Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 14 (4): 396-400, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.396.400

Grey-based Taguchi Method in Multi-objective Optimisation of the Routing Process in Mobile *Ad-hoc* Networks

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Abstract: Routing in mobile *ad-hoc* network (MANET) is a challenging task. Thus, the purpose of this paper is to study the multiple performance of metrics optimisation of the routing process in MANET. The Taguchi method, combined with the grey relational analysis have been employed to determine the optimal factor combinations, as well as their significance. Using L_8 orthogonal array design, network scenarios are simulated with network simulator 2. The effects of terrain, number of nodes, number of sources, number of packets transmitted, speed and pause time are optimised for maximum throughput and minimum routing overhead and packet drops. Five confirmatory tests are conducted, and the results indicate that the average values of the Relational Grade (GRG) fall within the 95% confidence interval, hence the experiment is proven to be reliable and repeatable. According to the analysis of variance of the GRG, the number of sources is the most significant factor that affects the multiple performance metrics.

Key words: Grey relational analysis, Taguchi method, mobile *ad-hoc* networks, multiple performance metrics

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 near to each other (Boppana and Mathur, 2005). The process of moving information packets and messages across a network from a source node to a destination node is called the routing process. Due to the dynamic movement of nodes in such a network, a link that is created by a pair of nodes can be destroyed in an unpredictable way. Considering that, an efficient routing protocol should be designed to solve the problem. Abolhasan *et al.* (2004) reviewed some protocols that have been designed which can be categorised as proactive and reactive protocols, in which they differ in terms of how to disseminate routing information through the intermediate nodes.

The overall performance of any routing protocol in MANET would be affected by several factors. Its performance can be improved by optimising those factors. A number of previous works have been done to study on the performance of MANET routing protocols through simulation-based (Broch *et al.*, 1998; Das *et al.*, 2000; Boukerche, 2004). They evaluated and quantified the effects of factors that may influence the measure of a single performance by adopting one-factor-at-one time approach. The Taguchi experimental design is a structured application of design and analysis of experiments for the purpose of designing and improving product or process quality (Ross, 1996; Roy, 2001). It utilizes a set of orthogonal arrays to study the effects of factors on particular performance measures in order to decide the optimum factor combination. Manna and Bhattacharyya (2004), Das and Sahoo (2010) and Ballal *et al.* (2012) have applied Taguchi orthogonal array in the optimization of the manufacturing process. It is not only applied in the field of production engineering, but also in the field of communication and information technology. Al-Darrab *et al.* (2009) applied the Taguchi Method for optimising the parameters, in order to maximise text message sending task performance of the mobile phone.

The original Taguchi technique is mostly applied in the optimisation of a single performance measure. However, the routine problem which exists in product or process design is in determining the optimal factor levels when there are multiple responses that should be considered simultaneously. While dealing with multiple

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performance measures, it is very incredible to find a setting for the control factors which could optimise all the performance measures simultaneously. Thus, several adjustments have been suggested to the original Taguchi technique in dealing with multiple performance measures.

This study proposes an optimisation approach using the orthogonal array and Grey Relational Analysis (GRA) in order to optimise the multiple performance measures simultaneously. Grey analysis is one of the multiple performance measures integration technique that has been widely applied to various fields in dealing with poor, incomplete and uncertain information (Kuo *et al*., 2008). The grey analysis is a part of the grey system theory proposed by Deng (1989) which is suitable in figuring out a variety of multiple attribute decision making problems. It has been successfully applied in many areas, such as in solving the problem of plant layout design (Yang and Hung, 2007) and in the manufacturing process (Moshat *et al*., 2010; Esme, 2010; Balasubramanian and Ganapathy, 2011). The grey analysis is capable of representing the grade of relationship between two sequences, so, that the distance of two factors can be measured separately, even with less data and many factors (Caydas and Hascalik, 2008).

MATERIALS AND METHODS

Taguchi's experimental design is used in measuring the network performance metrics and in analysing the effect of each of the parameters on multiple responses. The parameters which are considered in this research are terrain size (A), network size (B), transmission rates (C), number of sources (D), node speed (E) and pause time (F). The different levels of these factors are shown in Table 1.

The orthogonal array L_8, Table 2 is used because it requires only eight runs for the combination of six parameters, varied at two levels. The Network Simulator 2 is used to run the simulations. Each combination of factor levels is run for three times (for a total of 24 experiments) and the throughput, the routing overhead and packet drops are recorded. All simulations are performed on the Intel Pentium IV processor at 2.00 GHz, 2046 MB of RAM running Linux Fedora Core 4. Each simulation is executed for 500 sec.

In the grey relational analysis, data pre-processing is normally required, since the range and unit in one data sequence may differ from others or when the sequence scatter range is too large (Balasubramanian and Ganapathy, 2011). In this study, the data pre-processing for throughput is the higher-the-better as in Eq. 1. However, the routing overhead and packet drop is the lower-the-better as in Eq. 2:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (1)$$

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \quad (2)$$

where, x_i (k) is the value of the normalized data, min y_i (k) is the smallest value of y_i (k) and max y_i (k) is the largest value of y_i(k) for each performance metric.

The definition of the grey relational grade (GRG) in the grey relational analysis is to show the relational degree between the eight sequences (Table 2). To calculate the GRG, the grey relational coefficient γ_i (k) should be calculated first.

$$\gamma_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_i(k) + \zeta\Delta_{max}} \quad (3)$$

where, Δ_i (k) is the absolute value of the difference between the reference sequence, x_0 (k) and the comparability sequence, x_i(k), i.e., $\Delta_i(k) = |x_0(k) - x_i(k)|$, Δ_{min} = min {Δ_i(k), i = 1, 2,..., 8; k = 1,2,3}, Δ_{max} = max {Δ_i

Table 1: Factors and level values used in the experiment

Symbol	Factors	Level 1	Level 2
A	Terrain	500×500 m	1000×1000 m
B	Network size	50 nodes	100 nodes
C	Transmission rates	2 packets sec	8 packet sec
D	Number of sources	4 nodes	24 nodes
E	Node speed	1 m sec	10 m sec
F	Pause time	20 sec	120 sec

Table 2: Experimental layout using an L_8 orthogonal array

			Factor levels			
Experiment No.	Terrain (A)	Network size (B)	Transmission rates (C)	Number of sources (D)	Node speed (E)	Pause time (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

(k), i = 1, 2,..., 8; k = 1, 2, 3}, ζ is the distinguished coefficient with the values in the range of 0 and 1 and 0.5 is used in this work. The value of ζ can be adjusted according to the actual requirements. Changing its value will only change the value of the magnitude of the relative value; it will not affect the ranking of the grey relational grade (Lee, 2012).

The grey relational grade can be obtained using Eq. 4:

$$\Phi_i = \sum_{j=1}^{k} w_j \gamma_i(j) \qquad (4)$$

where, w_j represents the weighting value of the kth performance metric and . In this work, the corresponding weighting values are obtained based on the correlation matrix as was obtained in Mohamed *et al*. (2011). The grey relational grade, Φ_i, represents the correlation between the reference sequence and the comparability sequence. Higher grey relational grade means that the corresponding factor combination is closer to the optimum performance.

This study has used a level average analysis in determining the best factors combination, while the analysis of variance (ANOVA) has been used in quantifying the significant factors that contribute to the performance of the routing performance in the MANETs.

RESULTS AND DISCUSSION

A level average analysis is adopted to interpret the results. This analysis is based on the combination of the data associated with each level for each factor. The difference in the average results for the highest and lowest average response is the measure of the effect of that factor. The greatest value of this difference is related to the largest effects of that particular factor. The pre-processing data of each performance metric according to Eq. 1 and 2 are given in Table 3.

The Grey Relational Coefficients (GRC) and Grey Relational Grade (GRG) for each performance metric according to Eq. 3 and 4 are given in Table 4. In this work, the importance of all the performance metrics is determined using the correlation matrix method, without the experience and judgement of the experts. The weight for each performance metric is 0.319, 0.332 and 0.349 for throughput, routing overhead and packet drop, respectively.

According to the Taguchi method, statistic delta is used to determine the most influential factor. Statistic delta is defined as the difference between the highest and the lowest effects of each factor. The higher the grey relational grade, the closer it is to the optimal condition. The mean of the grey relational grade for each level of the different factors is summarized in Table 5. A response graph of the grey relational analysis is shown in Fig. 1. Table 5 and Fig. 1 indicate that the optimal factor sets are A_2, B_2, C_2, D_2, E_2 and F_1, that is a terrain of 1000 m χ 1000 m, network size of 100 nodes, transmission rates of 8 packets sec^{-1}, source number of 24 nodes, node speed of 10 m sec and pause time of 20 sec. Based on the results presented in Table 5, number of sources has the largest effect on the multiple performance metrics. This

Table 3: Data preprocessing of experimental results for each performance metric

Experiment No.	Throughput	Routing overhead	Packet drop
1	0.000	0.000	0.000
2	0.781	0.522	0.801
3	0.442	0.090	0.043
4	0.846	0.897	1.000
5	0.585	0.770	0.794
6	1.000	0.814	0.997
7	0.216	0.621	0.525
8	0.691	1.000	0.940

Table 4: Grey relational coefficient of each performance metric and their grey relational grade

Experiment No.	Throughput	Routing overhead	Packet drop	Grey relational grade
1	0.333	0.333	0.333	0.333
2	0.695	0.511	0.715	0.641
3	0.473	0.355	0.343	0.388
4	0.765	0.829	1.000	0.868
5	0.547	0.685	0.708	0.649
6	1.000	0.729	0.994	0.908
7	0.389	0.569	0.513	0.492
8	0.618	1.000	0.892	0.840

Table 5: Response table for the grey relational grade

Symbol	Parameter	Level 1	Level 2	Delta
A	Terrain	0.558	0.722	0.164
B	Network size	0.632	0.647	0.015
C	Transmission rates	0.576	0.703	0.127
D	Number of sources	0.465	0.814	0.348
E	Speed	0.617	0.662	0.045
F	Pause time	0.672	0.607	0.066

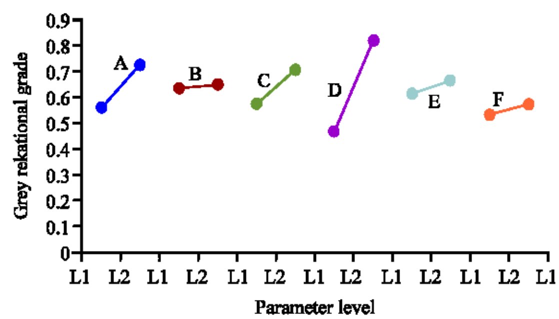

Fig. 1: Grey relational grade response graph

Table 6: ANOVA on grey relational grade

Factor	DoF	Sum of squares.	Variance	F-Ratio	Contribution (%)
A	1	0.055	0.055	360.58	15.08
B	1	0.000	0.000	2.29	0.05
C	1	0.029	0.029	193.38	8.07
D	1	0.263	0.263	1721.45	72.16
E	1	0.004	0.004	29.74	1.21
F	1	0.011	0.011	75.85	3.14
Error	1	-0.001	-0.001		0.29
Total	7	0.365.	0.365.		100.00

finding is consistent with the findings of the study by Perkins *et al.* (2002) which studies the effects of various factors on the overall performance of *ad-hoc* networks but focuses only on one performance response at a time and also the different level values. The sequence of the effects is as follows; terrain is second and is followed by transmission rates, pause time, speed and network size.

The Analysis of Variance (ANOVA) is used to investigate the factors that significantly affect the routing performance. The ANOVA module of the QUALITEK software is used in finding out the effects of the factors on the grey relational grade. The results of ANOVA in Table 6 indicate that those three input factors contribute towards the multiple performance metrics (F-ratio of the factor A, C and D is greater than $F_{0.05,1}$ = 161.5). The ANOVA has also produced results in the same order of importance as the network parameters, which is in the order of: D, A, C, F, E and B.

After the optimal level of the different factors is selected, the final step is to predict and verify the adequacy of the model in determining the multiple performance metrics. The estimated mean of the grey relational grade is calculated using the following additive law model.

$$\hat{\Phi} = \Phi_m + \sum_{i=1}^{s}\left(\bar{\Phi}_i - \Phi_m\right) \tag{5}$$

where, $\hat{\Phi}$ is the estimated mean of the grey relational grade, Φ_m is the total mean of the grey relational grade, $\bar{\Phi}_i$ is the mean of the grey relational grade at the optimum level and s is the number of factors that significantly affect the multiple performance metrics. The expected mean of the grey relational grade at optimal setting is found to be 0.961.

A 95% confidence interval (CI) for the predicted mean of the grey relational grade on a confirmation test is estimated using Eq. 6:

$$CI = \hat{\Phi} \pm \sqrt{F_{\alpha;1;fe} \times V_e \times \left(\frac{1}{n_{eff}} + \frac{1}{r}\right)} = 0.961 \pm 0.127 \tag{6}$$

where, $F_{\alpha;1;fe}$ is the F-ratio required for 100 (1-α)% CI, fe is the degree of freedom for error, V_e is the error of variance, r is the number of replications of the confirmation experiment, n_{eff} is the effective number of replications:

$$n_{eff} = \frac{N}{1+v}$$

where, N is the number of experiments in the orthogonal array and v is the total number of degrees of freedom of significant parameters. Therefore, 95% confidence interval of the predicted grey relational grade at optimum condition is between 0.834 and 1.088.

If the predicted and observed grey relational grade values of the multiple performance metrics are close to each other, the effectiveness of the optimal condition can then be ensured. In order to test the predicted results, confirmation experiments were conducted 5 times at the optimum conditions. The relational grade for the experiment is 0.853 which is in the range of the 95% confidence interval. Hence, the results of the confirmatory experiment tests show that the use of the additive law model is justified in the optimisation of the multiple performance metrics.

CONCLUSION

This study looks at the use of the Taguchi-grey relational analysis in determining the optimum parameter with multiple performance metrics in mobile *ad-hoc*. In this study, the effects of six factors (terrain, network size, speed, pause time, number of sources and transmission rate) have been evaluated and quantified simultaneously using the combination of Taguchi experimental design and Grey Relational Analysis (GRA) with regards to three performance metrics (throughput, routing overhead and the number of packet drop). The optimisation of the complicated multiple performance metrics can be converted into the optimisation of a single grey relational grade. As a result, complicated processess can be greatly simplified through this approach. However, all the findings in this study are based on the factor levels considered in the design and may vary if different factor levels are used. Future work will look into the different approach in finding weight factors for GRA so that the best approach can be identified.

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