Statistical study of performance metrics of Adaptive Fault Tolerant Replication Routing Protocol for MANET

SWATI SAXENA
Research Scholar
AIM & ACT Banasthali Vidyapith
Banasthali (Raj.)

Dr. MADHAVI SINHA
Asst. Prof. (HOD)
Dept. of Computer Science & Engineering
BIT Mesra, Jaipur Extension, Jaipur (Raj.)

Abstract

Ad hoc networks are multi-hop wireless networks having dynamic topology due to node mobility. Routing protocols for such networks should be able to respond rapidly to topological changes. Designing and analyzing routing protocols for handling time-constrained messages in such dynamic environment is very crucial. A number of routing protocols have been proposed that deal with time-constrained messages. But despite some faulty nodes, link failure, route breakage or some other faults, it is required that the messages reach their destination within time. An adaptive fault tolerant replication strategy has already been designed and referred as Adaptive Fault Tolerant Replication (AFTR) routing that handle time-constrained messages. This paper is an extension work to study the performance of such protocol. The performance of any protocol can be analyzed through some metrics under various influential factors. The paper presents performance study of AFTR routing protocol based on three performance metrics packet delivery ratio, routing overhead and throughput under five influential factors: network size, transmission rate, node mobility, pause time and optimal number of copies. A $2^k r$ factorial design strategy is used to quantify the main and interactional effects of various factors on metrics. A two-way interaction is expressed as linear regression equation.

Keywords: *factorial design, influential factors, interaction effects, linear regression equation, main effects, time-constrained messages.*

1. INTRODUCTION

Mobile Ad hoc Network (MANET) is an autonomous system where nodes are connected through wireless links. Nodes are free to move in any direction that leads to dynamic topology. This property of dynamic topology makes MANET unpredictable from the point of view of scalability [1]. Also, nodes have limited CPU capacity, storage capacity, battery power, limited bandwidth and limited transmission range. Due to dynamic topology, routing protocols for such networks have to discover the routes dynamically. These protocols are designed to work with route traffic having network congestion, faulty link and many other failures. Link failure often leads to packet drop or delay in transmission.

Time-constrained messages are characterized by their timely delivery. Their utility depends upon the time at which they arrive their destinations. Handling these messages in MANET environment is a challenging issue due to dynamic topology, limited bandwidth, power consumption, transmission range, contention among randomly arriving messages through node/link and many more. This will be more crucial task when one or some of the node/link becomes faulty. To ensure timely delivery of messages in faulty environment, a routing strategy has already been proposed which is based on multiple-copy approach. This strategy is named as Adaptive Fault Tolerant Replication (AFTR) Routing [2]. The performance of any protocol is analyzed through various metrics under different influential factors. Such metrics can be either quantitative or qualitative [3]. Qualitative metrics are those whose desirable attributes make them efficient for use in ad hoc wireless environment. These may include loop freedom, security, unidirectional link support and demand-based operation in case energy consumption is a major issue and many more. Quantitative metrics include statistical data which provide the tools to assess the performance of the routing protocols e.g. packet delivery ratio, throughput, average end-to-end delay, goodput, routing overhead, jitter, packet drop fraction etc. Here, we are using quantitative metrics to analyze the protocol performance.

The present paper is the second extension work to analyze the performance of AFTR routing protocol using statistical approach. Two performance metrics (packet drop fraction and end-to-end delay) are analyzed under five influential factors (network size, transfer rate, mobility speed, pause time and optimal number of copies) for

AFTR protocol in MANET [4] using $2^k r$ factorial design strategy. This was the first extension work. The objective of the present work is to analyze three other metrics named packet delivery ratio, routing overhead and throughput under five factors and quantify their main and interaction effects using $2^k r$ factorial design strategy.

The remainder of the paper is organized as follows. Section 2 explores the related work in the field of analyzing performance metrics of routing protocol with statistical approach. Section 3 highlights the concepts about factorial design we are using. Section 4 discusses the proposed analysis. Results are interpreted in section 5 and their inferences are concluded in section 6. Then section 7 explores the future work.

2. PREVIOUS WORK

To perform simulation based comparative study, we should have an idea about various metrics on which performance of the protocol is to be analyzed under certain factors. An important task is to identify the key performance metrics and factors that affect them. The statistical design of experiment strategy is used to quantify the main and interaction effects of factors on the required metrics. Factorial design, response surfaces, taguchi approach are some of the strategies from design of experiment (DoE) that are frequently using by many researchers to identify the effects of various factors on the metrics. Basically, DoE strategy is used to improve the design process. Following are some work from the literature:

The impact of factors and their interactions on MANET service delivery are analyzed in [5]. Here the performance factors like real-time throughput, total throughput and average delay are used to measure the delivered service under the factors like QoS architecture, routing protocol, MAC protocol, offered load and node mobility. The simulation data can be analyzed by using some statistical techniques like Analysis of Variance (ANOVA) to identify main and interaction effects of factors that explains the performance metrics. In [5], it was found that, for the average delay, the MAC protocol and its two-way interaction with the routing protocol are the most significant.

In [6], a 2^k factorial design strategy is used to analyze the performance of mobile ad hoc networks. The main and interactive effects of five factors (i.e. network density, node mobility, traffic load, network size and medium access control protocol) are quantified on two performance metrics (i.e. packet-delivery ratio and end-to-end delay).

The performance of Dynamic Source Routing (DSR) in mobile ad-hoc is analyzed in **[**7**].** Taguchi DoE strategy is used here to quantify the main effect of six influential factors (i.e. terrain, network size, node speed, pause time, number of sources and transmission rates) on two performance metrics (i.e. throughput and end-to-end delay). To obtain the best performance of DSR protocol, the analysis of means (ANOM) and analysis of variance (ANOVA) are used to identify the best factor combinations for two metrics. The transmission rate is the most important parameter that contributes the performance of throughput, while the number of sources is the important parameter that contributes to the performance of end-to-end delay. In the multiple performance metrics, throughput and end-to-end delay were simultaneously considered and the network size is the most important factor contributes to the performance.

In [4], end-to-end delay and packet drop metrics are used to analyze the AFTR routing protocol under MANET. These metrics are analyzed under five factors named network size, transfer rate, mobility speed, pause time and optimal number of copies. First four factors have usual definitions but the last one is an important factor specific to our previously designed protocol [2]. We are using the concept of sending more than one copy of same message through disjoint route to increase the probability of reaching at least copy within its deadline. This will increases the traffic load. So only the optimum copies will be sending and can be estimated on the basis of traffic load, deadline etc. It has been shown that end-to-end delay is strongly affected by network size and transfer rate. Optimal number of copies is also having a small impact. Packet drop is only affected by transfer rate.

3. STATISTICAL APPROACH

In general, performances of routing protocols are evaluated through simulation. Most of the studies are based on one-factor-at-a-time (OFAT) approach. In this approach, only one factor is varied, keeping other factors constant. Also, it doesn’t consider the interaction of factors. To enhance the methodology of analysis by quantifying the effects of various factors and their interactions on performance, statistical design of experiment (DOE) is used. It allows simultaneous study of several factor effects rather than one at a time. A brief overview is given as follows:

3.1 Terminology

Following terms are in general used while designing:

- *Factor:* A factor is a controlled independent variable that affects the response variable. Depending upon their use, a factor may be primary, secondary or constant. (For example, network size, transfer rate etc.)

- *Levels:* A factor is assumed to have a value called its level.
- *Response variable:* A dependent variable that measures the performance of the system under study is referred as response variable. (For example, throughput, packet delivery ratio etc.)
- *Design or Experiment:* The design describes the number of experiments, combinations of factor levels, number of replications, randomization etc.
- *Replication:* It is the process of replicating the experiment.
- *Main effect:* Describes variation or change in response variable due to factor level.
- *Interaction effect:* Interaction is a variation not describe by main effects. It describes the relative change in response variables due varying factor.

3.2 Full Factorial Design Strategy

The concept behind factorial design strategy is to measure the responses by using all possible combinations of all levels of all factors. Two main strategies are there: 2-level full factorial and general full factorial design. A two-level factorial assumes two factors at each level and general full factorial assumes *any* factor has more than two levels. Here, we are using 2-level full factorial. Further, 2-level factorial has following variations:

- 2^k *factorial design*: Effects are determined by assuming two levels for each factor. But limitation here is, it can't estimate the experimental error. The solution is to replicate each experiment.
- $2^k r$ *factorial design:* In 2^k design, each run is executed r times, and results in $2^k r$ design.
- 2^{k-p} *fractional factorial design:* Analyzes k 2-level factors with fewer runs.

Further, the main objective is to quantify main and interaction effects of factors. A 2^k full factorial design results in 2^k-1 effects in total. Out of which k are main effects and $\binom{k}{j}$ are j-interaction effects, where $2 \le j \le k$. Here, we are considering five factors each of with two levels. Thus, $k = 5$, so 32 design points are used. Each point is replicated $r = 5$ times, so $32 \times 5 = 160$ runs are made in total. Also, total effects will be 31 ($= 2^5-1$), out of which 5 ($= k$) are main effects, 10 are 2-interaction (for $j = 2$) effects, 10 are 3-interaction (for $j = 3$) effects, 5 are 4-interaction (for $j = 4$) effects and 1 is 5-interaction (for $j = 5$) effects. We are evaluating here 2-interaction effects only.

4. PROPOSED ANALYSIS

To quantify the effects of various factors on metrics, following steps are to be performed:

Step 1: Defining the objective:

The objective of the present work is to evaluate the performance of AFTR routing protocol using statistical design of experiment (DOE) strategy. A full factorial design is employed to quantify the main and interactive effects of some selective influential factors on performance metrics. Using these effects, a linear regression model is developed to predict the performance of the AFTR routing protocol on the results obtained through simulation done on NS2.

Step 2: Choosing the factors (with their levels) and metrics:

In general, a numerous factors may influence the performance of any routing protocol. We have selected only five of them (i.e. network size, transmission rates, node mobility speed, pause time and optimal number of copies) and others are considered as constant. For the network size, we consider two levels: a network with 25 numbers of nodes and another network with 100 nodes. For transmission rates, two levels considered are 250 Kb/s and 500 Kb/s. For mobility speed, two levels considered are 5 m/sec and 25 m/sec. For pause time, two levels considered are 10 sec and 20 sec and for optimal number of copies two levels considered are 2 and 7 (these can be obtained through the AFTR protocol). Table 1 describes all the factors in brief and for simplicity, factor levels are coded as a + (for high level) and – (for low level).

Table 1: Factors and their levels

S. no.	Factor	Low level (-)	High Level (+)
1.	Network Size	25 nodes	100 nodes
2.	Transmission Rates	250 Kb/s	500 Kb/s
3.	Node Mobility Speed	5 m/sec	25 m/sec
4.	Pause Time	10 sec	20 sec
5.	Optimal no. of copies	2	7

Step 3: Choosing the response metrics:

Three response metrics are considered here related with the performance of the protocol:

- *Packet Delivery Ratio* is defined as the percentage of number of packets received by the destination node over percentage of no. of packets sent by all source nodes within the period of simulation time.
- *Routing overhead* is the total of routing control data packets sent by the routing protocol through the duration of simulation. More control packets results in network delay.
- *Throughput* is defined as total data sent over a certain period of time. Efficient protocol has higher throughput. It is measured in bits per second. Here we are measuring it in Kilo bits per seconds.

Step 4: Designing the factorial combinations.

We are using here full factorial design with $2^k r$ factorial, k = 5 factors and each factor has two levels (or values). Using MINITAB 18 software we create $2^5 = 32$ design points and they are shown in standard order in table 2. Each design point relates a simulation scenario replicated as r = 5 times. The response values are also shown in the table 2. These values are the results of simulation carried out in NS2.

Step 5: Data Collection:

Simulations were carried out using NS2, an event-driven simulation. To obtain the results for packet delivery ratio, routing overhead and throughput, each of the 32 design points were executed 5 times and average were computed for five runs. The design points chosen for execution are based on the *run order* created by MINITAB. Thus table 2 shows the results of 160 simulation runs (32 × 5). Each simulation run was executed for 150 seconds.

Step 6: Computing the Main and Interaction effects:

Computing main and interaction effects that factors have on specific response metrics are the key concept of factorial design. In general, the functional relationship of response $y(x_1, x_2, x_3, x_4, x_5)$ with 5 factors (x_1 to x_5) for two-way interactions can be expressed as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{15} x_1 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{25} x_2 x_5 + \beta_{34} x_3 x_4 + \beta_{35} x_3 x_5 + \beta_{45} x_4 x_5. \quad (1)$$

Equation(1) considers 5 main effects and 10 2-way interaction effects. Here, β_0 is the average response over all simulation runs, β_1 to β_5 are the main effects of x_1 to x_5 respectively. β_{ij} is the interactive effect of factors x_i and x_j for $1 \le i, j \le 5$. This gives the idea that the main effect of each factor is the difference between the average response when the factor is at its *high* level and the average response when the factor is at its *low* level. Further, the interactive effect is the change in response metric when two factors are at the same level and when they are at different levels.

5. DATA INTERPRETATION AND RESULTS

In this section, the results of statistical DOE along with analysis of the results are presented. The design matrix (table 2) is used to generate graphs and equations in MINITAB 18 software.

To visualize the changes in metrics as factor levels change, scatter plot is the best way. Each response metric is first studied through scatter plot which is plotted against 32 design points by taking average for r = 5 simulation runs. Each design point reflects the change in network size from 25 nodes to 100. The point pairs 1-2/3-4, 5-6/7-8 and so on corresponds to the change in transfer rate from its low level to high level. Further, point-pairs 1-4/5-8, 9-12/13-16 and so on reflect the change in mobility speed from its low to high level. Similarly, point-pairs 1-8/9-16, 17-24/25-32 shows the change in pause time and 1-16/17-32 reflects the change in optimal number of copies from their low to high level.

Further, main effect plot, interaction plot and standardized effect plots are used to identify the effects visually for each of the response metric. Main effect plots visualize the change in performance metric as factor level is changed. Along x-axis, corresponding low and high level value of a factor is presented and the corresponding performance metric is presented along y-axis. The line connecting two points illustrates the average main effect on the performance metric when factor level changed from its low to high level. The slope of this line shows the degree to which a factor has a main effect on the performance metric. The greater the slope represents the average main effect upon the performance metric. A small slope exhibits the average main effect. It should be noted that main effect plots are plotted for the range of values used for low and high levels of factors.

Table 2: Design Matrix for full factorial design (k = 5)

	Factors					Performance Metrics		
Design points	Nsize	TransRate	MobSpeed	pauseTime	optNoCopies	PDR	R_ovhd	throughput
low level factor (-)	25	250 Kb/s	5 m/sec	10 sec	2	ratio	pkts	kb/s
high level factor (+)	100	500 Kb/s	25 m/sec	20 sec	7			
1	(-) 25	(-) 250	(-) 5m/sec	(-) 10sec	(-) 2	0.22	4500	6855.23
2	(+) 100	(-) 250	(-) 5m/sec	(-) 10sec	(-) 2	0.3	4996	7316.83
3	(-) 25	(+) 500	(-) 5m/sec	(-) 10sec	(-) 2	0.23	5000	6969.34
4	(+) 100	(+) 500	(-) 5m/sec	(-) 10sec	(-) 2	0.27	8995	7826.45
5	(-) 25	(-) 250	(+) 25m/sec	(-) 10sec	(-) 2	0.22	4890	6879.78
6	(+) 100	(-) 250	(+) 25m/sec	(-) 10sec	(-) 2	0.31	5014	7267.34
7	(-) 25	(+) 500	(+) 25m/sec	(-) 10sec	(-) 2	0.21	5020	6978.12
8	(+) 100	(+) 500	(+) 25m/sec	(-) 10sec	(-) 2	0.25	9019	7817.22
9	(-) 25	(-) 250	(-) 5m/sec	(+) 20sec	(-) 2	0.19	4512	6852.13
10	(+) 100	(-) 250	(-) 5m/sec	(+) 20sec	(-) 2	0.28	4999	7318.28
11	(-) 25	(+) 500	(-) 5m/sec	(+) 20sec	(-) 2	0.21	5011	6959.33
12	(+) 100	(+) 500	(-) 5m/sec	(+) 20sec	(-) 2	0.25	8999	7829.14
13	(-) 25	(-) 250	(+) 25m/sec	(+) 20sec	(-) 2	0.2	4899	6872.45
14	(+) 100	(-) 250	(+) 25m/sec	(+) 20sec	(-) 2	0.29	5019	7261.18
15	(-) 25	(+) 500	(+) 25m/sec	(+) 20sec	(-) 2	0.19	5028	6973.36
16	(+) 100	(+) 500	(+) 25m/sec	(+) 20sec	(-) 2	0.23	9020	7810.37
17	(-) 25	(-) 250	(-) 5m/sec	(-) 10sec	(+) 7	0.24	4520	7845.45
18	(+) 100	(-) 250	(-) 5m/sec	(-) 10sec	(+) 7	0.3	5017	8326.74
19	(-) 25	(+) 500	(-) 5m/sec	(-) 10sec	(+) 7	0.26	5022	7979.24
20	(+) 100	(+) 500	(-) 5m/sec	(-) 10sec	(+) 7	0.3	9012	8826.65
21	(-) 25	(-) 250	(+) 25m/sec	(-) 10sec	(+) 7	0.25	5027	7889.17
22	(+) 100	(-) 250	(+) 25m/sec	(-) 10sec	(+) 7	0.33	5026	8277.48
23	(-) 25	(+) 500	(+) 25m/sec	(-) 10sec	(+) 7	0.24	5036	7988.36
24	(+) 100	(+) 500	(+) 25m/sec	(-) 10sec	(+) 7	0.28	9031	8827.28
25	(-) 25	(-) 250	(-) 5m/sec	(+) 20sec	(+) 7	0.23	4533	7842.19
26	(+) 100	(-) 250	(-) 5m/sec	(+) 20sec	(+) 7	0.31	5024	8328.34
27	(-) 25	(+) 500	(-) 5m/sec	(+) 20sec	(+) 7	0.25	5035	7969.77
28	(+) 100	(+) 500	(-) 5m/sec	(+) 20sec	(+) 7	0.29	9014	8839.87
29	(-) 25	(-) 250	(+) 25m/sec	(+) 20sec	(+) 7	0.23	4998	7882.84
30	(+) 100	(-) 250	(+) 25m/sec	(+) 20sec	(+) 7	0.32	5038	8271.24
31	(-) 25	(+) 500	(+) 25m/sec	(+) 20sec	(+) 7	0.22	5049	7983.59
32	(+) 100	(+) 500	(+) 25m/sec	(+) 20sec	(+) 7	0.26	9039	8820.1

Main effects are the individual effects of the factors on the response metrics. Interaction effects are the combinational effects of more than one factor on response metrics. Here, we are using two-way factor interaction effects plots that visualize the change in response metric results from combined variation of two factors from their low to high levels. Parallel lines show the absence of factor interaction, whereas non-parallel lines show the presence of two-way factor interactions. Standardized effect plot shows factor that has individual or combined effect on the corresponding response metric. Estimated effect and coefficient table shows the estimate for each factor and two-way interaction. This estimate quantifies the change in response metric when factor (or two-way interaction) varies from its low to high level [6]. This table also shows those factors and two-way factor interactions that are statistically significant for the response metric under consideration.

Then a regression model comprising the factors and two-way interactions for each response metric is presented. A first regression model is designed that comprises only significant factors and two-way interactions. Finally Analysis of Variance (ANOVA) table for each response metric is given to explore further. This can be used as another tool for identifying main and interaction effects of factors that are statistically significant. The sum of square (SS) is the variation; the degrees of freedom (df) is equal to 1 for each factor and factor interaction; the mean square (MS) is the variance which is SS/df; F is the F-ration defined as MS/error; and the P-value is the probability that the computed F-statistic is greater than the tabulated F-value. The P-value is the indicator of statistical significance which indicates the degree to which the value of a factor is "true". $P < 0.05$ is the desirable values to consider as significant.

5.1 Packet Delivery Ratio

Fig. 1(a) shows the scatter plot for packet delivery ratio (PDR). Almost same pattern occurs from 17-32 design points as occurred at 1-16 design points but mean value of packet delivery ratio increases slightly. Design points 1-16 shows the behavior of PDR when optimal number of copies are 2 and those of 7 are shown through design points from 17-32.

Main effect plot clearly shows that varying network size, transmission rate, pause time and optimal number of copies from their low to high level, packet delivery ratio (PDR) is affected. It is slightly affected by varying mobility speed. For example, PDR increases roughly from 0.223 to 0.299 when network size increases from 25 (low level) to 100 (high level). It is greatly affected by network size than any other factors considered. In contrast it remains around 0.25 when mobility speed is varied from 5 to 25 mps.

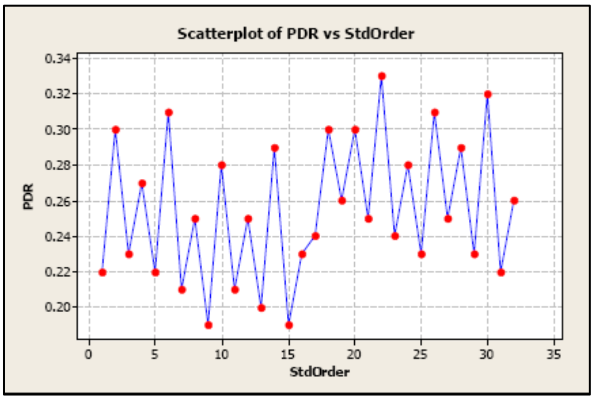
Fig. 1(d) shows the two-way interactions on the PDR by factors from their low to high levels. Following two-way interactions have remarkable impact on PDR: (i) network size and transfer rate (ii) transfer rate and mobility speed.

Estimated effects & coefficients given in table (fig. 1(e)) shows the estimate quantifying the change in PDR when varying factor or two-way interaction from their low to high level. For example, the estimate for network size is 0.06125 with respect to PDR. This table also shows the factors and two-way factor interactions that are statistically significant. For PDR, almost all factors are significant (as none of the estimates are 0). Two-way factor interaction that is not significant is *MobSpeed*optNoCopies* as its estimate is zero.

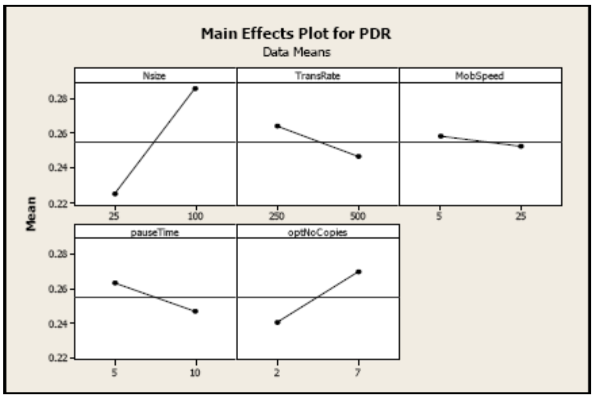
Mean of PDR can be easily calculated from table 2 which is 0.255. This is also achieved as coefficient (fig. 1(e)). Now we can derive a first regression model that comprises only significant factors and two-way interactions as follows:

$$y_{PDR} = 0.25500 + 0.3063\, x_1 - 0.00875\, x_2 - 0.00313\, x_3 - 0.00812\, x_4 + 0.01438\, x_5 - 0.01063\, x_1 x_2 + 0.00125\, x_1 x_3 + 0.00125\, x_1 x_4 - 0.00125\, x_1 x_5 - 0.00812\, x_2 x_3 - 0.00063\, x_2 x_4 + 0.00187\, x_2 x_5 - 0.00125\, x_3 x_4 + 0.00250\, x_4 x_5. \qquad (2)$$

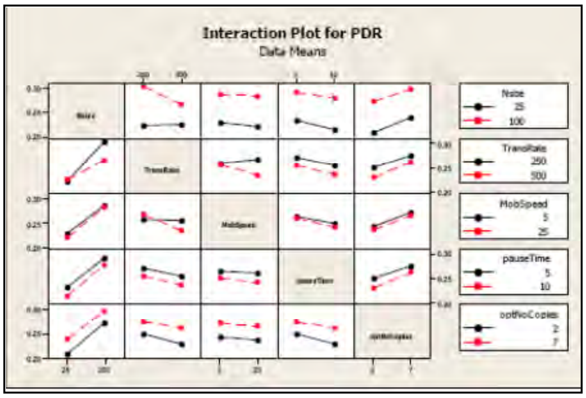
where x_1 = network size, x_2 = transmission rate, x_3 = mobility speed, x_4 = pause time and x_5 = optimal number of copies.



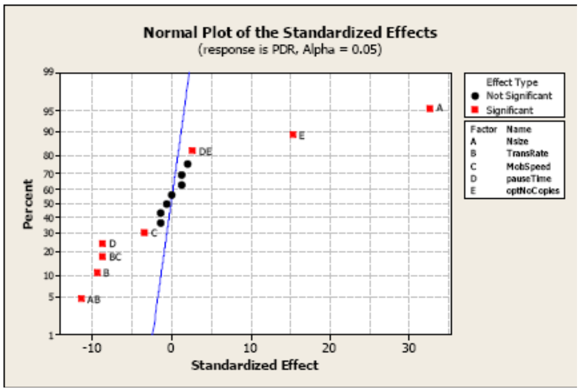
(a). Scatter plot



(b) Main Effect Plot



(c) Interaction Plot



(d) Effect plot

Estimated Effects and Coefficients for PDR

Term	Effect	Coef	SE Coef
Constant		0.25500	0.000938
Nsize	0.06125	0.03063	0.000938
TransRate	-0.01750	-0.00875	0.000937
MobSpeed	-0.00625	-0.00313	0.000938
pauseTime	-0.01625	-0.00812	0.000937
optNoCopies	0.02875	0.01438	0.000938
Nsize*TransRate	-0.02125	-0.01063	0.000937
Nsize*MobSpeed	0.00250	0.00125	0.000937
Nsize*pauseTime	0.00250	0.00125	0.000937
Nsize*optNoCopies	-0.00250	-0.00125	0.000937
TransRate*MobSpeed	-0.01625	-0.00812	0.000937
TransRate*pauseTime	-0.00125	-0.00063	0.000937
TransRate*optNoCopies	0.00375	0.00187	0.000937
MobSpeed*pauseTime	-0.00250	-0.00125	0.000938
MobSpeed*optNoCopies	0.00000	0.00000	0.000937
pauseTime*optNoCopies	0.00500	0.00250	0.000937

S = 0.00530330 R-Sq = 99.07% R-Sq(pred) = 96.27% R-Sq(adj) = 98.19%

(e). Estimated effects & Coefficient table

Analysis of Variance for PDR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	5	0.0415000	0.0415000	0.0083000	295.11	0.000
Nsize	1	0.0300125	0.0300125	0.0300125	1067.11	0.000
TransRate	1	0.0024500	0.0024500	0.0024500	87.11	0.000
MobSpeed	1	0.0003125	0.0003125	0.0003125	11.11	0.004
pauseTime	1	0.0021125	0.0021125	0.0021125	75.11	0.000
optNoCopies	1	0.0066125	0.0066125	0.0066125	235.11	0.000
2-Way Interactions	10	0.0062500	0.0062500	0.0006250	22.22	0.000
Nsize*TransRate	1	0.0036125	0.0036125	0.0036125	128.44	0.000
Nsize*MobSpeed	1	0.0000500	0.0000500	0.0000500	1.78	0.201
Nsize*pauseTime	1	0.0000500	0.0000500	0.0000500	1.78	0.201
Nsize*optNoCopies	1	0.0000500	0.0000500	0.0000500	1.78	0.201
TransRate*MobSpeed	1	0.0021125	0.0021125	0.0021125	75.11	0.000
TransRate*pauseTime	1	0.0000125	0.0000125	0.0000125	0.44	0.514
TransRate*optNoCopies	1	0.0001125	0.0001125	0.0001125	4.00	0.063
MobSpeed*pauseTime	1	0.0000500	0.0000500	0.0000500	1.78	0.201
MobSpeed*optNoCopies	1	0.0000000	0.0000000	0.0000000	*	*
pauseTime*optNoCopies	1	0.0002000	0.0002000	0.0002000	7.11	0.017
Residual Error	16	0.0004500	0.0004500	0.0000281		
Total	31	0.0482000				

(f). ANOVA table

Fig. 1: (a) Scatter Plot, (b) Standardized effect Plot, (c) Main Effect Plot, (d) Interaction Plot (e) Estimated effects & Cofficient table and (f) ANOVA table for Packet Delivery Ratio (PDR)

Equation (2) can be infer as follows: the mean PDR is 0.2550, the effect of network size, transmission rate, mobility speed, pause time and optimal number of copies is 0.3063, -0.00875, -0.00313, -0.00812 and 0.01438 respectively, when the corresponding factors are changed from their low to high level. The interaction between network size and transmission rate is -0.01063, between network size and mobility speed is 0.00125, between network size and pause time is 0.00125, between network size and optimal number of copies is -0.00125, between transmission rate and mobility speed is -0.00812, between transmission rate and pause time is -0.00063, between transmission rate and optimal number copies is 0.00187, between mobility speed and pause time is -0.00125 and between pause time and optimal number of copies is 0.00250. We have already observed that there is no interaction between mobility speed and optimal number of copies that is why x_3 x_5 term is missing in equation (2).

The quantity "R-square" is 99.07%. Since $0 \leq R^2 \leq 1$, the larger value is desirable. The *adjusted* R-square is 98.19%, it is a variation of R^2 statistic whose value decreases as more factors are included within the model.

Fig. 1(f) shows the analysis of variance (ANOVA) table for PDR. Clearly, all factors are significant for PDR and a two-way interaction such as pause time and mobility speed has no impact on PDR. From ANOVA table, we conclude that the regression equation (2) for PDR is acceptable.

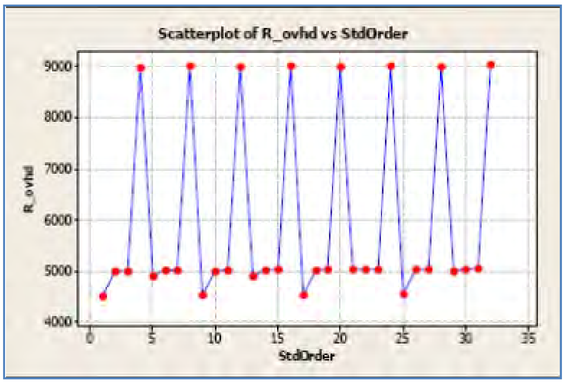
5.2 Routing Overhead

Fig. 2(a) shows the scatter plot for routing overhead. Almost same pattern occurs for 1-4/5-8 and so on design points. Each design point relates change in network size from 25 nodes to 100 nodes. It is clear that network size affects the routing overhead. Design pairs 1-2/3-4, 5-6/7-8 and so on reflect the change in transmission rate from its low level to high level.

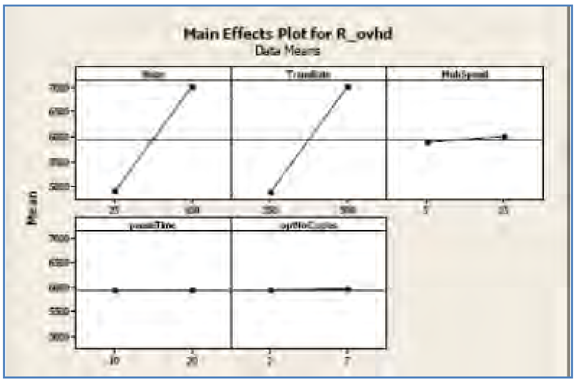
Fig. 2(b) shows the main effect plot for routing overhead. Clearly, network size and transmission rate greatly affect the routing overhead. The greater the number of nodes in the network, greater the number of hops that leads in sending more routing control packets. Since the slope of connecting lines of mobility speed, pause time and optimal number of copies are very small (about 0), it suggests that they have no effect on routing overhead.

Fig, 2© shows the two-way interaction plot for routing overhead. Parallel lines in first box suggests the presence of two-way factor interaction on the routing overhead i.e. routing overhead is affected by combined variation of network size and transmission rate.

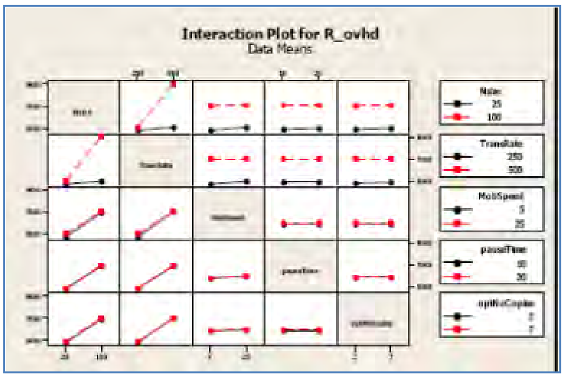
Fig. 2(d) represents the effect plot which shows that factor network size (A), transmission rate (B) and mobility speed (C) have significant main effect on routing overhead. Also, network size and transmission rate (AB), transmission rate and mobility speed (BC) and network size and mobility speed (AC) has significant two-way factor impact on routing overhead. From interaction plot, it is clear that network size and mobility speed has slight combined effect on routing overhead because both lines are not perfectly parallel (in third box).



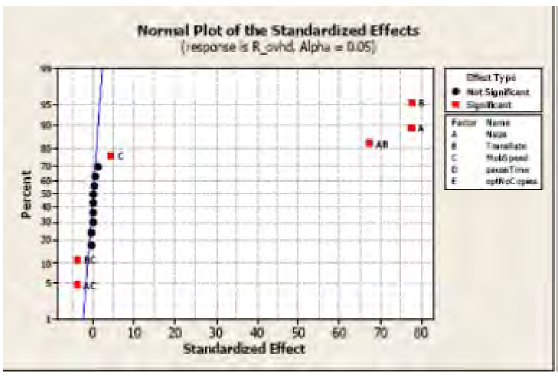
(a). Scatter plot



(b) Main Effect Plot



(c) Interaction Plot



(d) Effect plot

Estimated Effects and Coefficients for R_ovhd

Term	Effect	Coef	SE Coef
Constant		5948.19	13.78
Nsize	2136.37	1068.19	13.78
TransRate	2144.87	1072.44	13.78
MobSpeed	122.75	61.38	13.78
pauseTime	5.75	2.88	13.78
optNoCopies	31.25	15.63	13.78
Nsize*TransRate	1854.62	927.31	13.78
Nsize*MobSpeed	-104.00	-52.00	13.78
Nsize*pauseTime	-0.50	-0.25	13.78
Nsize*optNoCopies	-13.75	-6.87	13.78
TransRate*MobSpeed	-103.50	-51.75	13.78
TransRate*pauseTime	1.75	0.88	13.78
TransRate*optNoCopies	-13.00	-6.50	13.78
MobSpeed*pauseTime	-2.37	-1.19	13.78
MobSpeed*optNoCopies	10.63	5.31	13.78
pauseTime*optNoCopies	-0.87	-0.44	13.78

S = 77.9365 R-Sq = 99.90% R-Sq(pred) = 99.62% R-Sq(adj) = 99.81%

(e). Estimated effects & Coefficient table

Analysis of Variance for R_ovhd

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	5	73445313	73445313	14689063	2418.31	0.000
Nsize	1	36512785	36512785	36512785	6011.22	0.000
TransRate	1	36803910	36803910	36803910	6059.15	0.000
MobSpeed	1	120541	120541	120541	19.84	0.000
pauseTime	1	265	265	265	0.04	0.837
optNoCopies	1	7812	7813	7813	1.29	0.273
2-Way Interactions	10	27693142	27693142	2769314	455.92	0.000
Nsize*TransRate	1	27517071	27517071	27517071	4530.23	0.000
Nsize*MobSpeed	1	86528	86528	86528	14.25	0.002
Nsize*pauseTime	1	2	2	2	0.00	0.986
Nsize*optNoCopies	1	1512	1512	1512	0.25	0.625
TransRate*MobSpeed	1	85698	85698	85698	14.11	0.002
TransRate*pauseTime	1	25	25	25	0.00	0.950
TransRate*optNoCopies	1	1352	1352	1352	0.22	0.643
MobSpeed*pauseTime	1	45	45	45	0.01	0.932
MobSpeed*optNoCopies	1	903	903	903	0.15	0.705
pauseTime*optNoCopies	1	6	6	6	0.00	0.975
Residual Error	16	97186	97186	6074		
Total	31	101235641				

(f). ANOVA table

Fig.2: (a) Scatter Plot, (b) Standardized effect Plot, (c) Main Effect Plot, (d) Interaction Plot (e) Estimated effects & Cofficient table and (f) ANOVA table for Routing overhead

Estimated effects & coefficients given in table (fig. 2(e)) shows the estimate quantifying the change in routing overhead when varying factor or two-way interaction from their low to high level. The estimate for network size is 2136.37 with respect to routing overhead.

Now, first order regression model comprising factors and two-way interactions is

$$y_{R\_ovhd} = 5948.19 + 1068.19x_1 + 1072.44\ x_2 + 61.38\ x_3 + 2.88\ x_4 + 15.63\ x_5 + 927.31\ x_1\ x_2 - 52.00\ x_1\ x_3 -0.25\ x_1\ x_4 -6.87\ x_1\ x_5 -51.75\ x_2\ x_3 + 0.88\ x_2\ x_4 - 6.50\ x_2\ x_5 -1.19\ x_3\ x_4 + 5.31\ x_3\ x_5 -0.44\ x_4\ x_5 \quad (3)$$

where x_1 = network size, x_2 = transmission rate, x_3 = mobility speed, x_4 = pause time and x_5 = optimal number of copies.

It is clear from equation (3), the mean value of routing overhead is 5948.12 which can also be calculated from table 2. The effect of network size, transmission rate, mobility speed, pause time and optimal number of copies is 1068.19, 1072.44, 61.38, 2.88 and 15.63 respectively, when the corresponding factors are changed from their low to high level. These are the expected change in routing overhead when there is a per unit change in each of the factor. The interaction between network size and transmission rate is 927.31, between network size and mobility speed is 52.00, between network size and pause time is -0.25, between network size and optimal number of copies is -6.87, between transmission rate and mobility speed is -51.75, between transmission rate and pause time is 0.88, between transmission rate and optimal number copies is -6.50, between mobility speed and pause time is -1.19, between mobility speed and optimal number of copies is 5.31 and between pause time and optimal number of copies is -0.44.

The quantity "R-square" is 99.90%. Since $0 \leq R^2 \leq 1$, the larger value is desirable. The *adjusted* R-square is 99.81%, it is a variation of R^2 statistic whose value decreases as more factors are included within the model.

Fig. 2(f) shows the analysis of variance (ANOVA) table for routing overhead. Clearly, all factors are significant for routing overhead. From ANOVA table, we conclude that the regression equation (3) for routing overhead is acceptable.

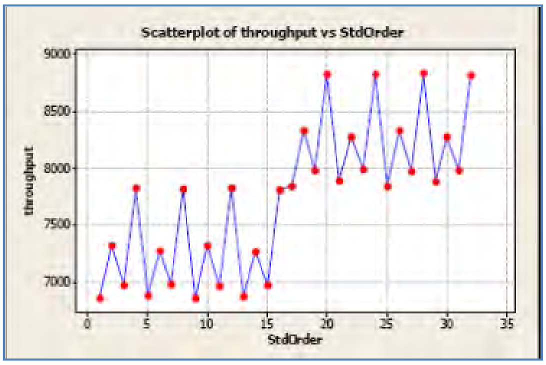
5.3 Throughput

Fig. 3(a) shows the scatter plot for routing overhead. Almost same pattern occurs for design points 1-16 and 17-32. This shows when optimal number of copies increases from 2 to 7 throughput also increase from its mean value 7236.66 kbps (mean of optimal number of copies from design points 1-16) to 8243.64 (mean of optimal number of copies from design points 1-16). This mean can easily be calculated using table 2.

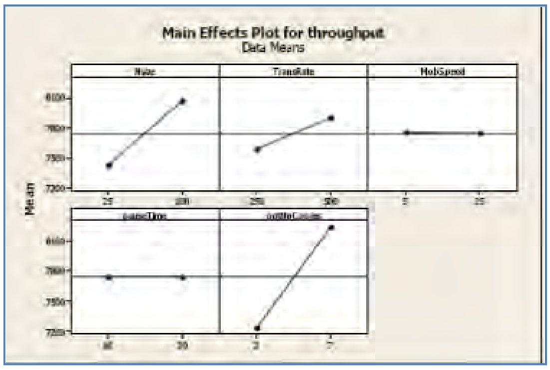
Fig. 3(b) shows the main effect plot for throughput. Clearly, throughput is greatly affected by network size, transmission rate and optimal number of copies. There is no or very little main impact of mobility speed and pause time on throughput as almost parallel connecting line appears in third and fourth boxes.

Fig, 3© shows the two-way interaction plot for throughput. As far as two-way interactions, throughput is affected by combined effect of network size and transmission rate.

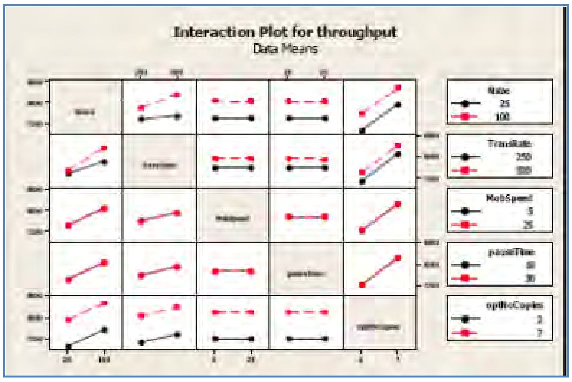
Fig. 3(d) represents the effect plot of standardized effect on throughput. Clearly, network size (A), transmission rate (B) and optimal number of copies (E) have main effects on throughput and combined two-way interaction effect is generated by network size and transmission rate (AB).



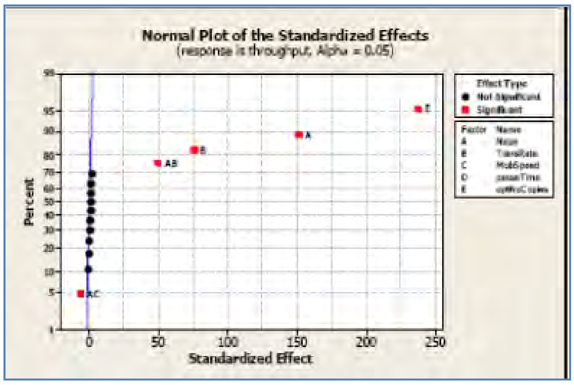
(a). Scatter plot



(b) Main Effect Plot



(c) Interaction Plot



(d) Effect plot

Estimated Effects and Coefficients for throughput

Term	Effect	Coef	SE Coef
Constant		7740.15	2.116
Nsize	640.26	320.13	2.116
TransRate	319.47	159.74	2.116
MobSpeed	-5.32	-2.66	2.116
pauseTime	-3.53	-1.77	2.116
optNoCopies	1006.98	503.49	2.116
Nsize*TransRate	209.24	104.62	2.116
Nsize*MobSpeed	-27.19	-13.60	2.116
Nsize*pauseTime	2.60	1.30	2.116
Nsize*optNoCopies	1.88	0.94	2.116
TransRate*MobSpeed	5.14	2.57	2.116
TransRate*pauseTime	0.14	0.07	2.116
TransRate*optNoCopies	1.96	0.98	2.116
MobSpeed*pauseTime	-2.67	-1.34	2.116
MobSpeed*optNoCopies	3.05	1.52	2.116
pauseTime*optNoCopies	0.73	0.36	2.116

S = 11.9690   R-Sq = 99.98%   R-Sq(pred) = 99.93%   R-Sq(adj) = 99.96%

(e). Estimated effects & Coefficient table

Analysis of Variance for throughput

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	5	12208428	12208428	2441686	17044.20	0.000
Nsize	1	3279463	3279463	3279463	22892.32	0.000
TransRate	1	816489	816489	816489	5699.51	0.000
MobSpeed	1	226	226	226	1.58	0.227
pauseTime	1	100	100	100	0.70	0.416
optNoCopies	1	8112150	8112150	8112150	56626.93	0.000
2-Way Interactions	10	356614	356614	35661	248.93	0.000
Nsize*TransRate	1	350238	350238	350238	2444.84	0.000
Nsize*MobSpeed	1	5915	5915	5915	41.29	0.000
Nsize*pauseTime	1	54	54	54	0.38	0.548
Nsize*optNoCopies	1	28	28	28	0.20	0.663
TransRate*MobSpeed	1	212	212	212	1.48	0.242
TransRate*pauseTime	1	0	0	0	0.00	0.974
TransRate*optNoCopies	1	31	31	31	0.21	0.650
MobSpeed*pauseTime	1	57	57	57	0.40	0.537
MobSpeed*optNoCopies	1	74	74	74	0.52	0.482
pauseTime*optNoCopies	1	4	4	4	0.03	0.866
Residual Error	16	2292	2292	143		
Total	31	12567334				

(f). ANOVA table

Fig.3: (a) Scatter Plot, (b) Standardized effect Plot, (c) Main Effect Plot, (d) Interaction Plot (e) Estimated effects & Cofficient table and (f) ANOVA table for throughput

Estimated effects & coefficients given in table (fig. 3(e)) shows the estimate quantifying the change in throughput when varying factors or two-way interaction from their low to high level. The estimate for network size is 640.26 with respect to throughput.

Now the first order regression model that comprises significant factors and two-way interactions for throughput is,

$$y_{Throughput} = 7740.15 + 320.13x_1 + 159.44x_2 - 2.66x_3 - 1.77x_4 + 503.49x_5 + 104.62x_1\ x_2 - 13.60\ x_1\ x_3 + 1.30\ x_1\ x_4 + 0.94\ x_1\ x_5 + 2.57\ x_2\ x_3 + 0.07\ x_2\ x_4 + 0.98\ x_2\ x_5 - 1.34x_3\ x_4 + 1.52\ x_3\ x_5 + 0.36\ x_4\ x_5 \quad (4)$$

The quantity "R-square" is 99.98%. Since $0 \le R^2 \le 1$, the larger value is desirable. The *adjusted* R-square is 99.96%. Fig. 1(f) shows the analysis of variance (ANOVA) table for throughput. Clearly, all factors are significant for throughput. From ANOVA table, we conclude that the regression equation (4) for throughput is acceptable.

5.4 Summary

In this section we analyze three response metrics packet delivery ratio, routing overhead and throughput, through variation of five factors network size, transmission rate, mobility speed, pause time and optimal number of copies. The results are analyzed on the basis of values obtained during simulation. Scatter plot, main effect plot, interaction plot standardized effect plot, estimated effects and coefficient table and ANOVA table drawn using MINITAB 18 software are used to analyze each of the response metric.

6. CONCLUSION

To make routing as fault tolerant for MANETs, we already proposed a multiple-copy or replication strategy that is adaptive. Adaptive in the sense that it adapts current network conditions to estimate the number of replicate copies. This protocol is referred as Adaptive Fault Tolerant Replication Routing. In the present work, we analyze its performance by examining the behavior of three response metrics packet delivery ratio, routing overhead and throughput under the variation of five factors network size, transmission rate, mobility speed, pause time and optimal number of copies. The last metric is calculated using our strategy. Packet Delivery Ratio describes the loss rate which in turn affects the maximum throughput that can network support. Routing overhead is an important metric as it measures the scalability of the protocol, the degree to which it will function in congested or low-bandwidth environments. Protocols that send large number of routing packets result in increased probability of packet collisions and delay in network interface.

It has been shown that PDR is greatly affected by network size, transmission rate and optimal number of copies. It is also affected by other two metrics. Routing overhead is strongly affected by network size and transmission rate. Other three factors are very little or no impact on routing overhead. Throughput is greatly affected by network size, transmission rate and optimal number of copies. A two-factor interaction on three metrics is also presented. PDR is affected by combined variation of (i) network size and transmission rate and (ii) transmission rate and mobility speed. Routing overhead is affected by combined variation of network size and transmission rate. Throughput is also affected by combined variation of network size and transmission rate.

7. FUTURE WORK

Numerous studies for evaluating performance of routing protocols mainly focus on one-factor-at-a-time approach. In contrast, we already evaluate and quantify the effects of five factors on various metrics like end-to-end delay, packet drop, packet delivery ratio, routing overhead and throughput. Now next step is to use Taguchi design to identify the best factor combination for these response metrics.

REFERENCES

[1] X. Hong, K. Xu and M. Gerla, "*Scalable routing protocols for mobile ad hoc networks*", IEEE Network, vol.16, pp. 11-21, Jul/Aug 2002.

[2] Swati Saxena, Madhavi Sinha, "A study of Adaptive Replication Technique in Routing time-constrained messages (VoIP) in MANET", *International Journal of Computer Science and Engineering (IJCSE)*, Issue 3, Vol. 6, June 2011.

[3] George Adam, Vaggelis Kapoulas, Christos Bouras, Georgios Kioumourtzis, Apostolos Gkamas and Nikos Tavoularis, "Performance Evaluation of Routing Protocols for multimedia transmission over Mobile Ad hoc Networks", *IFIP WMNC'2011*.

[4] Swati Saxena, Madhavi Sinha, "*Analysis of Performance metrics and influential factors of Adaptive Fault Tolerant Routing (AFTR) protocol for MANET*", All India Seminar on Recent Techniques of Future of Information Technology (RTFIT-2012), September 22-23, 2012 held at HBTI, Kanpur.

[5] K. K. Vadde & V. R. Syrotiuk, "*Factor interaction on service delivery in mobile ad hoc networks*", Journal on Selected Area in Communications, (22)7: 1335-1346, September 2004.

[6] Michael W. Torato and Dmitri D. Perkins, "Using Statistical Design of Experiments for Analyzing Mobile Ad Hoc Networks", MSWiM'05, October 10-13, 2005.

[7] Hazura Mohamed, Muhammad Hisyam Lee, Bahrom Sanugi and Mazalan Sarahintu, "Taguchi Approach for Performance Evaluation of Routing Protocols in Mobile Ad Hoc Networks", *Journal of Statistical Modeling and Analytics*, Vol.1, No.2, 10-18, 2010.

[8] Samir R. Das, Charles E. Perkins and Elizabeth M. Royer, "*Performance Comparison of two on demand routing protocols for ad hoc network*", 2000.

[9] Tamilarasan-Santhamurthy, "*A comparative Study of Multi-Hop Wireless Network Routing Protocols in MANET*", International Journal of Computer Science Issues, Vol. 8, Issue 5 No 3, September 2011.

[10] Santosh Kumar, SC Sharma, Bhupendra Suman, "*Simulation Based Performance Analysis of Routing Protocols Using Random Waypoint Mobility Model in Mobile Ad Hoc Networks*", Global Journal of Computer Science and Technology, Vol. 11 Issue 1, Version 1.0, February 2011.

[11] C. E. Perkins, "*Ad Hoc Networking*", Addison-Wesley, New York.

[12] R. Jain. *The Art of Computer System Performance and Analysis.* John Wiley and Sons. New York, 1991.

AUTHOR'S PROFILE:

Swati Saxena

Research Scholar

AIM & ACT, Banasthali Vidyapith,

Banasthali, (Raj.)

Dr. Madhavi Sinha

She received her Ph.D. degree from Banasthali Vidyapith, Banathali (Raj.) and currently working as Associate Professor and Head of Department (Computer Science & Engineering) at Birla Institute of Technology, Jaipur (Raj.). She has 25 years of teaching experience and published many National and International publications. Her research interests are Artificial Intelligence, soft and language computing.