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Determining the Effects of Scenario Metrics on the Performance of Dynamic Source Routing using Taguchi Approach

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Abstract Design and analysis of routing protocols used for mobile ad hoc network (MANET) is currently an active area of research. This paper deals with determining the effects of several scenario metrics on the performance of dynamic source routing (DSR) protocol with regard to routing overhead. The scenario metrics include terrain, network size, pause time, node velocity, transmission range, traffic load, and packet rates. In this paper, Taguchi approach is used to analyze and estimate the effects of the metrics. It is an extension of the author's previous study on the investigations of the effects of three scenario metrics on several performance metrics. It is discovered that network size was the most significant factor affecting the response, followed by pause time, node velocity, and finally traffic load.

Keywords Taguchi approach, design of experiment, mobile ad hoc network, dynamic source routing protocol.

1 Introduction

A mobile ad hoc network (MANET) consists of a collection of wireless mobile nodes that are capable of communicating with one another without relying to a static network infrastructure (see Johnson and Maltz [1]). MANET is very useful in military and other tactical applications such as emergency rescue or exploration missions, where static cellular phone infrastructure is unavailable or unreliable. In MANET, each node has a limited transmission range. When a receiver is out of the direct transmission range of a sender, an intermediate node needs, to behave as a router to forward data to a receiver. Therefore, each mobile node may operate not only as a host but also as a router transferring data from other mobile nodes. Moreover, each host is also free to move around, making the network topology always changes dynamically. As a result, routing, a process of finding and maintaining routes among group of nodes in the network, becomes a challenging issue.

Design and analysis of routing protocols for MANET is currently an active area of research. There are not any standard for the protocols, instead this work continues. This has resulted in a special working group for MANET formed within the Internet Engineering Task Force (IETF), which is signed to the task of developing and standardizing routing protocol specifications for MANET (Das et al [3]). To date a variety of protocols have been developed for MANET. Basically, these protocols can be divided into two categories:

proactive and reactive. In proactive, consistent and up-to-date routing information to all nodes is maintained at each node. Whereas, in reactive routes are created as and when required. Dynamic Source Routing (DSR) (Johnson and Maltz [1]) is an example of reactive protocols, while Destination Sequenced Distance Vector (DSDV) (Perkins and Bhagwat [2]) is an example of proactive ones.

In this study, we focus on the dynamic source routing (DSR) protocol. The DSR, one of the most prominent protocols for MANET, operates on reactive basis, where routes are created as and when required by nodes. This makes the DSR being efficient in term of energy consumption, as no periodic routing information must be maintained throughout the network. In addition, the DSR is also able to react quickly to routing changes when node movement is frequent. Hence, the broken routes in the network can be immediately changed with the fresh ones, and then data packets can be delivered quickly despite of high network topology. Besides the advantages, however, as pointed out by some researchers such as Marina and Das [5], several mechanisms in the DSR algorithm can outperform its performance, for example when the node movement is high. Therefore, there is still a room for improvement of this protocol. For further information about the DSR protocol, one should refer to Johnson and Maltz [1] and Das et al [3].

Before employing any routing protocols in a real network, it has to be thoroughly simulated in order to find bugs and test its reliability and robustness over a certain network configuration (Jacobson [6] and Sarahintu and Lee [9]). A set of performance metrics provides a good method for accessing the DSR protocol such as routing overhead, packet delivery ratio, and drop rates (Das et al [3]). In addition to these metrics, there are also scenarios metrics that describe the network environment and define the scenario which include terrain, network size, pause time, node velocity, transmission range, traffic load, and packet rates (Das et al [3]). A number of recent papers such as Das et al [3], Broch et al [4], and Marina and Das [5] have analyzed the performance of the DSR protocol, however, so far, no research has been done on estimating the effects of the scenario metrics. Hence, in this paper, we are interested in determining the effects of the scenario metrics on the DSR performance with regard to routing overhead. We present the use of Taguchi approach to analyze and estimate the effects of the scenario metrics. This is an extension of the previous study (Sarahintu and Lee [9] and Sarahintu et al [11]) on the investigation of the effects of three scenario metrics with respect to several performance metrics. This study also indirectly expands the use of this powerful design of experiment technique as a novel approach on the investigation and prediction of MANET's routing protocols performance, which was initiated by Lee [8].

Results of this study would be helpful for routing designers in designing and evaluating any other reactive protocols. This is because when conducting simulations the researchers can know what scenario metric should be given high priority compared to others, which can act directly to enhance the protocol performances.

This paper is organized as follows. Section 2 states the problem formulation. In section 3, we discuss our methodology involving computer simulation and Taguchi approach. Section 4 presents our analysis data and findings. Lastly, we conclude our results and discuss briefly the future study in the last section of this paper.

2 Problem Formulation

Our problem involves determining the effects the scenario metrics on the DSR performance with regard to routing overhead. Routing overhead is defined as the total number of routing packets which consists *route_request* and *route_reply*, propagated by the DSR to maintain connectivity throughout the network, for details see Johnson and Maltz [1]. This important metric reveals the efficiency of the DSR consuming node battery power and the scalability of the protocol.

In this study, we present the use of design of experiment technique based on Taguchi approach to analyze and estimate the effects of scenario metrics. We employ a $L_8(2^7)$ Taguchi orthogonal array to design experiments, which performs using computer simulations. We use analysis of average and analysis of variance (ANOVA) to estimate the effects of the scenario metrics, and determine the scenario metrics that are statistically significant. We also discuss the results of statistical analysis found in this study.

3 Methodology

3.1 Computer simulation

The data were obtained from computer simulations ns-2 [12]. The reasons for choosing the simulator are due to fact that the DSR protocol is already implemented (in source code) in the simulator, and most importantly, we found the DSR simulations worked well without any problems. ns-2 was developed using C++ and uses OTcl as a command and configuration interface. All simulations were performed on an Intel Pentium IV processor at 2.00 GHz, 256 MB of RAM running Linux Fedora Core 3. Each simulation was executed for 600 seconds.

Using the simulator, the effects of the scenario metrics on the DSR performance are examined. In order to maintain consistency with design of experiment terminology, the scenario metrics that affect the DSR performance are referred as factors and the actual performance of the protocol (i.e. routing overhead) is referred as response. We considered each factor to have two distinct levels (values). Generally, two levels of factors work well in screening experiments (Montgomery [15])–experiments in which many factors are considered and the objective is to identify which factors have large effects to response. The factors with their chosen levels are presented in Table 1. Since there are two levels for each factor, we assume that the response is approximately linear over the range of the factor level chosen.

We now provide justification for the factor levels that were chosen in this study. Terrain is an area size of network in which nodes are free to move and communicate one another. It affects the arrangement of the nodes and the length of the routes taken by a packet. In an attempt to generate results that would be representative of some potential, real life scenario, the values of terrain can be considered as a meeting room, lecture room, and multipurpose room (Sarahintu and Lee [9]). Network size, which has a considerable effect on the network connectivity, is the number of nodes participating in the networks. The nodes are composed of sources, destinations, and intermediate nodes acting as routers. Pause time is a dormant time taken by a node before moving to another destination measured in seconds. Pause time and node velocity stress the node mobility in the network, which impact the frequency of the topological changes and hence may cause link failures. We chose the two values of pause time to have a low and moderate mobility, respectively, in the network. The nodes are moving according to the speeds of hosts acting as pedestrians. The speeds of 0.72 m/s and 1.34 m/s are the minimum and maximum walking speeds for a pedestrian, respectively (see Young [16]). In real life, the differences can explained by the trip purpose of hosts, and the places where they walk (Lam and Cheung [17]). For example, a shopper in a shopping area tends to walk slower compared to a pedestrian in an airport terminal who is usually in a hurry. A transmission range of 10 m and 18 m is considered as one the Bluetooth has to date (Sarahintu and Lee [9]), and is a single-transmission range for MANET suggested by Jin et al [7], respectively. Traffic load is defined as a percentage of number of nodes acting as a source in the network. Each source transmits data in 512 byte at a certain value of packet sending rates. Both values for traffic load and packet rates were chosen in order to have a small and moderate congestion, respectively, in the network.

Table 1: Selected factors and levels

Label	Factors	Level 1	Level 2
A	Terrain size (m^2)	40×40	60×60
B	Network size	10	25
C	Node velocity (m/s)	0.72	1.34
D	Pause time (s)	10	60
E	Transmission range (m)	10	18
F	Traffic load (%)	10	20
G	Packet rates ($pckts/s$)	2	6

3.2 Taguchi approach

In order to estimate the effects of the scenario metrics on the response, we use Taguchi methodology. Taguchi method employs several standard orthogonal arrays (OAs) to design experiments. Concisely, the OAs are represented in the form of $\mathrm{L}_m(\theta^n)$. Here, m represents the number of experimental run conducted in the experiment. θ denotes the number of level for each factor, and n represents the number of factors to be studied. For example, $\mathrm{L}_9(3^4)$ means that 9 experiments are to be conducted in order to study 4 factors at 3 levels.

The comparison between the full factorial design (FFD) and Taguchi design is presented in Table 2. From the table, we can see that, for example, using L_{16} of a Taguchi orthogonal array, 15 two level factors can be studied by running only 16 experiments instead of 32768 experiments, which is a result of applying FFD. Therefore, there is definitely a greater saving in testing a larger number of factors when using Taguchi design.

In Taguchi approach, the selection of which OA to use depends on the number of factors and the number of levels for factors. These two items determine the total degrees of freedom (Df) required for an experiment. The Df for a factor is the number of its levels minus one, that is

$$Df = L - 1, \tag{1}$$

where L is the levels of a factor. The total Df available in an OA is

Table 2: Comparison between Taguchi design and full factorial design (FFD)

Taguchi design	Experiment number	FFD	Experiment number
$L_4(2^3)$	4	2^3	8
$L_8(2^7)$	8	2^7	128
$L_{12}(2^{11})$	12	2^{11}	2,048
$L_{16}(2^{15})$	16	2^{15}	32,768
$L_9(3^4)$	9	3^4	81
$L_{18}(3^7)$	18	3^7	2,187

$$Df_\alpha = N - 1, \tag{2}$$

where N is the total number of experiments. Therefore, to select a suitable OA for an experiment, the following inequality must be satisfied.

$$Df_\alpha \geq \sum Df, \tag{3}$$

where $\sum Df$ is the total degree of freedom of all factors considered in an experiment. In our case, we consider 7 two level factors, thus having total 7 Dfs. Therefore, according to equation (3), an orthogonal array of $L_8(2^7)$ is selected, conducting only 8 experiments for studying 7 two-level factors.

When experiments involving multiple runs, Taguchi approach uses signal-to-noise ratios (SNR) as a performance measure. Depending on response criteria, the SNR can be divided into three classes when a response is measured on a continuous scale. Suppose $y_1, y_2, \ldots, y_n$ represent multiple results of a response Y. The SNR denoted by $Z(\eta)$ can then be written as follows (Sarahintu et al [10]):

The smaller the better:

$$Z(\Theta) = -10\log(\frac{1}{n}\sum_{i=1}^{n} y_i^2). \tag{4}$$

The larger the better:

$$Z(\Theta) = -10\log(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}). \tag{5}$$

A specific target value is the best:

$$Z(\Theta) = 10\log(\frac{\overline{y}^2}{s^2}), \tag{6}$$

where

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i, \tag{7}$$

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \overline{y})^2. \tag{8}$$

For each type of the SNR, the higher is the SNR the better is the result. For this study, since lower routing overhead for the DSR protocol is desired, equation (4) is chosen. In Taguchi approach, a statistical analysis of variance (ANOVA) is performed to identify the factors that are statistically significant. The formulas to calculate ANOVA terms are the same as used in standard analysis. The difference is that all results are in SNR which can be positive or negative, depending to the characteristic of response being chosen. For complete references of Taguchi approach, see Ross [13] and Roy [14].

4 Analysis and Findings

4.1 Data

The experiments were randomized using repetitions, which aims to reduce the effects of irrelevant factors and other influences that are not being considered in the experiments (see Ross [13]). Table 3 shows the experimental data. Each experiment corresponds to a combination of factor levels and was run with eight repetitions, which makes up a total of 64 simulations being conducted. The SNR of the eight repetitions were then calculated using equation (4) as shown in column 3 of Table 3.

Table 3: Experimental data

Experiment	A	B	C	D	E	F	G	SNR
1	1	1	1	1	1	1	1	−53.674
2	1	1	1	2	2	2	2	−51.316
3	1	2	2	1	1	2	2	−73.810
4	1	2	2	2	2	1	1	−61.784
5	2	1	2	1	2	1	2	−55.247
6	2	1	2	2	1	2	1	−55.394
7	2	2	1	1	2	2	1	−64.473
8	2	2	1	2	1	1	2	−57.959
Grand average ($\overline{T}$)								−59.208

Note: 1: Level 1; 2: Level 2

4.2 Analysis of average effect

Using the experimental data shown in Table 3, we simply compute the effects of the seven factors on the response, thus ranking them based on their effects. Let us define the average effect for each factor. The average effect for factor$-i$ ($i = A, B, \ldots, G$) at level 1 which defined as $\overline{a}_{i_1}$ is

$$\overline{a}_{i_1} = \frac{y_{i_1}}{N_{i_1}}, \tag{9}$$

where y_{i_1} is the total of SNRs for factor$-i$ at level 1 and N_{i_1} is the number of responses with factor$-i$ at level 1 in the orthogonal array (refer to Table 3). The average effect for factor$-i$ at level 2 which defined as $\overline{a}_{i_2}$ is

$$\overline{a}_{i_2} = \frac{y_{i_2}}{N_{i_2}}, \tag{10}$$

where y_{i_2} is the total of SNRs for factor$-i$ at level 2 and N_{i_2} is the number of responses with factor$-i$ at level 2 in the orthogonal array. The absolute difference or delta between the average effect for factor at level 1 and level 2 is the effect of the factor. Thus, using equations (9) and (10), the effect of factor$-i$ is given by

$$\text{Effect of factor} - i = |\overline{a}_{i_1} - \overline{a}_{i_2}|. \tag{11}$$

After substituting the experimental data into equation (11), the delta and ranks of the seven factors are shown in Table 4. From the table, we can see that network size is the most influential factor, followed by pause time, node velocity, traffic load, transmission range, terrain, and finally packet rates. The magnitude influence of these factors and their significance effects can be determined using analysis of variance (ANOVA).

Table 4: Ranks of factor

Factors	Level 1	Level 2	Delta	Ranking
Terrain	−60.146	−58.269	1.877	6
Network size	−53.908	−64.507	10.600	1
Node velocity	−56.856	−61.559	4.703	3
Pause time	−61.802	−56.614	5.188	2
Transmission range	−60.210	−58.206	2.003	5
Traffic load	−57.166	−61.249	4.084	4
Packet rates	−58.832	−59.584	0.753	7

4.3 Analysis of variance (ANOVA)

In this study, analysis of variance (ANOVA) is used to determine the relative influence of the seven factors to the total variation of the results, and help identifying the factors that are statistically significant on the response. The ANOVA contains several terms which can be derived as follows (Roy [14]). The correlation factor (CF) is used for calculation of all sum of squares.

$$CF = \frac{T^2}{N}, \tag{12}$$

where T is the total of SNRs (results) and N is the total number of experiments. The total sum of squares SS_T is

$$SS_T = \sum_{j=1}^{N} y_j^2 - CF, \tag{13}$$

where y_j is the SNR of experiment$-j$. The sum of squares for factor$-i$ SS_i ($i = 1, 2, \ldots, 7$ where $1 = A$, $2 = B$, and so on) is

$$SS_i = \sum_{k=1}^{2} (\frac{y_{ik}^2}{N_{ik}}) - CF, \tag{14}$$

where $y_{ik}$is the total of SNRs for factor$-i$ at level$-k$ $(k = 1, 2)$ and N_{ik} is the number of SNRs with factor$-i$ at level$-k$ in the orthogonal array (refer to Table 3). Using equations (13) and (14), the sum of squares for error term SS_e is

$$SS_e = SS_T - \sum_{i=1}^{N} SS_i. \tag{15}$$

The degree of freedom for factor$-i$ Df_i is defined as the number of distinct level of factor minus one,

$$Df_i = L - 1, \tag{16}$$

where L the levels of factor. Since each SNR is counted as 1 degrees of freedom, regardless of the number of repetitions, the total degrees of freedom for an experiment Df_T is

$$Df_T = N - 1. \tag{17}$$

Using equations (16) and (17), the degrees of freedom for error term Df_e is

$$Df_e = Df_T - \sum_{i=1}^{N} Df_i. \tag{18}$$

Generally, the variance (mean sum of squares) is the sum of squares divided by degrees of freedom. Therefore, using equations (14), (15), (16), and (18) the variance for factor$-i$ V_i and error term V_e are

$$V_i = \frac{SS_i}{Df_i}, \tag{19}$$

$$V_e = \frac{SS_e}{Df_e}. \tag{20}$$

The variance is used in the evaluation of significance of the factor effects on the response. The $F-$test accomplishes this. This test requires evaluation of $F-$statistics which determined as the ratio of sum of squares for factor and sum of squares for error term.

$$F_i = \frac{SS_i}{SS_e}. \tag{21}$$

The total variation attributed to each factor is reflected in the percent influence. Using equations (14), (16), and (20), the pure sum of squares for factor$-i$ SS'_i is

$$SS'_i = SS_i - V_e Df_i. \tag{22}$$

Using equation (13) and (22), finally, the percent influence for factor$-i$ P_i and error term P_e is calculated as

$$P_i = \frac{SS'_i}{SS_T}, \tag{23}$$

$$P_e = 100 - \sum_{i=1}^{N} P_i. \tag{24}$$

Substituting the experimental data into equations (12) to (24), the values of the terms are summarized in Table 5. Column 6 of the ANOVA table indicates the percent influence of the factor to total effects. From the column, we see that the most effective factor is network size with 60.346%, followed by pause time with 14.459%, node velocity with 11.884%, and finally traffic load with 8.953%. Next, based on the delta values of 2.158%, 1.893%, and 0.303% for transmission range, terrain, and packet rates, respectively, we can consider these three factors have very little effects on the response.

Table 5: ANOVA table

Factors	Df	SS	V	SS'	P (%)
Terrain	1	7.050	7.050	7.050	1.893
Network size	1	224.672	224.672	224.672	60.346
Node velocity	1	44.245	44.245	44.245	11.884
Pause time	1	53.834	53.834	53.834	14.459
Transmission range	1	8.034	8.034	8.034	2.158
Traffic load	1	33.334	33.334	33.334	8.953
Packet rates	1	1.129	1.129	1.129	0.303
Error term	0	0.000	0.000		0.000
Total	7	372.301			100.000

In order to provide better estimate of the error variance, the factors that considered insignificant are pooled (combined) with the error term. In Taguchi method, a factors is considered insignificant if its SS is 10% or lower than the most influential factor (see Roy [14]). After following the rule, the new ANOVA table is shown in Table 6. From the table, we can see that network size, pause time, node velocity, and traffic load have a significant effect on the response.

The variance for error is a measure of the variation due to: factors excluded from the experiment, uncontrollable factors, and experimental error (see Roy [14]). Based on the 5.404 of error variance, we may argue that the variation due to the three sources in this experiment can be negligible. Meanwhile, the P for error term provides an estimate of the adequacy of this experiment. In this experiment, since the P for error term is 10.164% (less 15%), we can say that the experiment has been satisfactory, which all critical process parameters have been evaluated (Ross [13]).

If we define the predicted SNR based on the selected levels (highest SNR) of the significant effects as $\hat{\eta}$, the prediction equation can be written as (Roy [14])

$$\hat{\eta} = \overline{B}_1 + \overline{C}_1 + \overline{D}_2 + \overline{F}_1 - 3\overline{T}, \tag{25}$$

Table 6: Pooled ANOVA table

Factors	Df	SS	V	F	SS'	P (%)
Terrain	{1}	{7.05}	-	-	-	-
Network size	1	224.672	224.672	41.568	219.267	58.895
Node velocity	1	44.245	44.245	8.186	38.840	10.432
Pause time	1	53.834	53.834	9.960	48.429	13.008
Transmission range	{1}	{8.034}	-	-	-	-
Traffic load	1	33.334	33.334	6.167	27.929	7.501
Packet rates	{1}	{1.129}	-	-	-	-
Error term	3	16.213	5.404			10.164
Total	7	372.301				100.000

where $\overline{B}_1$, $\overline{C}_1$, $\overline{D}_2$, and $\overline{F}_1$ are the average effect for network size at level 2, node velocity at level 1, pause time at level 2, and traffic load at level 1, respectively (Table 4), and $\overline{T}$ is grand average (Table 3). Confidence interval ($C.I$) around the predicted SNR is (Roy [14])

$$C.I = \pm\sqrt{\frac{F(\alpha; n_1, n_2)V_e}{N_e}}, \tag{26}$$

where $F(\alpha; n_1, n_2)$ the value from the F table where α confidence level, n_1 (always 1) the Df of the mean performance, and n_2 the Df for error term, Ve error variance, and N_e effective number of replications. For our experiment runs, $\alpha = 95\%$, $V_e = 5.404$, $n_1 = 1$, $n_2 = 3$, and $N_e = 1.6$. Solving equations (25) and (26), we obtained $\hat{\eta} = -46.923$ and $C.I = \pm 3.43848$. Thus, the 95% confidence interval for the expected routing overhead is $[-50.3615, -43.4845]$. We conducted four confirmations runs. The average routing overhead was 314.25 and the corresponding SNR was -49.979. As can be seen, the confirmations results fall within the 95% confidence interval. Thus, this is an evidence that the interpretation about the factor effects using the orthogonal array design can be considered correct and satisfied.

5 Conclusion and Future Study

This study shows the effectiveness of Taguchi approach in estimating the effects of scenario metrics on the performance of the dynamic source routing (DSR) protocol. We have determined the effects of the scenario metrics on the DSR performance with regard to routing overhead. Using analysis average effects, we found the ranks of influence of scenario metrics in descending order are network size, pause time, node velocity, traffic load, transmission range, terrain, and packet rates. The results of analysis of variance (ANOVA) discovered that network size was the most significant effect on the response, followed by pause time, node velocity, and finally traffic load. As a result, if the values of the scenario metrics are controlled precisely, then the total variation of routing overhead could be reduced.

Future study will determine the effects of the scenario metrics with regard to drop rates, which is another important performance metric to evaluate the DSR protocol. Future work will also include some potential interactions between the scenario metrics, to see whether their effects are statistically significant, compared to the individual effects.

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