Taguchi Approach for Performance Evaluation of Routing Protocols in Mobile Ad Hoc Networks

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ABSTRACT

In this paper we evaluate the performance of Dynamic Source Routing (DSR) protocol in mobile ad hoc network for single-performance metric and multi-performance metrics. Using Taguchi design of experiment, we quantify the main effects of six influential factors (terrain, network size, node speed, pause time, number of sources and transmission rates) on two performance metrics (throughput and end-to-end delay). The analysis of means (ANOM) and analysis of variance (ANOVA) on single and multi-response signal to noise ratio are employed to determine the best conditions required and to identify the level of importance of factors in order to obtain the best performance of DSR protocol.

Keywords: *Taguchi design of experiment, performance metric, DSR routing protocol, ad hoc network.*

Introduction

A mobile ad hoc network (MANET) is a multi-hop wireless network formed by a group of mobile nodes that have wireless capabilities and are in proximity of each other (Boppana and Mathur 2005). As nodes are mobile in a MANET, links are created and destroyed in an unpredictable way, which makes quite challenging the determination of routes between a pair of nodes that want to communicate with each other. Because of this, routing is the most studied problem in MANETs and a great number of routing protocols have been proposed (Perkin, 2001; Abolhasan et al., 2004). Routing protocols can be classified into two major classes: proactive protocols and reactive protocols. Proactive protocols disseminate routing information from each node to each other periodically, and find routes continuously, whereas reactive protocols find routes on demand, *i.e*. only when a source sends information for forwarding to a destination. Performance analysis shows that, in general, reactive protocols outperform proactive protocols. Dynamic source routing (DSR) is one of the most representative reactive routing protocol (Perkin, 2001; Johnson and Maltz, 1998). In DSR each node in the network maintains a route cache in which it caches the routes. To find a route to its destination, a source broadcasts a route request packet to all nodes within its radio transmission range. The DSR is

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able to react quickly to route changes when node movement is frequent. Hence, the broken routes in the network can be immediately changed with the new ones and the data packets can be delivered quickly in spite of high network topology.

The performance evaluation of routing protocols has been performed mostly in simulation-based (Broch et al., 1998; Das et al., 2000; Boukerche, 2004). As seen from the literature, the studies carried out by researchers on evaluating the performance of MANET routing protocols have addressed about the one factor at a time analysis approach. In one factor at a time approach, the experimenter selects the factor believed to have the strongest affect on protocol performance and varies that parameter across some experimental range while holding all other parameters constant at static point condition. To the author's knowledge, little work has been reported in the literature on optimization of such network performance with analysis several factors simultaneously. Thus, this article attempt to improve the methodology analysis aspects of evaluating the MANET routing protocols by employing a Taguchi parameter design approach.

The rest of this paper is organized as follows. Section 2 describes the Taguchi design of experiment and experimental setup. Section 3 presents simulation results and analysis, whereas Section 4 gives some concluding remarks.

Taguchi Technique

Taguchi technique using based concept as statistical design of experiment which is refers to the process of planning an experiment such that data can be collected and analyzed using statistical methods. Unlike the commonly used one-factor-at-a-time approach, in the Taguchi technique, we study many factors simultaneously and the best factor combination can be determined (Ross, 1996). This combination can generate the best performance of the product or process under study. The Taguchi experimental design uses orthogonal array (OA) to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi technique test only part of combinations. Perkins et al.(2002) and Totaro and Perkins (2005) used $2^k r$ factorial experimental design in quantify the effects of five factors on the performance of ad hoc networks. The purpose of conducting an experiment is to collect the necessary data and determine which factors most affect process or product quality with a minimum number of experimentation which is minimize the time and cost of experiments.

Each column of the OAs designates a parameter and its setting levels in each experiment and each row designates an experiment with the level of different parameters in that experiment. Taguchi suggests signal to noise ratio (SNR) as the objective function for matrix experiments (Ross, 1996; Roy, 2001). The SNR is used to measure the performance metrics as well as the significant parameters through analysis of variance (ANOVA). Taguchi classifies objective functions into three main categories such as the-smaller-the-better, the-larger-the-better and nominal-the-best.

The Taguchi technique is a systematical application of design and analysis of experiments for the purpose of designing and improving product or process quality. It has been used widespread especially in industry to optimize a single performance metric. Handling multiple performance metrics is much more complicated because optimization of the multiple performance metrics is concerned with optimizing a vector of objectives. For the routing process in DSR protocol, throughput is a higher-the-better performance metric. However, end-to-end delay is a lower-the-better performance metric. As a result, an improvement of one performance metric may require a degradation of another performance metric. A single setting of factors may be best for the throughput but the same setting may not yield best results for the end-to-end delay. In this paper, the orthogonal array with the quality loss function approach (Ames et al., 1997) is used to investigate the multiple performance metrics in the DSR routing process.

Experimental Design and Computer Simulation

The purpose of this paper is to use the Taguchi technique to find the best parameters so that both the average and the variation of performance metrics can be reduced. The parameters that influence the performance metrics are determined by literature study. In practice, numerous factors may impact the performance metrics. Using statistical design of experiment strategy and Taguchi design, we determine the impact only of six factors, while holding other factors constant. Table 1 shows the parameters examined in this study. Each factor is examined at two different factor levels-a low level (1) and a high level (2). According to the number of parameters and their levels, a $L_8(2^7)$ orthogonal array (as the degree of freedom for the orthogonal array should be greater than or at least equal to, those of factors) is the most suitable array for the current investigation (Roy, 2001). Hence, eight experiments were planned with all parameters are varied together (as opposed to one-at-time). The experimental layout for the parameters using the L_8 OA is shown in Table 2. Each combination of parameter levels is called design point. Each design point corresponds to a simulation scenario, which is replicated three times in our experiments. As the simulation experiments are finished, the throughput and the end-to-end delay are computed as performance metrics. The throughput is defined as the total number of delivered data packets divided by the total duration of simulation time and the end-to-end delay is defined as the time a data packet takes to travel from source to the destination number of routing packets transmitted, respectively (Boukerche, 2004).

Table 1: Experimental Parameters and Their Levels

Label	Factors	Level 1	Level2
A	Terrain size	500m x 500m	1000m x 1000m
B	Network size	50 nodes	100 nodes
C	Node speed	1 m/s	10 m/s
D	Pause time	20 s	120 s
E	Number of sources	4	24
F	Transmission rates	2	8

Table 2: Experimental Layout Using L_8 Orthogonal Array

Design point	Level of factors					
	A	B	C	D	E	F
1	1	1	1	1	1	1
2	1	1	1	2	2	2
3	1	2	2	1	1	2
4	1	2	2	2	2	1
5	2	1	2	1	2	1
6	2	1	2	2	1	2
7	2	2	1	1	2	2
8	2	2	1	2	1	1

The ns-2 simulator was used to simulate MANET environment. All simulations were performed on an Intel Pentium IV processor at 2.00 GHz, 2046 MB of RAM running Linux Fedora Core 4. Each simulation was executed for 500 seconds. The radio transmission range of each node is 100 metres. The simulation will run using movement patterns generated for 2 different pause times: 20 and 120 seconds and 2 different speeds: 1 and 10 metre/seconds. Constant Bit Rate (CBR) traffic generators will be used as sources to run the simulation.

Data Analysis

Based on the literature study, the research chose two performance metrics and six influential parameters with two levels and adopted a $L_8(2^7)$ OA to proceed with the experiment. The experiment data are shown in Table 3.

Table 3: Experimental Results

Design point	Throughput			Average end-to-end delay		
1	149.28	163.15	152.83	8.41	11.01	8.77
2	2000.08	2027.84	2010.09	8480.95	7203.28	7437.11
3	600.42	608.00	611.24	31.47	16.7	17.11
4	917.91	890.94	924.77	105	2947.3	431.08
5	1007.32	958.03	949.05	10343.13	7312.16	8246.86
6	2135.29	2057.01	2115.62	7073.44	9404.37	6040.51
7	1888.67	2018.80	1995.46	153337.59	14807	8266.43
8	196.08	269.41	200.74	15.82	29.8	18.92

When a single performance metric is considered, traditional Taguchi method can be employed to obtain the best parameter level combination. The SNR is used to represent the performance metric and the largest SNR is required. The analysis of means (ANOM) was carried out to determine the effects of parameter.

A larger throughput is normally required in transmitting data packet process. Therefore, the-larger-the better methodology of SNR was employed for the optimization of throughput. The SNR for each performance metric of the eight experimental runs are listed in Table 4. The effect of each parameter on the SNR at different levels can be separated out since the experimental design is orthogonal. To obtain the effect of each parameter on each performance metric for each level, the SNR with same level of parameter are average for the eight experiments.

The response table of SNR for the throughput is summarized and listed in Table 5. The maximum SNR of parameter A - F is at A_2, B_1, C_2, D_2, E_2 and F_2, respectively. As a result, the parameter level combination $A_2B_1C_2D_2E_2F_2$, was recommended. The results of ANOVA for the SNR of the throughput are shown in Table 6. It can be seen that the contribution of factor F to the throughput was the largest (45.09%). The transmission rate (factor F) was the most important factor to the throughput followed by the number of sources (factor E).

Table 4: SNR Values for Throughput and End-to-End Delay

Design point	Throughput	End-to-end delay
1	43.79	-19.53
2	66.08	-77.76
3	55.66	-27.17
4	59.19	-64.72
5	59.74	-78.82
6	66.45	-77.66
7	65.87	-82.41
8	46.67	-26.98

Table 5: Response Table for Throughput

Parameter	Mean SNR		|L2 - L1|	Rank
	Level 1	Level 2		
A	56.18	59.68	3.5	4
B	59.01	56.85	2.16	6
C	55.60	60.26	4.66	3
D	56.26	59.59	3.33	5
E	53.14	62.72	9.58	2
F	52.35	63.51	11.16	1

Table 6: Analysis of Variance for Throughput

Parameter	df	SS	F	P(%)
A	1	24.55	3.83	3.37
B	1	9.41	1.47	0.56
C	1	43.39	6.77	6.87
D	-1	22.2	3.46	2.93
E	1	183.37	28.61	32.85
F	1	249.33	38.9	45.09
Error	1	6.41		8.33
Total	7	538.67		100

The same analysis procedure is applied to optimize the end-to-end delay. The response table of SNR for the end-to-end delay is listed in Table 7. The levels that gave the largest average response were selected from the response table. The parameter level combination $A_1B_2C_1D_1E_1F_1$ was recommended. The result of ANOVA in Table 8 shows that the number of sources (factor E), 52.75% was the most important that effect performance end-to-end delay. It can also be seen that the terrain (factor A) was quite an important parameter to the end-to-end delay.

Table 7: Response Table for End-to-End delay

Parameter	Mean SNR		|L2 - L1|	Rank
	Level 1	Level 2		
A	-47.29	-66.46	19.17	2
B	-63.44	-50.32	13.12	4
C	-51.67	-62.09	10.42	5
D	-51.98	-61.78	9.8	6
E	-37.83	-75.93	38.1	1
F	-47.51	-66.25	18.74	3

Table 8: Analysis of Variance for End-to-End Delay

Parameter	Df	SS	F	P(%)
A	1	735.93	5.21	11.35
B	1	344.37	2.44	3.88
C	1	217.15	1.54	1.45
D	1	192.01	1.36	0.97
E	1	2902.35	20.58	52.75
F	1	702.41	4.98	10.72
Error	1	141.02		18.86
Total	7	5234.72		100

It was found that the optimal parameter levels or the most important parameter for one performance metric was usually different from that for another performance metric. It is obvious that there is a great inconsistency between the two optimal solutions, so the traditional Taguchi technique is not suitable for the problem with multiple performance metrics.

The Taguchi's quality loss function concept has been employed in this study to deal with multi-performance metrics. First, the quality loss function for the performance metrics were calculated using,

The-larger-the-better: $L_{ij} = \frac{1}{r}\sum_{k=1}^{r}\frac{1}{y_{ijk}^{2}}$ $L_{ij} = 1/y^2_{ij}$ (1)

The-smaller-the better: $L_{ij} = \frac{1}{r}\sum_{k=1}^{r} y_{ijk}^{2}$ $L_{ij} = y^2_{ij}$ (2)

where y_{ij} is the response for ith performance metric in the jth experimental run and r is the number of repetition for each design point. As each metric has different units of measurement, the quality loss function should be normalized by using,

$$N_{ij} = \frac{L_{ij}}{L_{i*}} \quad (3)$$

where L_{i*} is the maximum loss function of the ith performance metric due to n design point. A weighting method is used to combine the two or more normalized loss function, that is:

$$TL_j = \sum_{i=1}^{m} w_i N_{ij} \quad (4)$$

where w_i is a scalar weighting factor for ith performance metric. In the weighting method of computing total quality loss function, it is required to assign proper weighting factors to each of the normalized quality loss function. The purpose of weight is to express the importance of each metric relative to other metrics. The association of weights in multiple performance metric problems is a critical stage in the whole decision making process (Diakoulaki et al., 1995). There is no one standard method in determining a metric weight although many methods have been developed as author in (Johnson and Maltz, 1998) discussed which includes assigning weight based on standard deviation, correlation matrix and method CRITIC. In this paper, weight based on standard deviation (SD) is used.

SD weights are derived by using Equation

$$w_i = \frac{1/\sigma_i}{\sum_{k=1}^{m} 1/\sigma_k} \quad (5)$$

The total loss function for multi-performance metrics optimization is further transformed into a multi-response signal-to-noise ratio (MSNR). The MSNR η in the jth experimental run can be expressed as

$$\eta_j = -10\log(TL_j) \qquad (6)$$

Table 9 shows the values of loss function, normalized loss function, total normalized loss function and corresponding multi-response signal-to-noise ratio for each design point. The weighting factors for throughput and end-to-end delay are 0.49 and 0.51, respectively, which is calculated using Equation (8). The analysis of means (ANOM) was carried out to determine the effect of factors. The MSNR for each parameter level is determined by averaging the MSNR obtained when parameter is maintained at that level. The response table and ANOVA for MSNR are listed in Table 10 and 11, respectively. It can be seen that when multiple performance metrics were considered, $A_1B_2C_2D_2E_2F_2$ was recommended and network size (factor C) was the most important parameter. The contribution from network size was 45.45%. In addition, the recommended parameter level combination was different from the combination when the single performance metric is considered. This clearly indicates the difference between single performance metric and multi-performance metrics.

Table 9: Tabulation of Computed Values of Multi-Performance

Design point	Loss function		Normalized loss function		TL	MSNR
	L_{1j}	L_{2j}	N_{ij}	N_{2j}		
1	4.18E-5	89.6	1.00	5.14E-7	0.49	3.11
2	2.47E-7	59708120.3	0.01	3.43E-1	0.18	7.50
3	2.72E-6	520.7	0.07	2.99E-6	0.03	14.97
4	1.21E-6	2961144.1	0.03	1.70E-2	0.02	16.42
5	1.06E-6	76152907.3	0.03	4.37E-1	0.24	6.28
6	2.26E-7	58321163.2	0.01	3.35E-1	0.17	7.60
7	2.59E-7	174274260.3	0.01	1.00E+0	0.51	2.89
8	2.15E-5	498.8	0.52	2.86E-6	0.25	5.98

Table 10: Response Table for MSNR

Parameters	Level 1	Level 2	|L1 - L2|	Rank
A	10.49	5.69	4.8	2
B	6.12	10.07	3.95	3
C	4.87	11.32	6.45	1
D	6.81	9.38	2.57	4
E	7.91	8.27	0.36	5
F	7.95	8.24	0.29	6

Table 11: Analysis of Variance for MSNR

Factor	df	SS	F	P(%)
A	1	46.32	16.703	24.619
B	1	31.12	11.209	16.007
C	1	83.17	29.98	45.436
D	1	13.16	4.735	5.856
E	1	0.255	0.092	0
F	1	0.173	0.061	0
Error	1	2.772		8.082
Total	7	176.879		100

Conclusions

A great number of previous studies for performance evaluations of routing protocols in MANET mainly focus on one-factor-at-a-time approach. In this paper, we evaluate and quantify the effects of six factors (terrain, network size, speed, pause time, number of sources and transmission rate) simultaneously using Taguchi experimental design with regards to two performance metrics (throughput and end-to-end delay). The simulation data was analyzed for single metric and multiple metrics. The results are summarized as follows:

1. Based on ANOM and ANOVA, the best factor combinations for the throughput $A_2B_1C_2D_2E_2F_2$ and end-to-end delay $A_1B_2C_1D_1E_1F_1$ were recommended. The transmission rate (45.09%) is the most important parameter contributes to the performance of throughput, while the number of sources (52.75%) was the most important parameter contributes to the performance of end-to-end delay.
2. In the multiple performance metrics, throughput and end-to-end delay were simultaneously considered. The factor levels combination $A_1B_2C_2D_2E_2F_2$ was recommended and network size was the most important factor contributes to the performance.

It is important to note that, our results and conclusions are based upon the parameter levels used in this design and may vary if different factor levels are used. Future work will look into different relative weightings of performance metrics on the multiple signal-to- noise ratio.

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