Modeling and Optimization of Mobile Signal Strength in challenging Atmospheric Conditions

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Research Article

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Modeling and Optimization of Mobile Signal Strength in challenging Atmospheric Conditions

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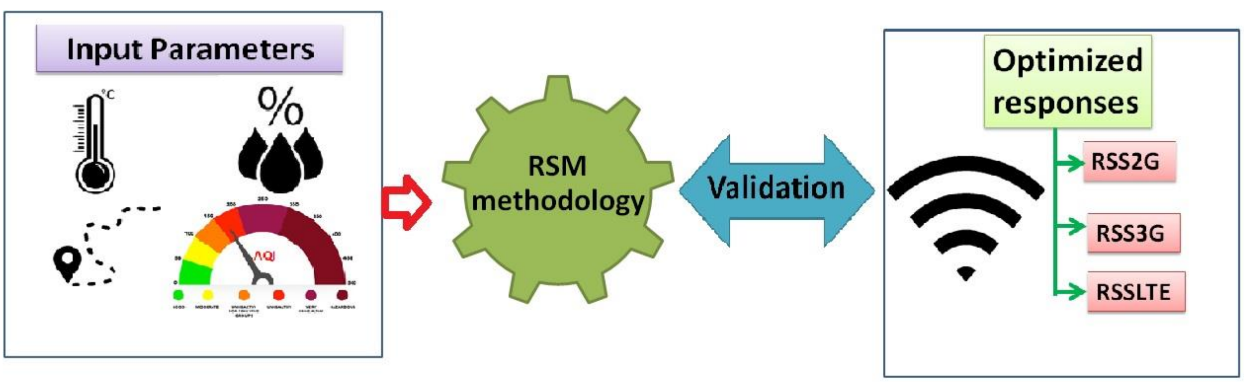
Graphical Abstract



Abstract

For the network planning in the field of telecommunication networks received signal strength plays an important role. The received signal strength gets affected due to the varying environment condition through which the signal propagates and it also depends on the distance between the location of signal transmitter and the receiver. So complete information about these parameters are very much requires for proper mobile network planning. By keeping all these challenges in mind, this study was aimed to determine the received signal strength for Long-Term Evolution (LTE), Second Generation (2G) and Third Generation (3G) wireless technologies with challenging environment conditions. All the experiments were conducted at Lajpat Nagar residential area which is located in New Delhi. During the experiments received signal strength for all the three above mentioned wireless technologies were monitored with respect to varying environment conditions (Temperature, Relative Humidity and Air quality index for Particulate Matter 2.5) and distance from the base station. Later the optimization of received signal strength was carried out by using response surface methodology. Measurement results showed that Second Generation (2G) signal strengths was significantly higher than Third Generation (3G) and Long-Term Evolution (LTE) and the best values obtained for received signal strength for Long-Term Evolution (LTE), Third Generation (3G) and Second Generation (2G) were -77.9264dBm, -60.0345dBm and -58.1280dBm respectively. ANOVA results shows good mathematical modeling between input and output responses.

Keywords – Received Signal Strength, Response surface methodology, LTE, 3G, 2G.

Nomenclature			
Temperature	TEMP	Received Signal Strength for third-generation cellular network	RSS3G
Relative Humidity	RH	Response Surface Methodology	RSM
Air Quality Index	AQI	Central composite rotating design	CCRD
Distance from Base Station	DFBS	Long Term Evolution	LTE
Received Signal Strength for Long Term Evolution	RSSLTE	Third-generation	3G
Received Signal Strength for second-generation cellular network	RSS2G	Second-generation	2G
		Multiple input and multiple output	MIMO

1. Introduction

Mobile plays a vital role in our day to day life from our personal stuff to connecting people it is required in every dimension of our life. All these devices communicate through radio waves [1]. The transmitter transmits these radio waves which are being received by the receiver which operated within a frequency band. The received signal strength of these radio waves is an important factor to be considered. Telecommunication had a drastic change from analog to digital communication. There are three main components that are required to setup a communication system and they are Transmitter, Receiver and the channel between the two.Transmitter and receiver antenna are important part for the communication and these channels between them plays the important role to depict the received signal strength. These channel communication gets affected by various different reasons.There are many types of obstacles due to which there is a loss of signal strength in the channel which is termed as path loss. The signal which passes through this channel crosses the troposphere layer of atmosphere of earth. Our atmosphere consists of several layers one of which is troposphere.It is that layer which covers the earth region to 16 km from equator and 8 km from pole.This layer is responsible for the refractivity of the air which plays an important role in signal transmission. Although there are various other reasons that affect the propagation of waves among which the varying atmospheric parameters in the transmission channel plays the important role. These effects are directly or indirectly related with the troposphere layer of the atmosphere. The refractive index of air in the troposphere and the refractivity of air varies due to the changes in the temperature, humidity, wind speed, atmospheric pressure etc. In the study of troposphere it was found that there is a frequent decrease in temperature with rate of 10 ^{0}C per km of the altitude of troposphere [3]. Whereas the speed of the wind is related with the atmospheric pressure variation in this layer, it does not effects the signal directly it can lead to disconnection or low rate of data transmission in a network [6]. Due to some factors like refraction as discussed above, reflection, absorption of the signal in this layer results into propagation loss and it can also be noted that communication system is sensitive to the transmission losses. Moreover, the additional losses are due to the Doppler Effect produced by the movement of the mobile user due to which the base station keeps on changing for every user, resulting in attenuation of the signal and results in reduced signal strength.

In view of all the above mentioned issues, this research work was focused to study and to optimize the variation in received signal strength with respect to four major parameters i.e. varying Temperature, Relative Humidity, user Distance form Base Station and Air QuantityIndex (AQI) for Particulate Matter (PM2.5). This complete study was carried out for three different wireless communication technologies i.e. LTE, 3G and 2G technologies.

2. Related Work

Cellphones have become an essential object of use for each and every person in the world.It is a stepping stone to the digitalization era in which network plays an important role for utilization of this handset.Sometimes these networks face obstacles due to the environmental changes affecting the strength of the signal. These atmospheric distraction can be varying humidity, temperature, wind speed and many more .There are many research works taken place to study the relation of these atmospheric parameters and the networking system. For instances, Ofure et al. in their work studied the impact of these parameters on GSM(Global System For Mobile Communication) in their 19 months of experiment at the Bosso Campus of the Federal University of Technology, Minna, Nigeria. They found that there is a positive relation between the signal strength and atmospheric temperature and a negative relation with the humidity in the range of 0.57 to 0.88 and -0.57 to -0.89 respectively with received strength of GSM signal [1]. Similarly Joseph in his research over atmospheric effect on ultra-high frequency at two location, one at Cross River State Broadcasting Co-operation (4057'54.7"N, 8019'43.7"E) and in a residence along Etta-abgor, Calabar (4057'31.7"N, 8020'49.7"E) was measured in which they found that the signal strength is inversely proportional to atmospheric pressure,speed of the wind and direction of the flow of the wind [2].Even Chima et al. analyzed the variation of signal strength due to the effect of temperature and wind speed they practically performed it for five months of duration at Enugu State University of Science and Technology (ESUT),they studied the effect of Temperature, Pressure, Relative Humidity And Wind Speed on UHF radio waves and they found that ducting effect is created in atmosphere due to temperature inversion and thus effects the radio waves and the wind speed effects the bending properties of waves[3]. Usman et al. pointed out a very important factor towards this researcher that even though the atmospheric parameters play an important role in the signal strength but also the location as well as the weather condition affects the network.In their research they found out that temperature has a negative relation with the refractive gradient while humidity has a positive relation [4] . Voznak and Rozhon in their work of over 20 thousand measurement to analyse the effect of atmospheric parameter on GSM/UTMS signal strength and they explained a decreasing quality of speech in the correlation between the speech signal and humidity.[5]. Zafar et al. in his work examined the effect of wind speed humidity as well as temperature over the signal strength which was measured at East Coast of Peninsular Malaysia and they found that the signal strength decreases with the increase of humidity and temperature is inversely proportional to it.They performed this analysis over varying ranges of frequency 382.5 MHz, 945 MHz, 1867.5 MHz and 2160 MHz. It was observed that high temperature low humid weather as well as high humidity and low temperature weather condition ,they concluded that below (0^0C) the temperature have negative relation when the humidity is high on the signal strength[6]. Eli-Chukwu and Onoh in their observation on signal strength readings mainly taken for WCDMA networking at Nigeria. They performed this analysis for five years at Enugu State Nigeria for both summer and rainy season. They observed that there was the maximum number of blocked and dropped calls and in adverse conditions it increased by 4% and 8% respectively. And in summer season it increases by 8.76% and in rainy seasons by 12.89% [7]. Luomala and Hakala in their work they study the behavior of signal with atmospheric variations. They used Atmel Zigbit in a university campus during the December 2013 to July 2014 they found that the result actually varies in summer and winter with respect to the variation of the temperature and humidity. According to them the temperature while near 0°C does not have significant effect but temperature has a negative impact on signal below 0°C. They also found that the temperature has a huge impact rather than any other environmental factor effecting the networking system and suggested that these impacts can be reduced by increasing the frequency diversity to overcome the attenuation produced by these factors [8]. Tchao et al. in their work evaluated about the performance of LTE network of 2400 MHz range at countries like Ghana in Sub-Sahara Africa, they tried to analyse to configuration MIMO for 2X2 and 4X4 and then found that 2X2 MIMO covered more number of users about 60.41% from 1-40 mbps while 4X4 MIMO had only 55.87% [9]. David et al. in their work tried to figure out to pre-predict the fog condition to avoid cases of accidents [10]. Igbekele et al. in their experiment at Jos Nigeria where they divided the experiment location into two parts, one as low josland and other as high josland and they recorded speed upto 4.27 mbps for 2G/3G in rain and 4.29 mbps for clear sky [11]. Lo Sciuto in his research presented a different idea about the factors which affects the strength of the signal. In his work he showed that pollutants present in air can be affect the signal strength and it occurs because of the cross polarization phenomenon. This experiment was performed by the department of electrical, electronics and informatics in the University of Catania [12]. Alim et al. proposed that the radio wave propagation is actually a function frequency itself. They choose a frequency of 900MHF for mobile system antenna which was compared with large scale radio wave propagation practiced on Okumura, Hata, and Lee models [13]. Alshurideh in his work showed that a customer choice in buying a smartphone network is also based on the signal strength that is provided by the server at different location of the world and hence signal strength plays an important role for a server [14]. Yusuf et al. in their work used International Telecommunication Union Radio assembly model (ITU-R P.453-13) in two locations of entirely different vegetation characteristics in Nigeria. They studied the surface refractive gradient of a network for seasonal and diurnal trends in Nigeria. For this they installed to Automatic Weather System at a height of 3 m at Lagos and Anyigba. They concluded that monsoon has a direct impact on the signal strength for any network [15]. Fang et al. analysed the impact of weather condition over the GSM network. They worked on the central weather bureau at Taiwan. They studied the distance and wind speed affecting received signal strength and finally concluded that the strength of GSM signal keeps on decreasing as the speed of the wind or breeze increases [16]. Pooja et al. in their research work concluded that there is a dominating effect of atmospheric parameters on the received signal strength. For a network they studied the variation of temperature, humidity, atmospheric pressure over the signal. In the result they found that temperature is inversely proportional to the signal strength, atmospheric pressure has a negative impact on the signal and also as there is an increase in the humidity it leads to the decrease of signal strength for a network [17]. Hanchinal et al. performed a survey to analyse factors affecting the signal strength path loss in winter season specifically and at a specific location at different time intervals.They studied different models and concluded from their respective results for each time interval that there is a major impact of atmospheric parameters in the path loss for a signal[18]. Guidara et al. researched over a very different idea where they analysed the impact of atmospheric parameters on the signal strength with the change in the environment for indoor as well as for outdoor. They found that the signal strength has a positive relation with relative humidity and for temperature it has a negative relation if the distance between the transmitter and receiver is more than 5m and positive if the distance is less than or equal to 4m[19]. Madariaga et al. in their worked showed the feasibility of the mobile signal strength using crowded data corresponding to the server in Santigo, Chile in their study they found the effects of gatherings over the signal strength of a system[20]. Dinc and Akan in their work proposed that the atmospheric ducts have significant effect on the mobile signal system especially in 2G [21]. Usman et al. in their work experimented about the propagation of 900/1800 MHZ in Bauchi at Nigeria. They showed that Egli and Hata model in appropriate to use with the network of 900/1800 MHz [22]. Ofure et al. in their work they proposed a model to read GSM signal strength with varying atmospheric parameter as input [23]. Engiz et al. compared the signal strength for 2G/3G and 4G networks at a specific route of OndokuzMayis University (OMU) Kurupelit Campus that is helpful for study of enhancement in different areas for different mobile networks [24]. Yang et al. studied the effect of troposphere scattering and the atmospheric duct on signal propagation. They found that over the non-uniform surface propagation shows long distance co-channel interference as there is a change in weather condition [25]. Choudhary et al. [26, 27] in their work they optimized the output parameters using response surface methodology and error between the experimental and optimized results were found to be within 5%. Apart from this, RSM is a commonly used technique to solve many industrial challenges. Hamze et al. [28] explored that RSM is a collection of mathematical and statistical approaches used for simulation and problem solving, where in many running or process variables affect the response. When experiments conducted to optimize performance and minimize emissions levels, RSM proved to be very efficient. Ma et al. [29] explaining the key benefit of the RSM that the nature of RSM-based studies requires fewer tests and is less time-consuming than a true experimental study. In many research reports, this technique is commonly used and has been implemented.

From the literature review it was found that much of research work has already been done to identify the effect of atmospheric parameters on received signal strength (RSS) of wireless communication technologies and many path loss models have also been proposed but the main gap which was found in the research is that no one yet have optimized the received signal strength (for LTE, 3G and 2G technologies) with respect to be the atmospheric variations. So keeping this aspect in mind this research work was focused for multi objective optimization of the Received signal strength for LTE, 2G and 3G with respect to varying input parameters like Temperature-Temp (12°C to 48°C), Relative Humidity – RH (25% to 75%), Distance from Base Station - DFBS (98m to 300m) and Air Quality index - AQI for PM 2.5 (50 to 500). Optimization was carried out by using response surface methodology. The RSM-based method to desirability was used in this research work to refine input variable. For optimization evaluation by dimensionless desirability effect, Minitab'17 software was used.

3. Materials and Methods

This research work was focused to observe the variation in received signal strength for LTE, 3G and 2G wireless communication technologies. All these variation were observed between the time duration from January 2019 to March 2020. This period was selected for the observation because in this whole duration the extreme variation in the atmospheric parameters like temperature, Relative humidity and AQI could be observed. All these observations were taken at Lajpat Nagar (residential area), New Delhi. It is densely populated area with high rise buildings which could help us to observe the effect of deep shadow area on receives signal strength. Effect of four input parameters i.e. varying Temperature (12°C to 48°C), Relative Humidity (25% to 75%), Distance from Base Station (98m to 300m) and Air Quality index (AQI) for PM 2.5 (50 to 500) were observed on Received Signal Strength of LTE (RSSLTE), 3G (RSS3G) and 2G (RSS2G). Spectrum analyzer was use to observe the variation in Receives Signal Strength, a digital hygro-thermometer was used to measure the temperature and humidity variations and the AQI variations were measured with the help of air quality pollution meter. Technical specification of all the components is shown in Table 1. The complete research methodology is shown with the flow chart shown in figure 1.

Table 1: Components technical specifications

<table>
<tr><th>Components Used</th><th>Digital Hygrometer-Thermometer</th><th>Air Quality meter (PM 2.5)</th><th>Spectrum Analyzer</th></tr>
<tr><td rowspan="5">Technical Specifications</td><td rowspan="3">Temperature Measuring range:
Indoor: 10~+50°C(+14~+122°F)
Outdoor:50~+70°C (-58~+158°F)</td><td>Make - SMILEDRIVE</td><td>Make - Rohde&Schwarz</td></tr>
<tr><td rowspan="2">Model Number - SDMIS915I1197C H1704</td><td>Model - FPC1500+B2+B3+FPC</td></tr>
<tr><td>Frequency range - 5 KHz - 3 GHz</td></tr>
<tr><td rowspan="2">Humidity measure range: 20~99%RH.
Accuracy: +/-1°C, +/-5%RH</td><td rowspan="2">Voltage - 5 volt</td><td>Low noise floor of typ. - 150 dBm</td></tr>
<tr><td>1 Hz resolution bandwidth setting</td></tr>
</table>

Different levels of coding for all the input parameters are shown in Table 1. This extreme range of input variables were selected as per probable variations in climatic conditions which may exist throughout the year. So practically the existence of these input parameters is not possible above and below the selected range. So, after exhaustive experimental run(s) Table 1 was generated. Using these parameters experimental design was developed through the statistical tool MINITAB 17. Experimental results obtained after implementing the CCRD are shown in Table 2. After the experiments as per the designed matrix, ANOVA was applied and good R^2 correlation relation was found between input and output responses.

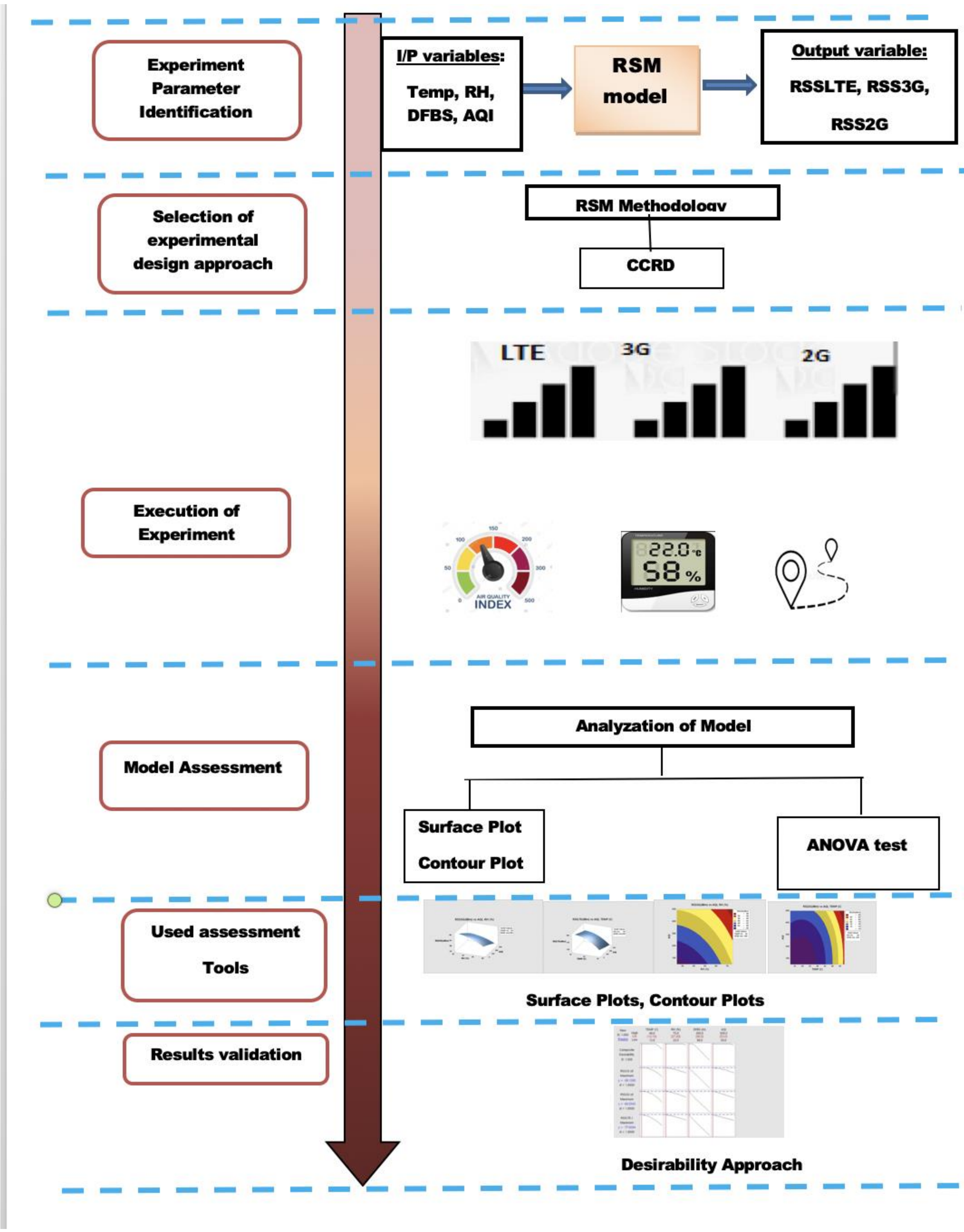


Figure 1. Methodology Flow chart

3.1. RSM Methology

With the help of Response Surface Methodology (RSM) optimum solution can be found. RSM mathematical modelling is used to access the optimum values of input variables to obtain the best output and that too with minimum number of tests. This technology is not application specific and can be utilized in any field. In this work, RSM architecture that is suitable for the CCRD matrix, which has five stages with respect to the individual factors. The most fruitful and best among architecture available is the middle composite rotating architecture which is adept by adding two lab experiment level along each coordinate axis at opposite direction of the origin and at a distance same to the semi-diagonal of the hypercube of the factorial architecture and new extreme values (low and high) for each factor added in this architecture. In RSM, the correlation between the response variable y and the parameters x_1, x_2, x_3.........x_n is commonly represented as.

$$y = f(x_1, x_2, x_3, x_4.........x_n) + \varepsilon \qquad ....(1)$$

Where x_1, x_2, x_3, and x_4.........x_n is the input variable and y is the output response needed to boost it, ε is error or noise found in response y and f is the response surface.

In equation (1), the function f corresponds to the correlation between a response variable and a factor that is normally unknown. Thus in RSM, the initial step is to find an adequate approximation between the unknown factor and the response variable. The linear model is the simplest approximation function (linear model) is used to represent the relationship between a response variable and the unknown factor, which can be described as follows:

$$Y = \beta_\circ + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{j\geq 1}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad \dots\dots\dots\dots\dots\dots (2)$$

Where Y is the response, x_i the magnitude of the factor, β_0, β_i, β_{ii} and $\beta_{ij}$are the coefficient of regression, i and j are linear and quadratic coefficients, and ε is the experimental error. Equation 2 can be assumed to be the extension of a Taylor expansion (of degree 2) of any real underlying function.

In this model of RSM, the atmosphere Temperature (TEMP), Relative Humidity (RH), Air Quality Index (AQI) for PM 2.5 and Distance from Base Station (DFBS) are taken as input variables that could potentially affect the output response such as Received Signal Strength for LTE Technology (RSSLTE), 3G Technology (RSS3G) and 2G Technology (RSS2G). The input parameters are design variables and their limiting range are the design constraints. Here mid-value is taken as 0 for input variables. The CCRD values assigned are -2, -1, 0, 1, and 2. System inputs range with at different coded levels is stated in Table 2. Experimental results as per CCRD are listed by Table 3.

Table 2: Coded stages and range for experiments

Factors or input parameters	**Symbol**	**Coded Levels**				
		-2	**-1**	**0**	**1**	**2**
Temperature (°C)	Temp	12	23	30	40	48
Relative humidity (%)	RH	25	37	50	63	75
Distance from Base Station(m)	DFBS	98	150	200	250	300
Air Quality Index	AQI	50	150	250	370	500

Table 3: Experimental according to RSM Array

Exp. Run	**Temp. (°C)**	**Relative Humidity-RH (%RH)**	**Distance from Base Station-Dis(m)**	**Air Quality Index-AQI**	**LTE Signal Strength-RSSLTE (dBm)**	**3G Signal Strength-RSS3G (dBm)**	**2G Signal Strength-RSS2G (dBm)**
1	40	63	250	370	-123.60	-97.59	-86.68
2	30	50	200	250	-107.00	-84.00	-75.00
3	30	50	200	250	-107.00	-84.00	-75.00
4	30	50	300	250	-123.00	-97.00	-86.60
5	40	37	250	150	-116.55	-92.35	-82.63
6	23	37	250	150	-108.75	-86.50	-78.13
7	40	63	250	150	-120.15	-95.10	-84.72
8	23	37	150	370	-97.20	-77.19	-69.29
9	23	37	250	150	-108.75	-86.50	-78.13
10	30	50	200	50	-103.86	-81.22	-74.54
11	30	50	200	250	-107.00	-84.00	-75.00
12	30	50	98	250	-89.00	-68.00	-62.80
13	23	63	150	370	-100.80	-79.94	-71.38

14	30	50	200	250	-107.00	-84.00	-75.00
15	30	50	200	500	-110.90	-87.00	-77.55
16	40	63	150	150	-105.15	-83.30	-73.92
17	23	63	250	370	-115.80	-91.74	-82.18
18	12	50	200	250	-102.70	-81.60	-73.50
19	23	63	250	150	-112.35	-89.10	-80.22
20	30	25	200	250	-104.00	-81.55	-73.02
21	30	75	200	250	-111.50	-87.60	-77.85
22	23	37	250	370	-112.20	-88.99	-81.09
23	30	50	200	250	-107.00	-84.00	-75.00
24	30	50	200	250	-107.00	-84.00	-75.00
25	40	37	150	370	-105.00	-83.04	-73.79
26	40	63	150	370	-108.60	-85.79	-75.88
27	40	37	250	370	-120.00	-94.84	-84.59
28	23	63	150	150	-97.35	-77.45	-69.42
29	30	50	200	250	-107.00	-84.00	-75.00
30	40	37	150	150	-101.55	-80.55	-71.83
31	48	50	200	250	-119.00	-94.50	-82.80

The objective for using RSM techniques here was to reach the proximity of the optimum quickly and effectively. The simplest version of the model was then used, i.e., the linear model. All association between variables was also considered to be negligible, and only primary impacts were considered.

4. RSM Modelling Results

The ANOVA results of Received Signal Strength for LTE Technology (RSSLTE), 3G Technology (RSS3G) and for 2G Technology (RSS2G) are shown in Tables 4. From the

ANOVA results, the p-value is considered the most important factor. Awad et al. [30] stated that the p-value of various parameters must be not more than 0.05 and the parameters having a p-value greater than 0.05 are considered as not important. The variables having p-values less than 0.05 indicates that the variable has a great impact on the developed model.

Table 4: ANOVA results for RSSLTE, RSS3G and RSS2G

		RSSLTE				RSS3G				RSS2G			
Sources	DF	Adj. SS	Adj. MS	F-value	P-value	Adj. SS	Adj. MS	F-value	P-value	Adj. SS	Adj. MS	F-value	P-value
Regression	4	1490	372.51	764	0.000	976.4	242.3	327.3	0.000	493.40	73.35	36.74	0.000
Temp (C)	1	37.45	37.45	76.82	0.000	28.25	28.18	38.07	0.000	221.02	221.22	6.93	0.014
RH (%)	1	9.28	9.28	19.03	0.000	4.63	4.19	5.66	0.025	78.19	78.19	2.76	0.04
DFBS (m)	1	1479.1	1479	3034.03	0.000	959.5	959.4	1296	0.000	6.04	66.04	2.07	0.02
AQI	1	7.09	7.09	14.54	0.001	3.276	3.27	4.42	0.045	42.62	22.62	11.58	0.000
Lack-of-fit	19	19	12.68	*	*	19.24	1.03	*	*	7.35	4.97	8.88	0.003

From Table 4, it clear that for RSSLTE, the p-value of temperature content, RH, and DFBS are zero and for air quality index p-value is 0.001 for RSSLTE. It shows that the air quality index have lesser impact on the RSSLTE parameter. Similarly, for RSS3G, the p-value of all parameters is less than 0.05. For RSS2G, the p-value of temperature and RH is more than other input parameters.

The models have also been tested using a computational approach using the decision coefficient R^2. Sarıkaya and Güllü [31] believed that that R^2 values below 1 suggest that the experimental effects are consistent with the findings of the model indicates that the reliability is very strong form Table 5, it is showing that the finding of R^2 is 99.16%, 98.05%, 96.18% for RSSLTE, RSS3G and RSS2G respectively. These values of R^2 are nearly close to 1 which indicates that this mode gives reliable results.

Table 5: Model summary

Model	**S**	**R^2 (%)**	**Adj. R^2 (%)**	**Pred. R^2 (%)**
RSSLTE	0.69822	99.16	99.03	98.64
RSS3G	0.86044	98.05	97.75	96.89
RSS2G	0.33612	96.18	95.05	94.26

R^2: Correlation coefficient

The MINITAB 17 software is used to developed empirical correlations for RSSLTE, RSS3G and RSS2G are mentioned below Eqs. (3-5).

$$RSSLTE(dBm) = -61.2 + 0.14 * Temp(°C) - 0.1 * RH(\%) - 0.22 * DFBS(m) - 0.019 * AQI - 0.004 * \{Temp(°C)\}^2 - 0.00034 * \{RH(\%)\}^2 + 0.00011 * \{DFBS(m)\}^2 - 0.000001 * AQI^2 - 0.00036 * Temp(°C) * RH - 0.000047 * Temp(°C) * DFBS\,(m) - 0.00004 * Temp(°C) * AQI + 0.0003 * RH(\%) * DFBS(m) + 0.00016 * RH(\%) * AQI + 0.00004 * DFBS(m) * AQI. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$RSS3G(dBm) = -46.6 + 0.018 * Temp(°C) + 0.001 * RH(\%) - 0.2 * DFBS(m) - 0.01 * AQI - 0.004 * \{Temp(°C)\}^2 - 0.001 * \{RH(\%)\}^2 + 0.0001 * \{DFBS(m)\}^2 - 0.00001 * AQI^2 + 0.001 * Temp(°C) * RH + 0.0004 * Temp(°C) * DFBS\,(m) + 0.00014 * Temp(°C) * AQI + 0.00017 * RH(\%) * DFBS(m) + 0.00008 * RH(\%) * AQI + 0.000027 * DFBS(m) * AQI. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (4)$$

$$RSS2G(dBm) = 122.6 - 0.1062 * Temp(°C) - 0.15 * RH(\%) + 0.0019 * DFBS(m) + 0.00093 * AQI - 0.0014 * \{Temp(°C)\}^2 + 0.000006 * \{RH(\%)\}^2 + 0.000004 * \{DFBS(m)\}^2 - 0.000006 * AQI^2 + 0.0003 * Temp(°C) * RH + 0.000043 * Temp(°C) * DFBS\,(m) + 0.00001 * Temp(°C) * AQI + 0.000013 * RH(\%) * DFBS(m) + 0.000011 * RH(\%) * AQI + 0.000002 * DFBS(m) * AQI. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (5)$$

To warrant RSM viability of established model, S value were seen for RSSLTE, RSS3G and RSS2G which are 0.6922, 0.86044 and 0.33612 respectively. R^2 (adj) values are 99.03%, 97.75% and 95.05%.

5. Result and Discussion

Surface and contour plots were obtained by using MINITAB17 software. In this study, atmosphere Temperature (TEMP), Relative Humidity (RH), Air Quality Index (AQI) for PM2.5 and Distance from Base Station (DFBS) were considered as input variable. Plots were drawn only with two input parameters while keeping other two parameters at constant or hold value and these hold values has been mentioned at the top right corner of each surface and contour plot. These hold values are the center values taken for each input parameter as shown in Table 1.

5.1. Impact of Varying Relative Humidity (RH) and Air Quality Index (AQI) on Signal Strength for LTE, 3G and 2G Technology.

Figure 2(a) and Figure 2(b) shows the surface and contour plots which displays the variation in Received Signal Strength for LTE Technology (RSSLTE) when two input variables i.e. Relative Humidity (RH) and Air Quality Index (AQI) are varying from 25% to 75% and 50 to 500 respectively. At the same time remaining two input parameters i.e. Temperature (Temp) and Distance from Base Station (DFBS) were kept at constant value of 30°C and 200m respectively. From these plots it can be observed that RSSLTE keeps on reducing with the increase in RH and from the same graph it can be observed that RSSLTE marginally reduces with increase in AQI which is approximately negligible. Figure 2(b) shows the total variation range of RSSLTE and it was approximately ranging from -114.5dBm to -100.5dBm. The minimum value of -114.5dBm was observed when RH and AQI were having the value of 75% and 500 respectively and the maximum value of -100.5dBm was observed for 25% and 50 values of RH and AQI respectively. Variation in Received Signal Strength for 3G Technology (RSS3G) with same input parameters has been shown in Figure 2(c) and Figure 2(d). Figure 2(c) shows the surface plot and contour plot has been shown in Figure 3(d). From these Figures the same trend has been observed i.e. with increasing RH, RSS3G decreases whereas the AQI has negligible effect on it. From Figure 2(d) extreme variations in RSS3G can be observed and it is varying from -90.5dbm to -79dBm. Figure 2(e) and Figure 2(f) are the surface and contour plots which shows the variations in Received Signal Strength for 2G Technology (RSS2G) with respect to same input parameters as shown in Figure 2(a) and Figure 2(b). From these Figures it can be observed that RSS2G behaves in similar way with varying RH and AQI as RSSLTE and RSS3G does. The only difference is variation range of RSS2G is much higher than RSSLTE and RSS3G and it can be observed from the contour plot shown in Figure 2(e). Figure 2(e) shows that RSS2G attained its maximum and minimum values of approximately -71dBm and -80.5dBm respectively.

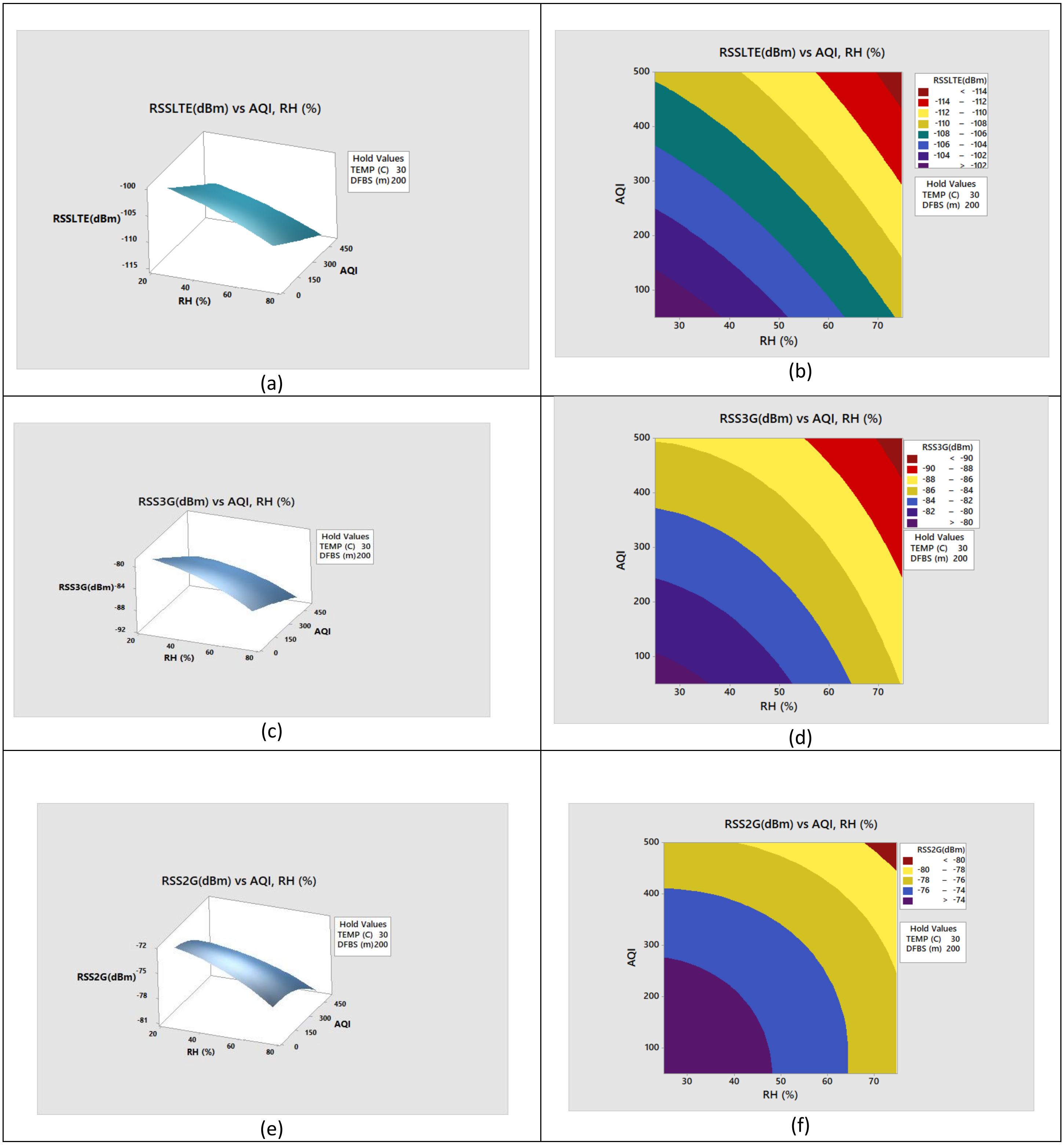


Fig. 2.Effect of environment parameters on read range in presence of LTE

From all the plots shown in Figure 2 it was commonly observed that RSSLTE, RSS3G and RSS2G reduce with increase in Relative Humidity (RH). It occurs because the radio waves are type of electromagnetic wave so the radio waves will have same characteristics as of light. As light beam passed through the water molecule it gets absorbed by water molecule and light intensity decreases. It occurs because of collides with water molecule and increased air pressure. Similarly increased humidity in atmosphere results in increased air pressure and also will increase the number of water molecule in atmosphere which will result into weaker transmission of radio waves and the receives signal strength reduces. Also radio wave have to face reflection, diffraction and scattering if the high number of water molecules are present in the atmosphere due to which signal gets attenuated and results into reduced receives signal strength. From these Figures it was also concluded that effect of AQI is almost negligible on RSSLTE, RSS3G and RSS. It was also observed that attenuation in RSSLTE was of 14dBm (-100.5dBm to -114.5dBm), in RSS3G it was of 11.5dBm (-79dBm to -90.5dBm) and for RSS2G it was 9.5dBm (-80.5dBm to -71dBm).So from the above values it was observed that the attenuation in LTE signal was maximum, minimum attenuation was observed for the 2G signal and for 3G signal it was observed in between. It occurs because the high frequency signal gets attenuated more easily as compared to low frequency signal.

5.2. Impact of Varying Relative Humidity (RH) and Distance from Base Station (DFBS) on Signal Strength for LTE, 3G and 2G Technology.

Figure 3(a) and Figure 3(b) are the surface and contour plots which shows the variation in Received Signal Strength for LTE Technology (RSSLTE) with respect to varying Relative Humidity (RH) and Distance From Base Station (DFBS) ranging from 25% to 75% and 98m to 300m respectively whereas the other two input parameters i.e. Temperature (TEMP) and Air Quality Index (AQI) were at constant value of 30°C and 250 respectively. From these Figures it can observed that RSSLTE reduces with increase in RH and same is the effect of DFBS but there is sharp decrease in RSSLTE with respect to DFBS as compared to RH. Figure 3(b) shows that RSSLTE can reach up to the maximum value of approximately -85dBm and can attain the minimum value of -124dBm. Figure 3(c) and Figure 3(d) shows the Surface and contour plot which depict the variation in Received Signal Strength for 3G Technology (RSS3G) for same input parameters as shown in Figure 3(a) and Figure 3(b). From these Figures same trend had been observed for the RSS3G with respect to varying RH and DFBS as it was observed for RSSLTE. The extreme variation which RSS3G can achieve can be observed for the Figure 3(d) and it is ranging approximately from -98dBm to -68dBm.

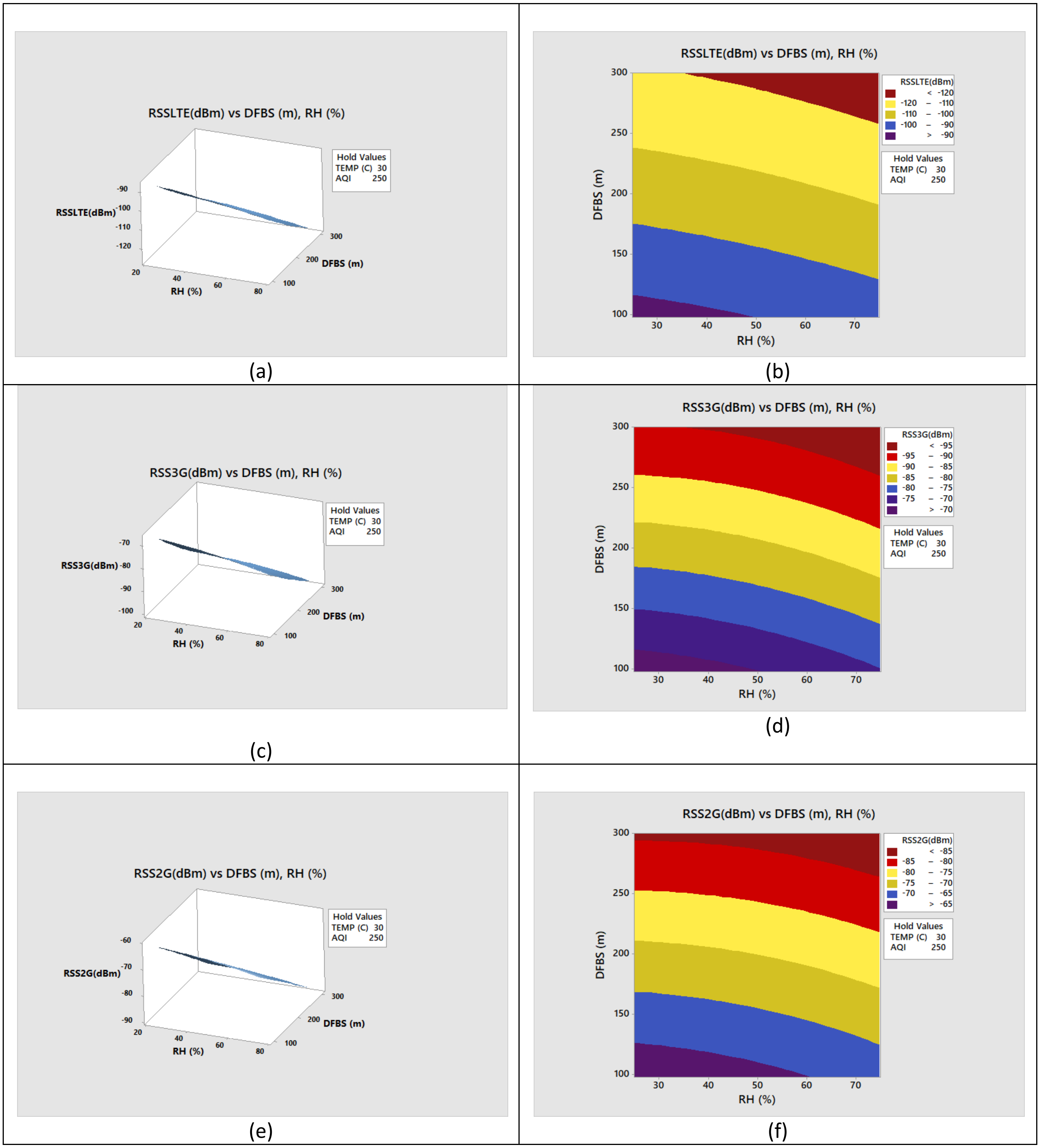


Fig.3. Effect of input parameter on Signal Strength for 3G Technology

Variation in Received Signal Strength for 2G technology (RSS2G) can be observed from surface and contour plots shown in Figure 3(e) and Figure 3(f) respectively. Here the variation in RSS2G has been plotted for the same input parameters as RSSLTE and RSS3G were plotted in Figure

3(a) to Figure 3(d). From Figure 3(e) and Figure 3(f) it can be observed that RSS2G responds to varying RH and DFBS the similar ways as RSSLTE and RSS3G does. From Figure 3(f) it can be observed that the maximum (-62dBm approximately) and minimum (-88dBm approximately) values attained for RSS2G is more than RSSLTE and RSS3G.

From all the plots shown in Figure 3, it was commonly observed that RSSLTE, RSS3G and RSS2G reduces with increase in RH and same is the effect of DFBS but there is sharp decrease in RSSLTE, RSS3G and RSS2G with respect to DFBS as compared with respect to RH. Decrease in RSSLTE, RSS3G and RSS2G with increase in DFBS occurs because radio wave intensity follows the inverse square law. This means if the distance between the transmitter and receiver is doubled the received signal power will be reduced four times. The reason behind the sharp decrement is because the completed observations were taken in the area which comes under the deep shadow reason (area which is densely populated and having high rise buildings etc.) due to which signal get attenuated more easily and results in low received signal strength. From the same Figures it was also observed that attenuation in RSSLTE was maximum i.e. of 39.5dBm (-85dBm to -124.5dBm), minimum for RSS2G and it was 26dBm (-62dBm to -88dBm) and for RSS3G it was observed to be in between i.e. 30dBm (-68dBm to -98dbm) and it occurs because the high frequency signals get attenuated more easily as compared to low frequency signals.

5.3. Impact of Temperature (TEMP) and Air Quality Index (AQI) on Signal Strength for LTE, 3G and 2G Technology.

Figure 4(a) and Figure 4(b) shows the variation in Received Signal Strength for LTE Technology (RSSLTE) with respect to varying Temperature (TEMP) and Air Quality Index (AQI) ranging from 12°C to 48°C and 50 to 500 respectively with rest two input parameters i.e. Relative Humidity (RH) and Distance from Base Station (DFBS) were kept at constant or hold value of 50% and 200m respectively. From these plots it can be observed that variation of RSSLTE with increasing AQI is same as it was observed for the plots shown in Figure 2 i.e. RSSLTE reduces marginally with increase in AQI or it has negligible effect on it whereas with the increase in TEMP, RSSLTE reduces.

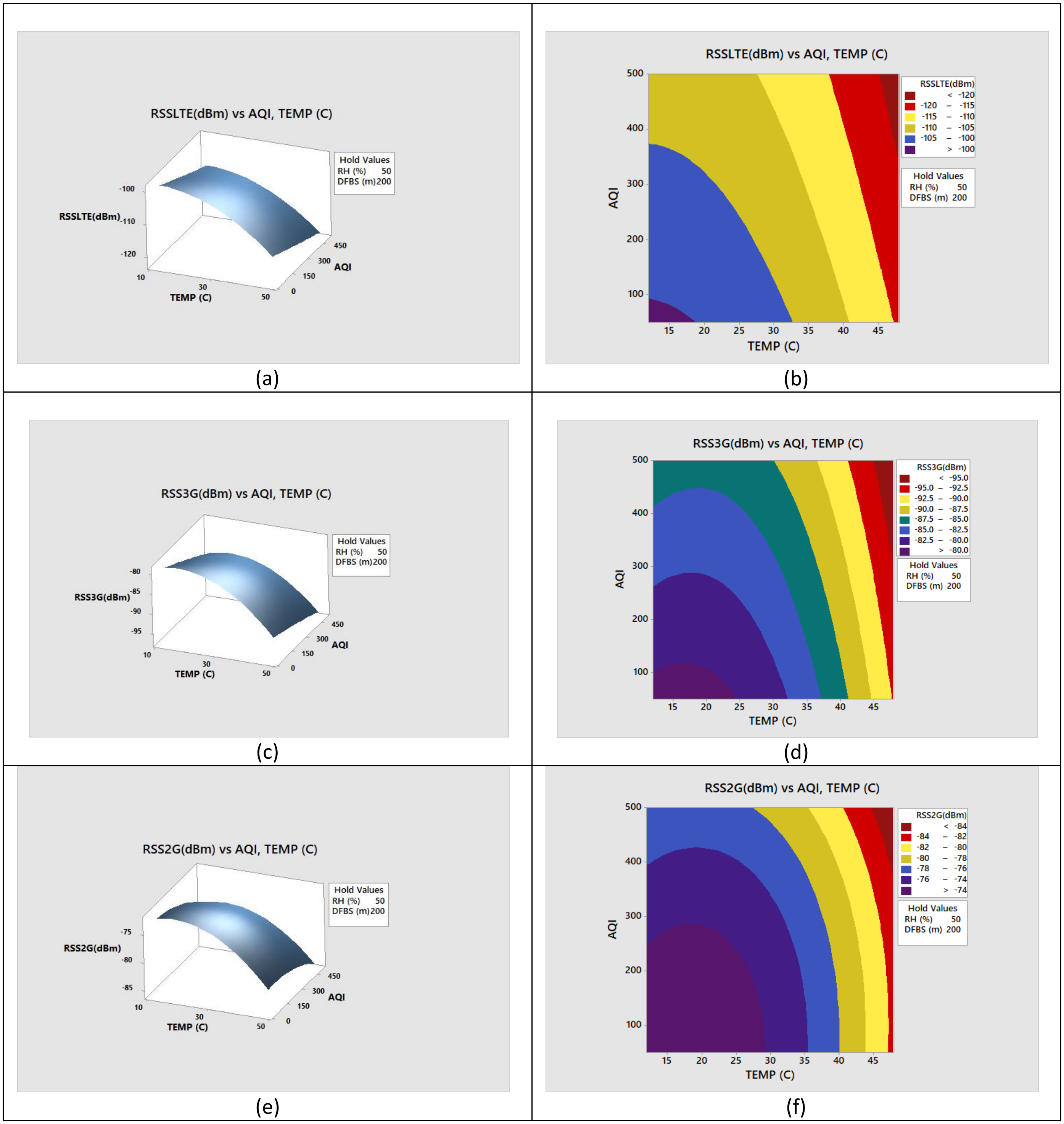


Fig.4. Effect of input parameter on Signal Strength for 2G Technology

Variations in Received Signal Strength for 3G (RSS3G) and 2G (RSS2G) with respect to same input parameters (Used in Figure 4(a) and Figure 4(b)) has been shown in Figure 4(c), Figure 4(d) and Figure 4(e), Figure 4(f) respectively. Same trend was observed for RSS3G and RSS2G as it was observed for RSSLTE i.e. RSS3G and RSS2G reduce with increase in TEMP and have negligible effect of AQI. Figure 4(b), Figure 4(d) and Figure 4(f) shows the extreme variation range for RSSLTE, RSS3G and RSS2G and these were approximately ranging from -121dBm to -98dBm, -96dBm to -76dBm and -85dBm to -67dBm respectively.

For all the plots shown in Figure 4 it was commonly observed that RSSLTE, RSS2G and RSS3G keeps on decreasing with increase in TEPM and it may occur because the resistivity of medium increases with increase in temperature which results into decrease in power and current of the device for a particular voltage. So the signal to noise for the radio transceiver decreases with the increase in temperature and resulting in decrease in received signal strength. From the same plots it was observed that attenuation in RSSLTE was of 23dBm (-98dBm to -121dBm), in RSS3G it was of 20dBm (76dBm to -96dBm) and for RSS2G it was 18dBm (-67dBm to -85dBm) and it occurs because the high frequency signals gets attenuated more easily as compared to low frequency signal. From the same time it was observed that effect of AQI is almost negligible on RSSLTE, RSS3G and RSS2G.

From all the plots shown in Figure 2, Figure 3 and Figure 4 it can be observed that Received Signal Strength for 2G signal was maximum, for LTE signal it was observed to be at minimum value and for 3G signal it lies in between the Received Signal Strength for LTE and 2G signals.

6. RSM response optimization and its validation

Figure 5 shows the RSM optimizer which is used to get the optimum values of input parameter setting for best possible values of Received Signal Strength for LTE, 3G and 2G technologies. The multi objective optimization was carried out with equal weightage on output responses. In this research work, the objective was to enhance the Received Signal Strength for LTE, 3G and 2G technologies. Optimum values of atmosphere temperature (TEMP), Relative Humidity (RH), Air Quality Index (AQI) for PM2.5 and Distance from Base Station (DFBS) were found to be 13.10°C, 27.30%, 55 and 98m respectively. At above said input setting, optimum responses were found -77.9264dBm for (Received Signal Strength for LTE- RSSLTE); -60.0345dBm for (Received Signal Strength for 3G- RSS3G) and -58.1280dBm for (Received Signal Strength for 2G- RSS2G).

Figure 5. Optimization plot: Effect of process parameters on responses.

The desirability value obtained is unity, and is recommended since it is higher and nearest to the optimization criteria. This needs the assurance and evaluation of the optimized output. To validate RSM results, experiment were carried out at 13°C ambient temperature, 98 meter distance from base station, 27% relative humidity and at air quality index (AQI 55). For this, the experimental test was performed at the obtained input variables configuration through RSM techniques and the test was repeated 3 times. From the outcomes, their mean value and the standard deviation were calculated and mentioned in Table 6.

Table 6: The experimental values with their mean and standard deviation of output parameters.

Output parameters	**Experimental Outcomes (No. of trials)**			**Mean Value**	**Standard deviation**
	1	**2**	**3**		
RSSLTE (dBm)	-80.01	-80.24	-80.45	-80.23	0.215
RSS3G (dBm)	-61.12	-63.11	-62.11	-62.13	0.99
RSS2G (dBm)	-60.72	-61.1	-61.51	-61.11	0.41

The lab examination details are shown in Table 7 shows the response for RSSLTE, RSS3G and RSS2G. Experimental responses were compared with the RSM optimizer values.

Table 7: Validation test

Response at 13°C, 98 DFBS, 27% RH, with 55 AQI			
Response	**Predicted**	**Actual**	**% Error**
RSSLTE (dBm)	-77.926	-80.23	2.96
RSS3G (dBm)	-60.034	-62.13	3.5
RSS2G (dBm)	-58.128	-61.11	5.11

The error percentage for RSSLTE, RSS3G and RSS2G are 2.96, 3.5 and 5.11 respectively, and within the limits.

7. Conclusions

As the received signal strength gets affected due to the varying environment condition present in the channel through which the signal propagates and it also depends on the distance between the location of signal transmitter and the receiver. So, this research work was carried out to monitor the received signal strength for LTE, 2G and 3G wireless communication technologies and to mitigate the effect of varying environment conditions which these signals have to face. Later on the optimization was carried out by using RSM technology. Complete details of the input parameters used for optimization and the received optimized responses are as follows -

- The significant input parameters for the analysis of Received Signal Strength for LTE, 3G and 2G Technologies were Temperature (12°C to 48°C), Relative Humidity (25%RH to 75%RH), Distance from Base Station (98m to 300m) and Air Quality Index (50 to 500).
- Optimum conditions were recovered when environment parametersTemperature(TEMP), Relative Humidity (RH), Air Quality Index (AQI) for PM2.5 and Distance from Base Station (DFBS) were found to be 13.10°C, 27.30%, 55 and 98m respectively
- Received Signal Strength for LTE- RSSLTE, Received Signal Strength for 3G - RSS3G and Received Signal Strength for 2G - RSS2G werefound to be -77.9264dBm, -60.0345dBm and -58.1280dBm respectively.

- S value was obtained for RSSLTE, RSS3G and RSS2G which are 0.69822, 0.86044 and 0.33612 respectively defined closer to regression line.
- Regression coefficient (R^2 value) are 99.16%, 98.05% and 96.18%, respectively for RSSLTE, RSS3G and RSS2G shows good mathematical modelling among input and output parameters.
- Optimized RSM results were validated though the confirmation trial. The error between actual and predicted was found to be within the range of 5%.

In this research work the optimization was carried with response surface methodology. By using response surface methodology, optimization can be done with minimum experiment runs and it is not application specific. From this study after the completion of experiment and optimization it is clear that the mobile with any of the three wireless communication technologies i.e. LTE, 3G or 2G can provide maximum Received Signal Strength for the combinations of environment parameters as mentioned above.

Declaration

- Funding (information that explains whether and by whom the research was supported) - NA
- Conflicts of interest/Competing interests (include appropriate disclosures)- NA
- Availability of data and material (data transparency) - Yes
- Code availability (software application or custom code) - NA

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Figures

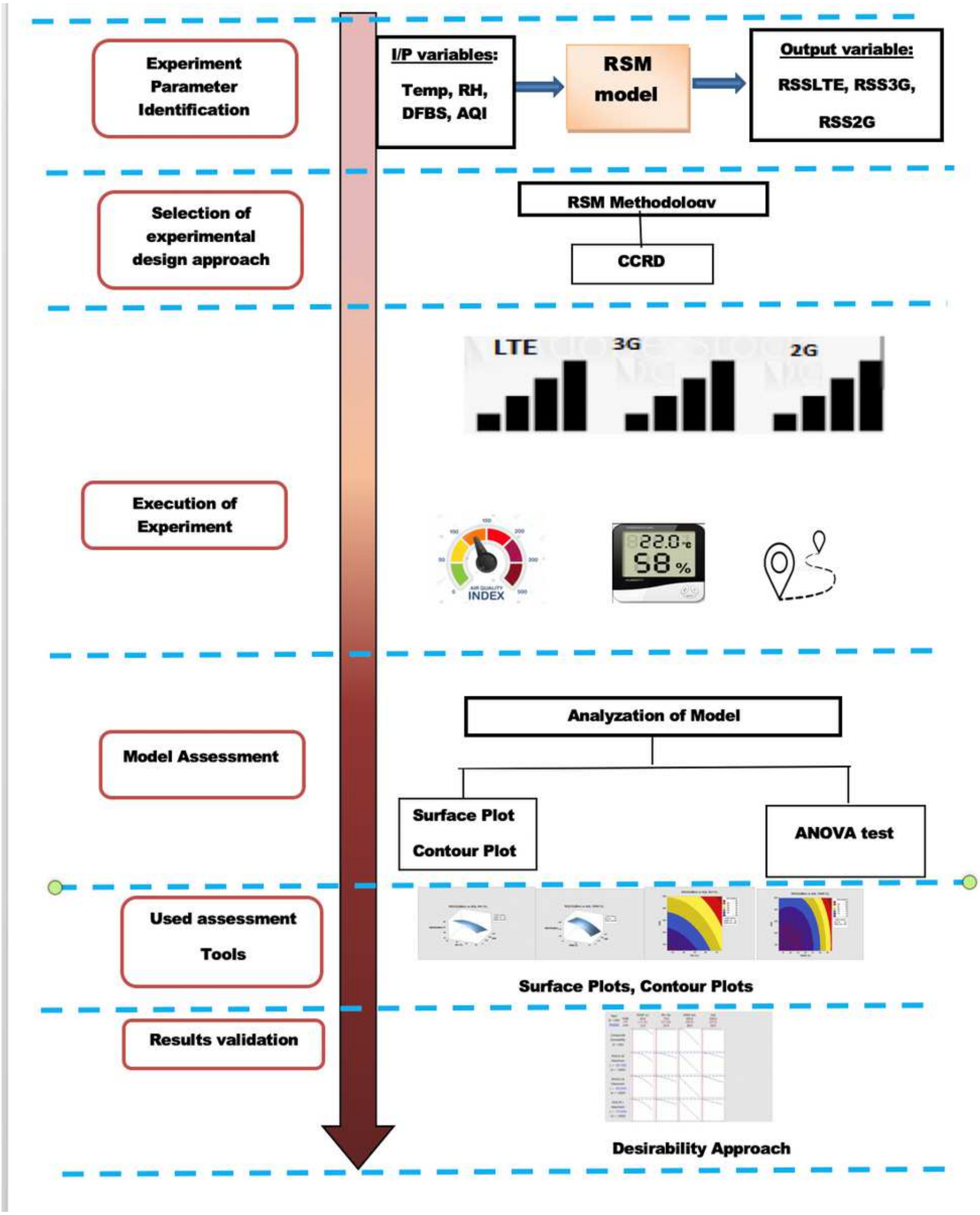

Figure 1

Methodology Flow chart

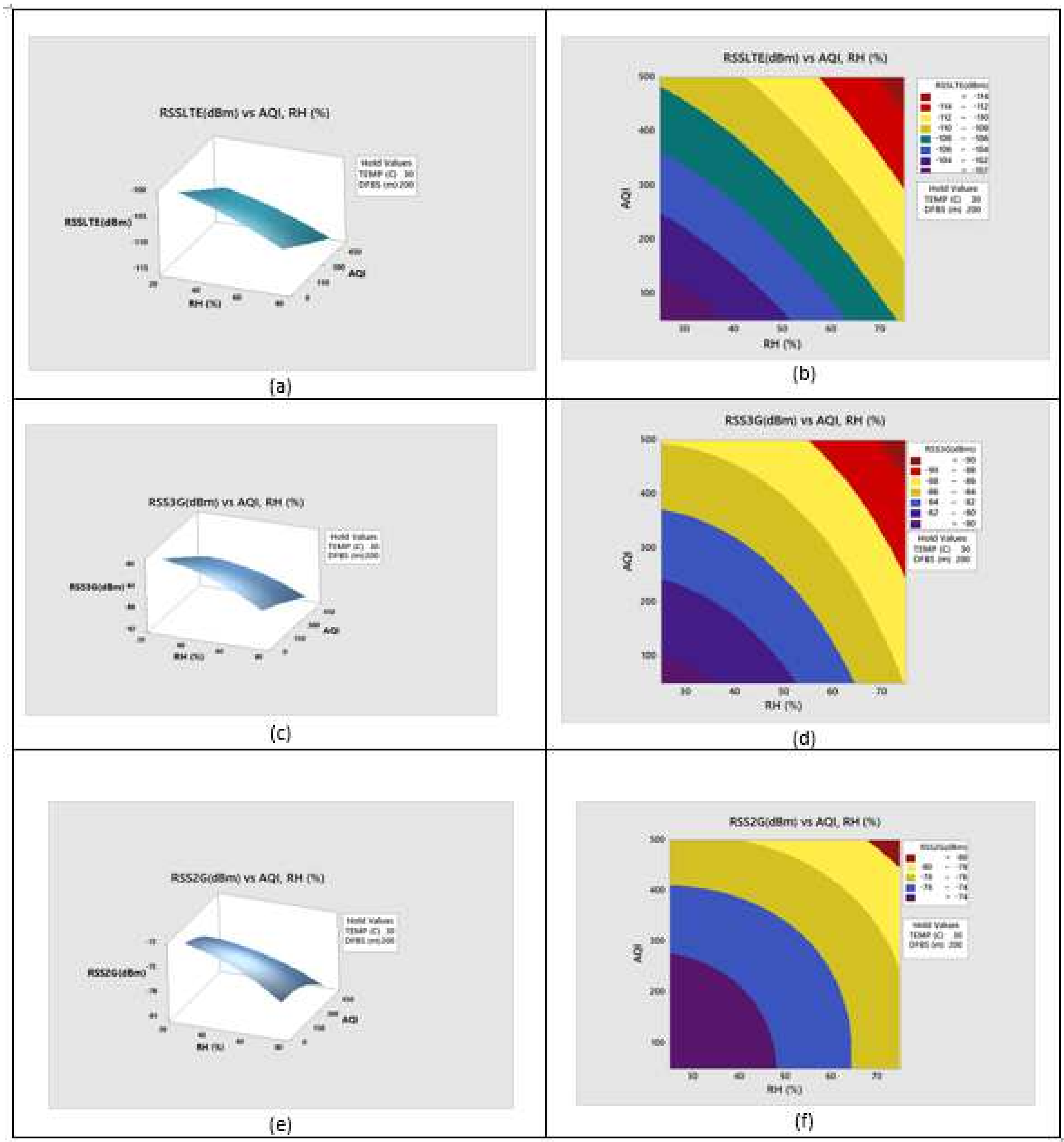

Figure 2

Effect of environment parameters on read range in presence of LTE

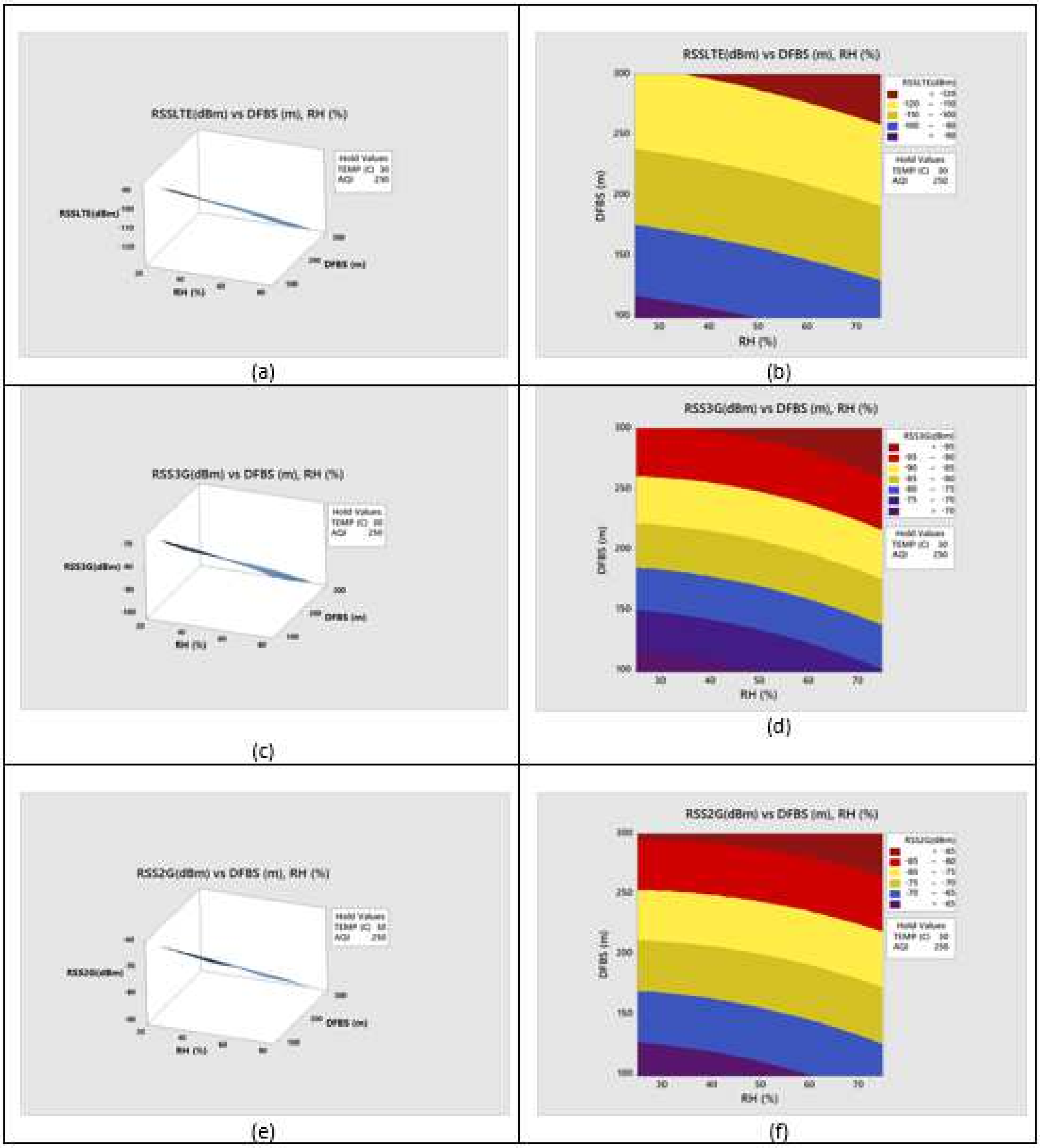

Figure 3

Effect of input parameter on Signal Strength for 3G Technology

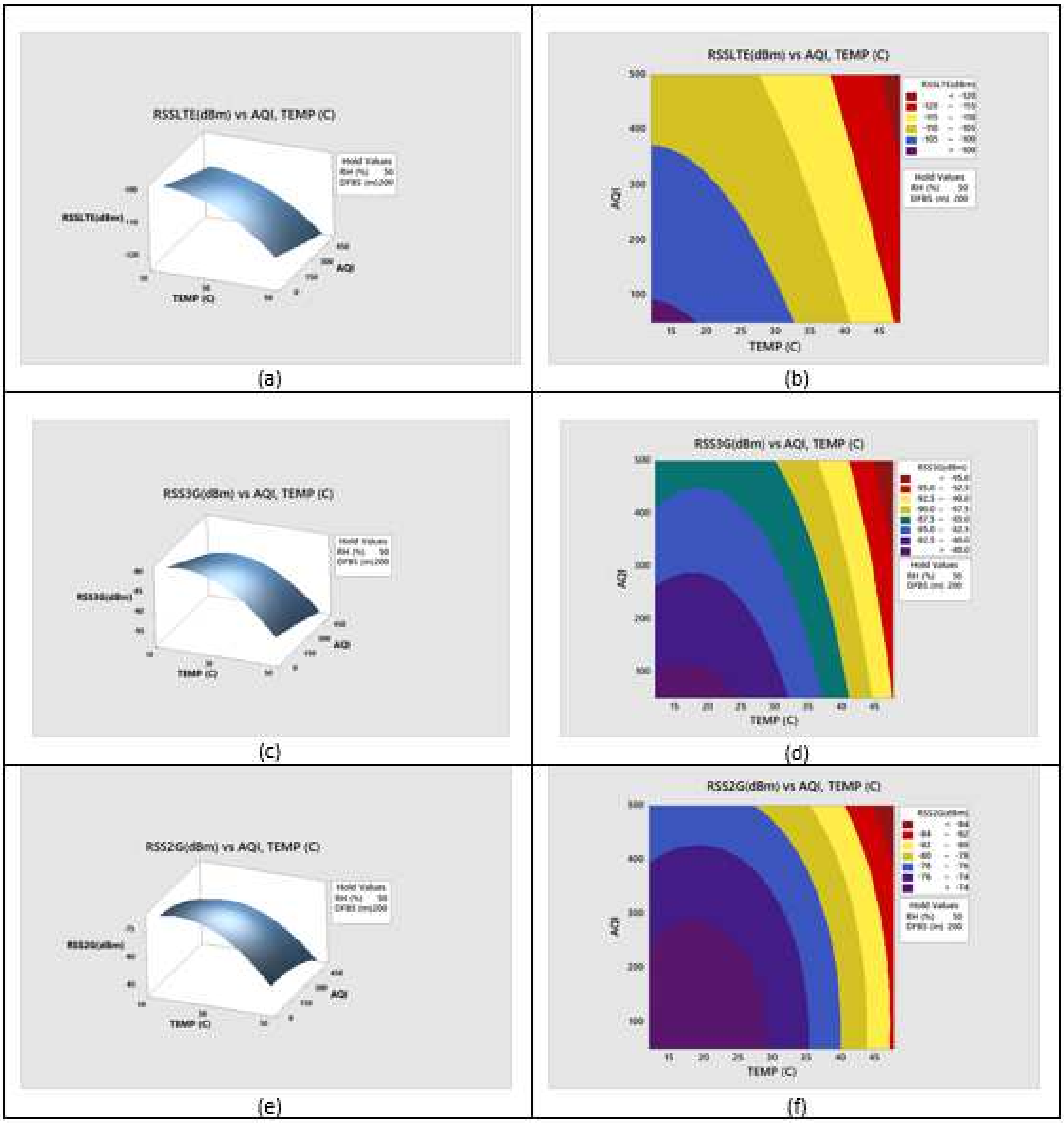

Figure 4

Effect of input parameter on Signal Strength for 2G Technology

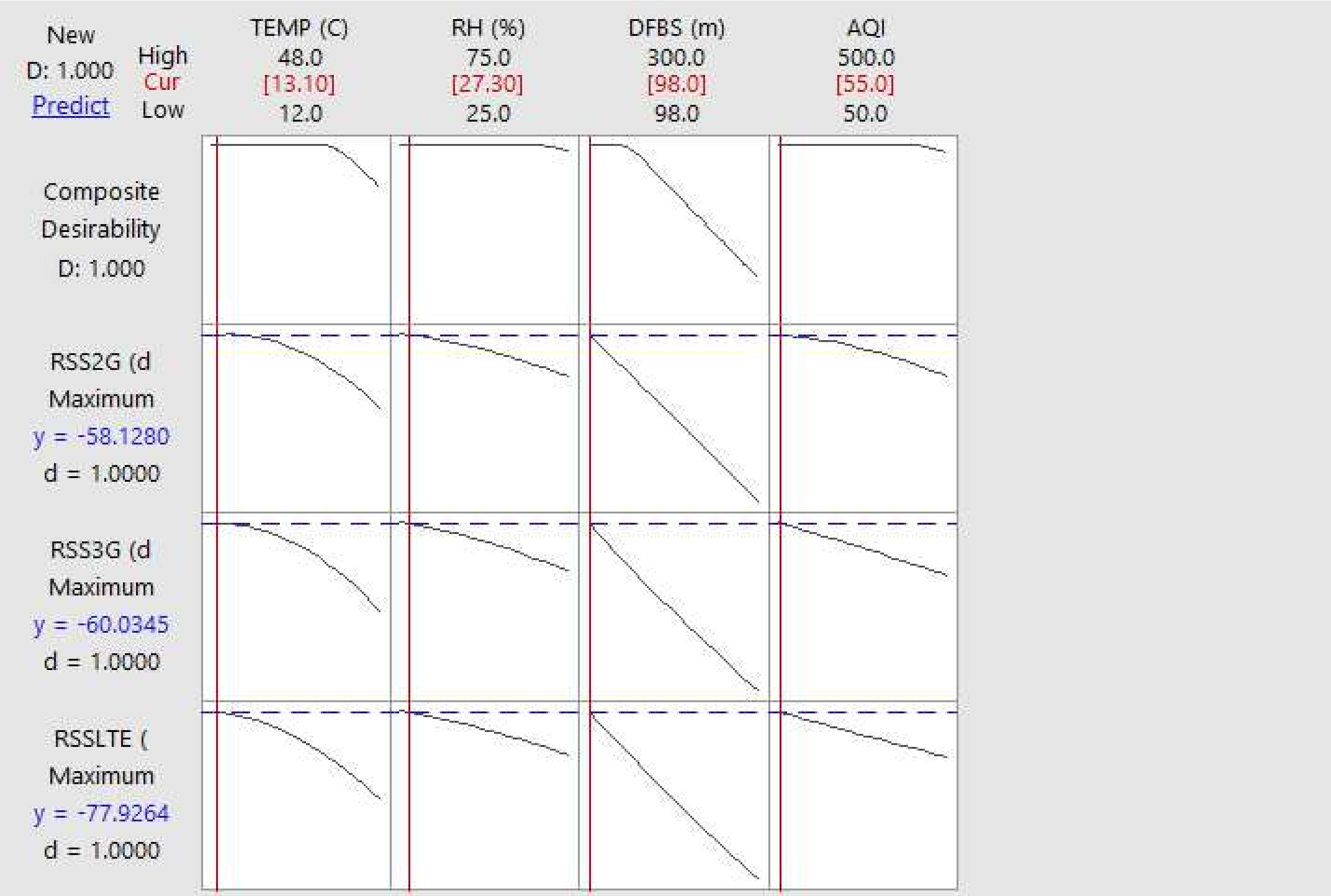

Figure 5

Optimization plot: Effect of process parameters on responses.

Supplementary Files

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