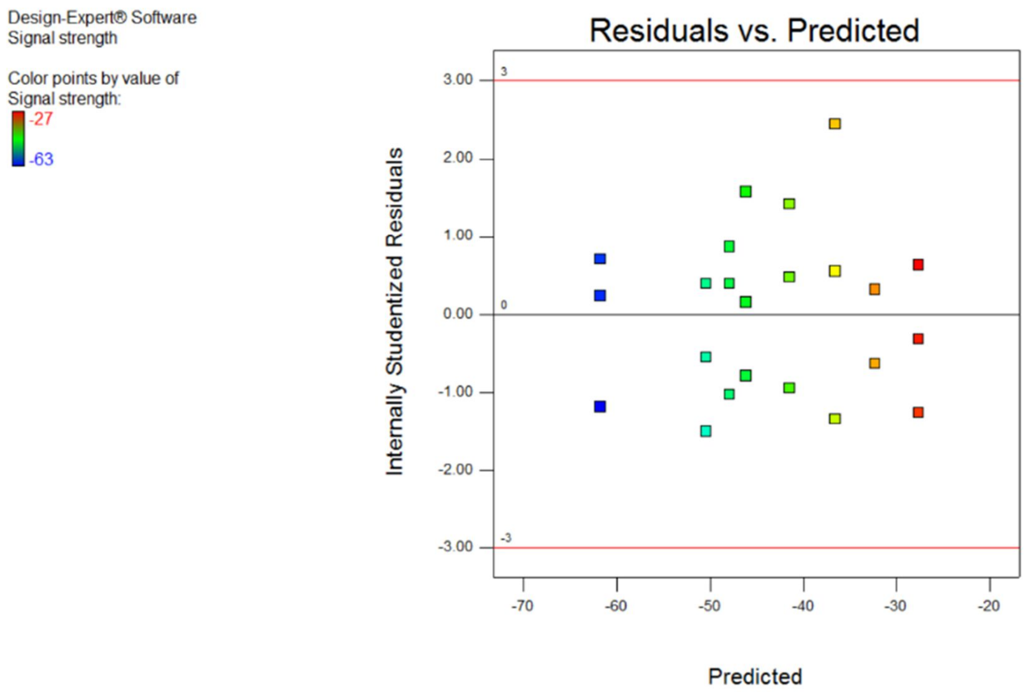
As seen from the table the percentage contribution of factor A, B &C is relatively higher as compared to their interactions. However, the AB interaction is significant but not as much as the individual factors, which is also conclusive from the half normal plot.

7.4 RESIDUAL ANALYSIS:



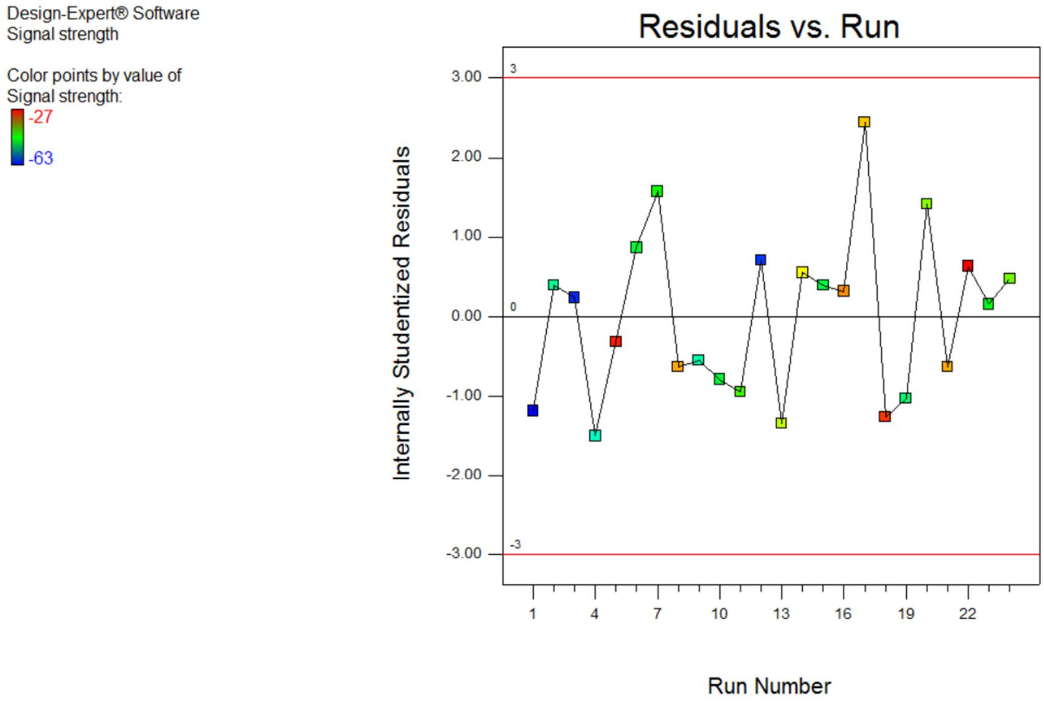
Violation of basic assumptions and model adequacy can be easily investigated by examination of residuals. By analyzing residuals we can determine whether the results from the factorial analysis can be depended upon. A normal probability plot of residuals is plotted to verify that data comes from a population of normal distribution. This assumption holds good if the residuals fall along the straight line with little deviation. In our case, majority of the residuals tend to fall in line with emphasis being laid on center values of plot than on extremes. Only few residuals at extremes tend to deviate from the line indicating presence of outliers which should not significantly affect our data. Therefore we can conclude that there are no alarming problems with normality and the model is adequate.

Residuals vs. predicted



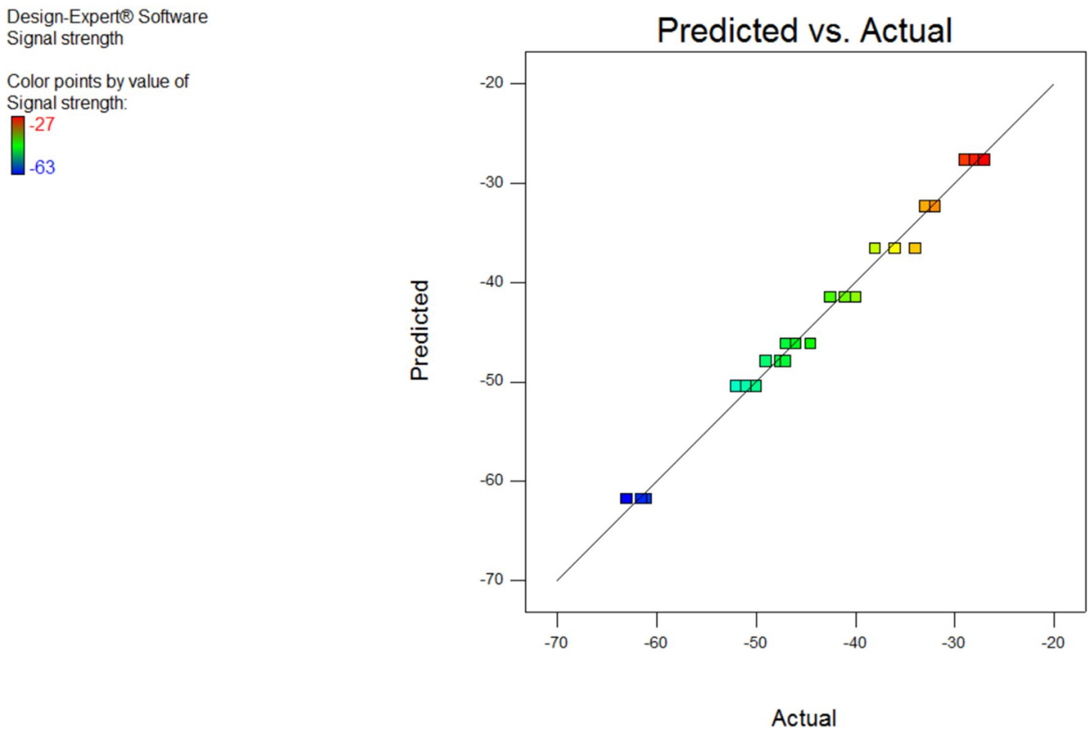
A plot of Residuals by predicated values is another method to check on model adequacy and validity of assumptions. Predicted values plot is a structureless model and shows no obvious pattern (like outward or inward funnel) or correlation between points, hence the model is correct and constant variance assumptions are satisfied.

Residuals vs. Run order



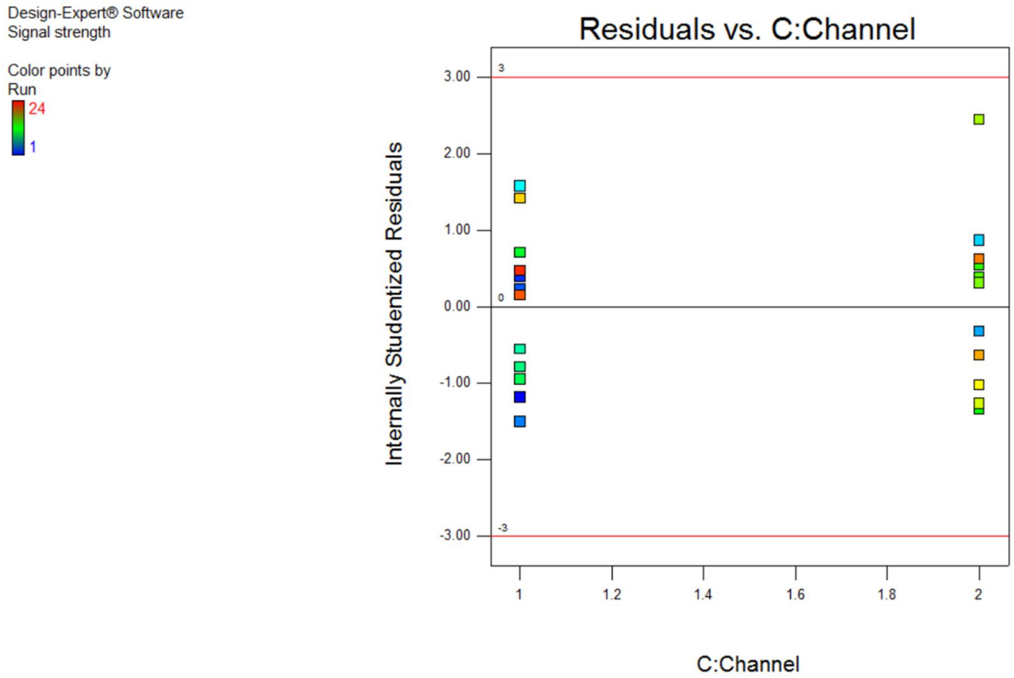
Plot of residuals by run order helps in detecting strong correlation between residuals. The model seems good without violating independence and constant variance assumption.

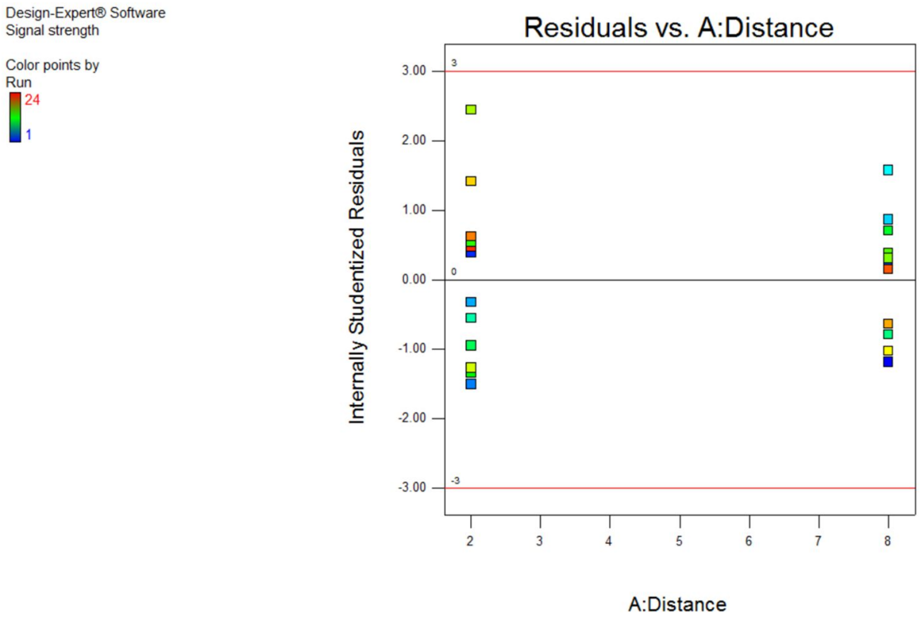
Predicted vs. Actual values

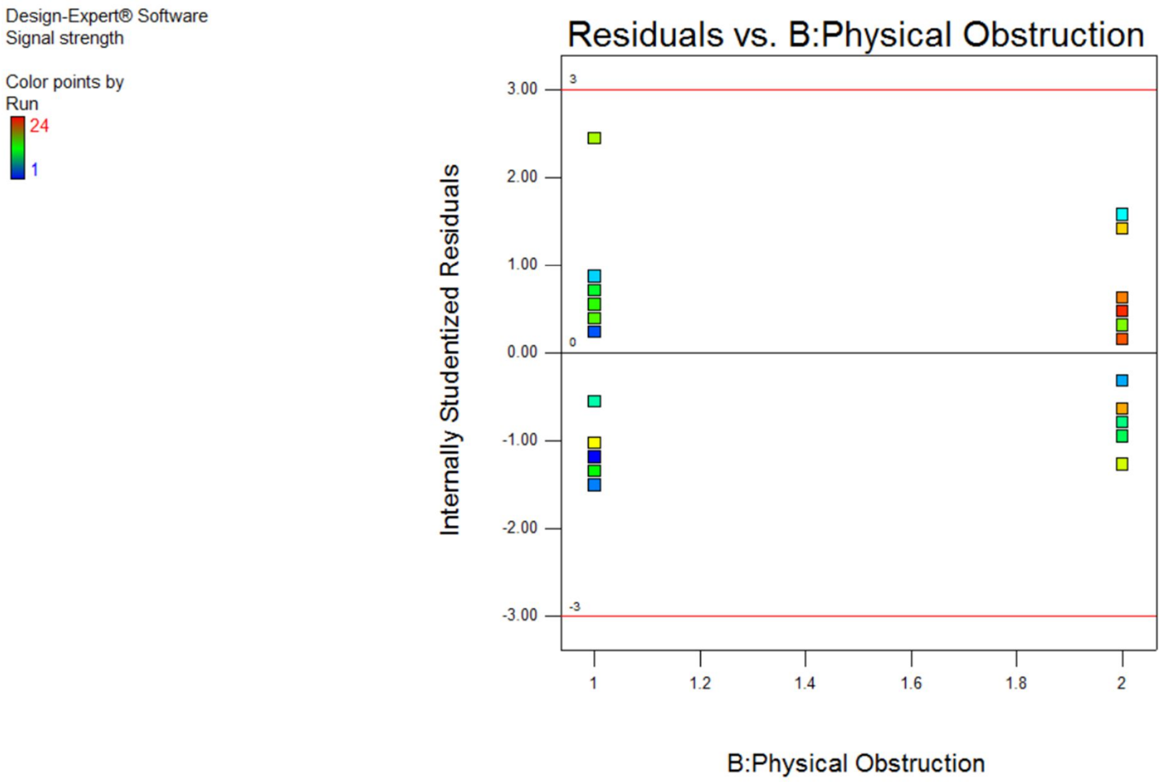


By plotting predicted by actual values, we can determine how well the model fits the data. In this case the points fall along a straight line and makes a complete fit for the data. With little variance between the values, we can confirm that model provides a good fit.

7.5 RESIDUALS VS EACH FACTOR

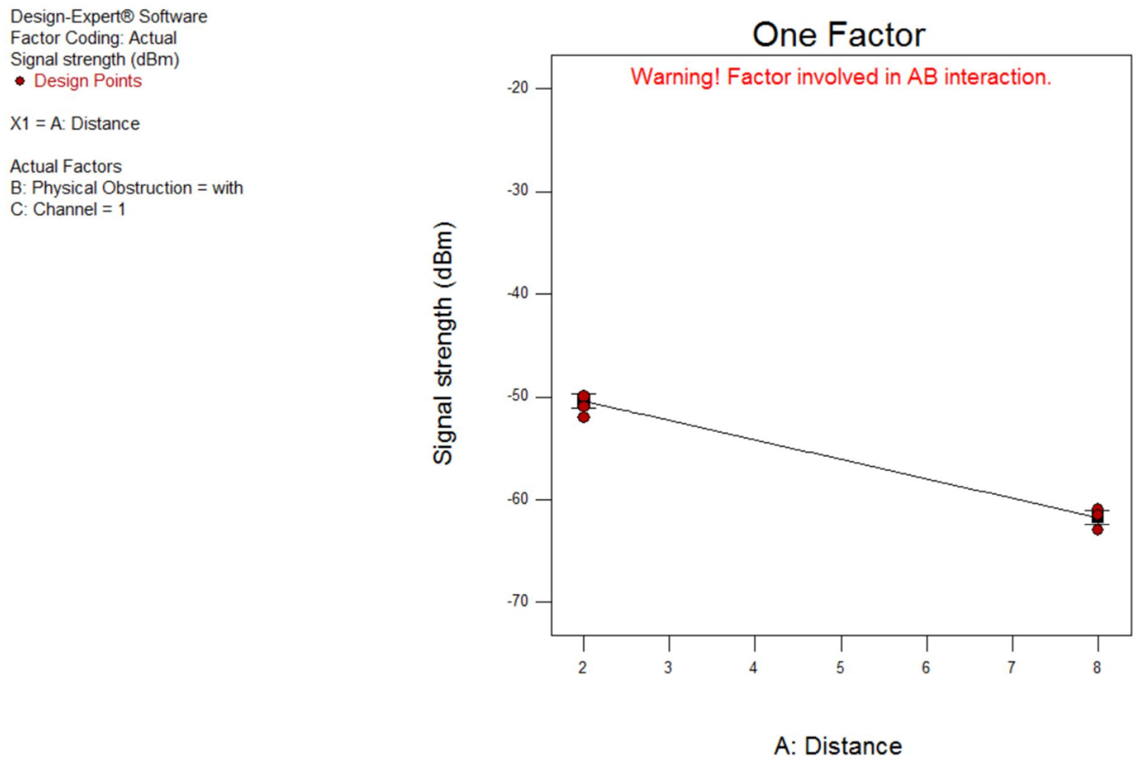


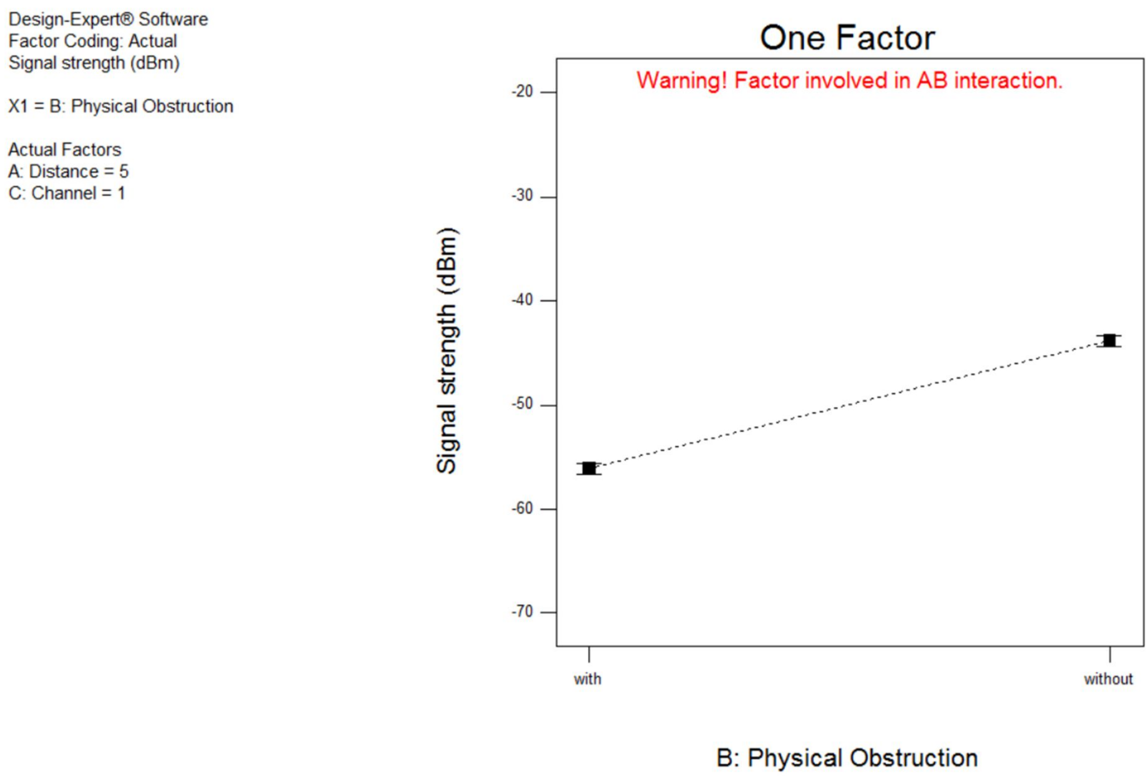


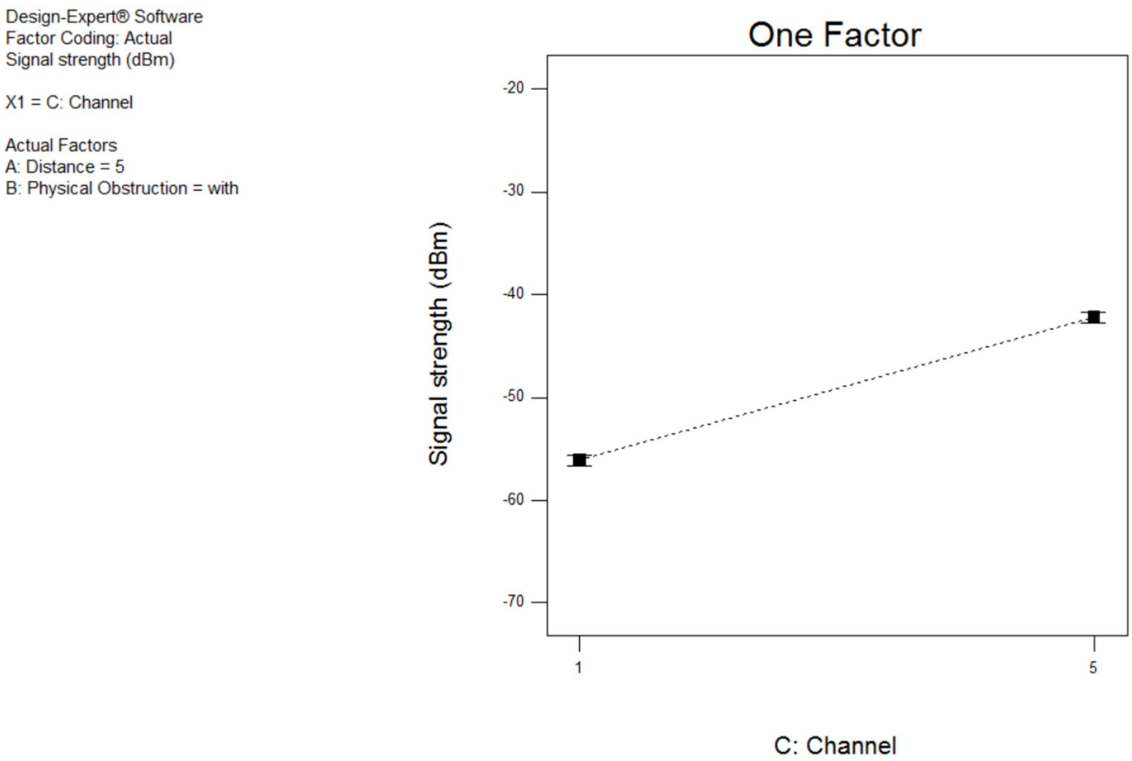


From this plot, we can determine the variability of each factor with some levels. Factors A, B have a certain variability at their respective low levels whereas factor C has some variability at its high level. But the variability difference is not so high in each factors. The distribution between positive value and negative value is random and has no tendency to be one side. Hence we can conclude that there is nothing unusual in the experiment.

7.6 VARIATION OF SIGNAL STRENGTH WITH SIGNIFICANT FACTORS:







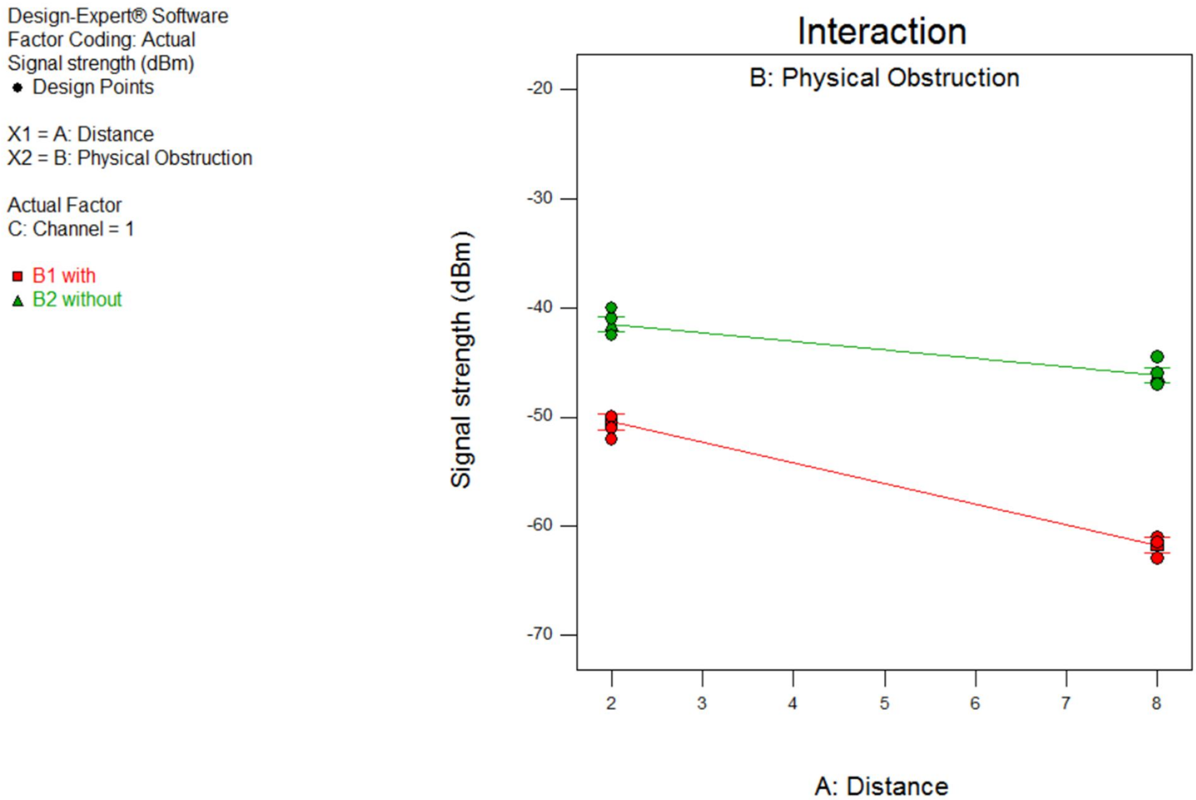
Signal strength varies with each factor as follows:

Distance: Signal strength decreases as distance shifts from low level (2) to high level (8).

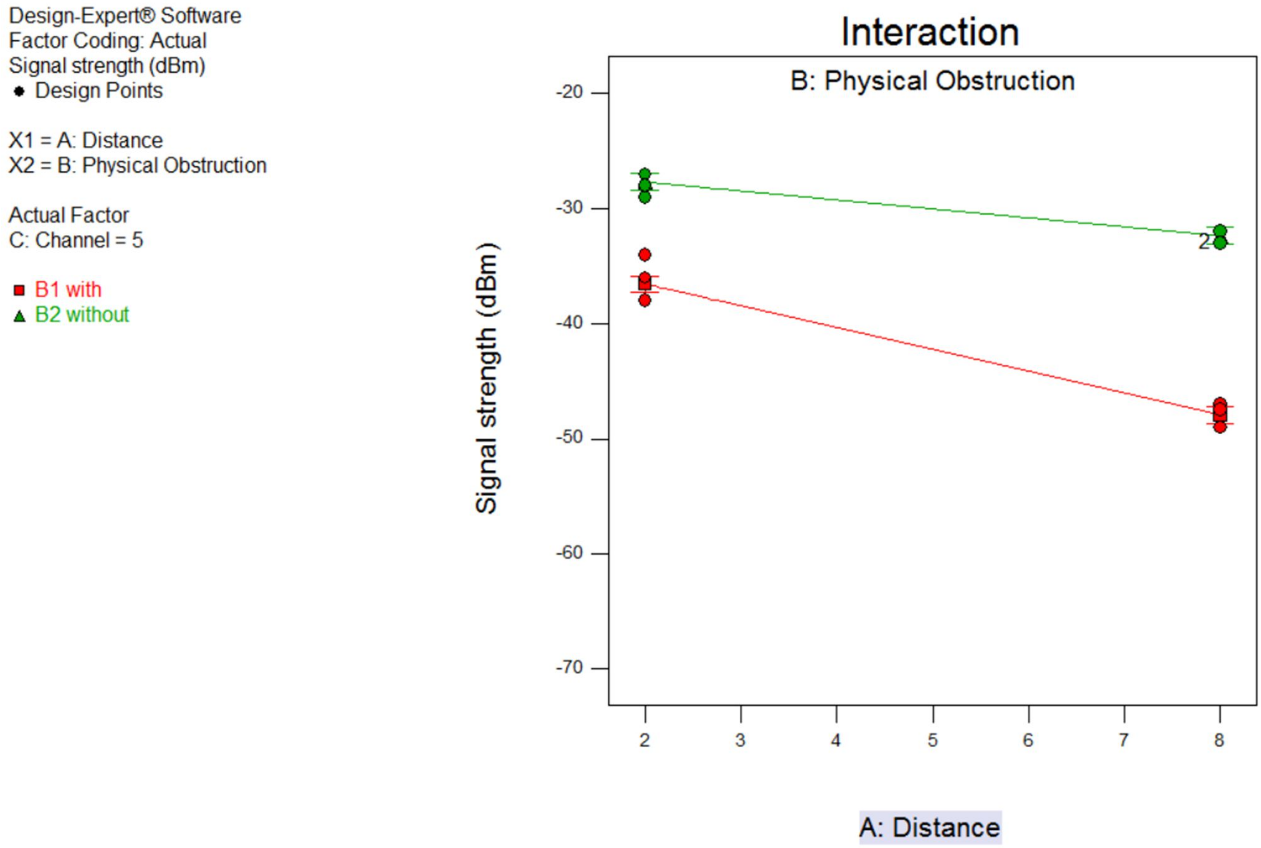
Physical Obstruction: Signal strength is low with physical obstruction and high without physical obstruction.

Channel: Signal strength increases as channel shifts from low level (1) to high level 5).

INTERACTION PLOTS:

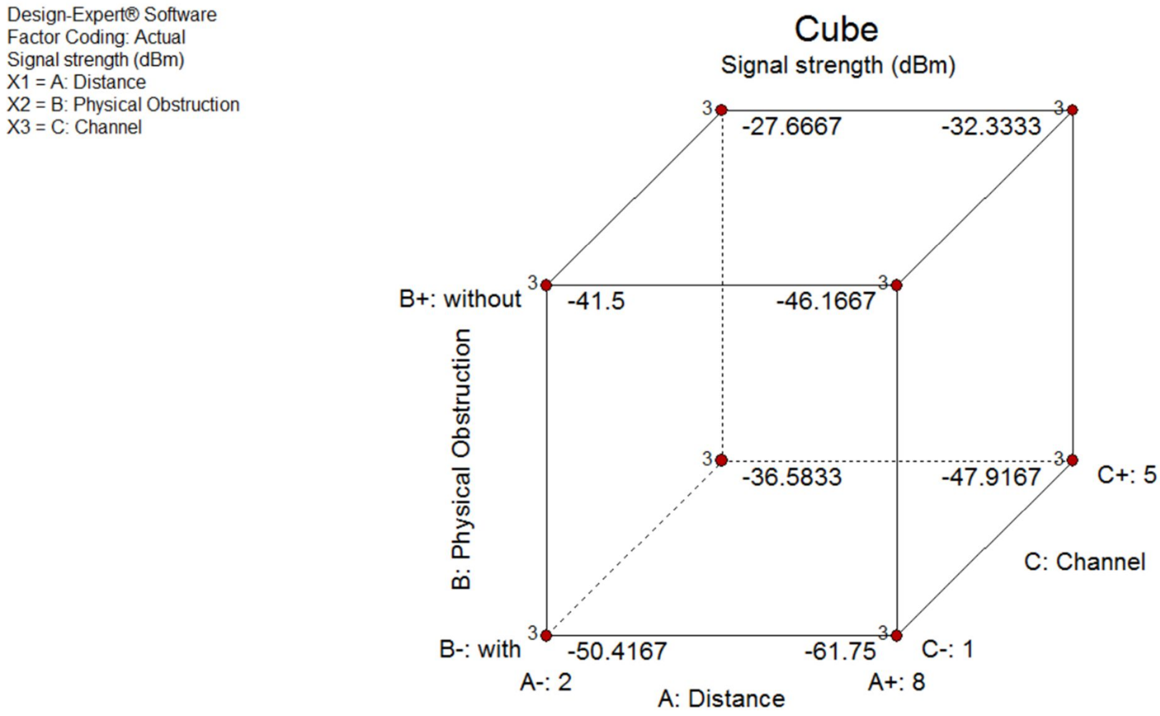


This can be observed from almost parallel nature of curves. From the plot, we can observe that as the distance from the Wi-Fi router increases, the signal strength decreases (gets worse) without the physical obstruction in channel 1. In the presence of physical obstruction, the signal strength gets even more worse as depicted by the red line in the plot. However, with the combination of low level for Distance (2) and high level for physical obstruction (without) for channel 1, the signal strength is better.



This plot gives the same interpretation as the the previous one but since the channel 5 is being considered, the signal strength is better compared to the previous case. From the plot it can be seen that signal strength is the best at 2 meter without physical obstruction and worst at the distance of 8 meters with obstruction, indicating the relation between the two. From interaction graphs obtained, we can infer that the best combination of factors for obtaining good signal strength is at a distance of 2 meters from the router without any physical obstruction and with a channel 5 having least interference.

Cube Matrix



The cube matrix is as shown in the figure. The best value (in this case the least positive) of the response variable is when the factors B & C are at high levels and the factor A at the low level. Or in other words, the best signal strength can be observed at a distance of 2 meter from the router without the physical obstruction and at channel 5.

8. CONCLUSION

The objective of this project was to establish the best internet experience for users.

Analyzing the experimental results, it can be concluded that the conditions that would yield best internet experience for users are:

Distance: 2 meters. (Devices connected to Wi-Fi should be closer to the router).

Physical obstruction: Without. (Less physical obstruction between router and device).

Channel: 5. (Optimum channel should be selected with less or no overlapping of Wi-Fi networks).

Choosing the best Wi-Fi channel on your router helps to reduce interference and improve your Wi-Fi signal strength.

There are tools that can help you find the clearest channel, such as Vistumbler. It helps you to just switch between channels until you find one that works well. Using these tools, we can make sure that we are using the optimum channel (with least interference) and get the best signal strength. Changes were made at home according to the significant factor combinations obtained in our analysis and internet experience was made even better.

9. REFERENCES

- 'Design and Analysis of Experiments', Eighth Edition by Douglas C Montgomery, John Wiley & Sons, Inc.
- https://en.wikipedia.org/wiki/DBm
- https://www.microsoft.com/en-nz/store/p/wifi-analyzer/9nblggh33n0n