Eng. Sci., 2022, **19**, 83–88

Engineered Science
DOI: https://dx.doi.org/10.30919/es8d684

Ad-hoc Network Experimental Design with Taguchi Method to Analyze Performance of Routing Protocols

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Abstract

The Taguchi method is a powerful approach in the Design of experiments for quantifying multiple parameters. In ad-hoc network multi-constrained quality of service routing protocol designs, parameters such as the number of nodes, node mobility, transmission range, traffic load, end-to-end delay, and throughput will play a significant impact on the performance of the routing protocol. To analyze the performance variation of routing protocols such as dynamic source routing (DSR), priority aware – DSR (PA-DSR), and adaptive multi-constrained quality of service (QoS) in consideration of various parameters numerous experiments are designed by incorporating the Taguchi method. The number of nodes and mobility speed is considered to control factors and signal-to-noise ratio (SNR), transmission speed (Tx), and Packet load are considered noise factors in the analysis of routing protocols. A total of 48 experiments were carried out in Network Simulator-2 as planned in an orthogonal array of designs of experiments. Finally, an analysis of variance (ANOVA) test is carried out to prove the performance variation of designed experiments with the Taguchi method. The significance of AMQoS in comparison with the DSR and PA-DSR proved to be higher for more nodes and high mobility.

Keywords: Ad-hoc network; Quality of service; Design of experiment; Taguchi method.
Received: 28 December 2021; Revised: 05 April 2022; Accepted: 05 April 2022.
Article type: Research article.

1. Introduction

The evolution of mobile devices and Mobile to Mobile (M2M) connectivity is a reliable indicator of the growth of mobile IoT, which brings together people, things, and data to make networks more effective and valuable. Globally, M2M connections are expected to grow 30% by 2023.[1] The effect of accelerating growth on ad-hoc connections generates a huge amount of resource-starved traffic on the network. In this scenario applications running on the network demand quality of service (QoS) in packet delivery rather than best-effort service.

Providing guaranteed service should address various QoS constraints under uncertain network conditions. A single-constrained QoS routing path is inefficient due to mobile Ad-hoc NETwork (MANET) characteristics, collisions, inference, and link failures. A multi-constrained routing protocol considers two or three fixed QoS metrics. Since a static set of QoS metrics is considered in routing, there is a high possibility that the remaining QoS metrics are not achieved. In the sense of MANET constraints and applications running on MANET, the QoS parameters should be prioritized.[2] Decision-making from imprecise knowledge will provide an optimal solution for the NP-complete problem of providing configurable multi-constrained QoS routing.

In order to solve the problem of multi-constrained QoS routing, the dynamic decision-making method would be an important strategy. Multi-constrained dynamic decision-making must provide QoS on an individual flow basis, taking MANET characteristics into account.[3] The network characteristics and stack parameters residing at the application, MAC, and physical layer are aligned with each other. Identifying a trade-off point between these stack parameters to estimate the significance of stack parameters on QoS metrics is crucial because the set of these stack parameters has a significant impact on the different quality of service parameters.[4] Multi-constrained decision-making recommends the ruleset, which incorporates significant stack parameters to consider the MANET characteristics.[5,6]

In a realistic environment of MANET, where a good number of changeable factors make an impact on the QoS of

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packet delivery. This makes identifying trade-offs to propose adaptive algorithms a tedious job. In such cases, the design of experiments by statistical means is very important to explain and predict network performance before the experiments are carried out to find the suitable combination of various factors before real implementation. As a powerful tool, the Taguchi method is used for quantifying the effects of multiple factors at once.[7] This method is used to find the best possible performance by determining the optimum combination of various factors. The consistency of performance is obtained by making the proposed protocol insensitive to the influence of the various control factors.

Dr. Genichi Taguchi first proposed the Taguchi method in 1960, to produce a quality product at a lesser cost and it is used to reduce the variation in the process where robust experimental design is involved.[8] The system design stage occurs during the implementation of new ideas or methods into a new product or process. The design stage of the parameters is to enhance a product's uniformity. Tolerance design is intended to determine the appropriate variability range around the normal value defined in the parameter level. The Taguchi method proposes a new kind of design of experiments (DOE) that examines how different factors influence the mean and variance of a process performance characteristic. If you're looking for near-optimal settings, you can use this iterative optimization procedure based on the orthogonal array (OA).[9] This method is widely used in manufacturing processes, engineering fields, power electronics, wireless communications, and much more areas where such kind of optimization is complex. Taguchi Method has to go through these three phases: the planning phase, the experiment phase, and the analysis phase.

The planning phase is required to identify the problem and area of concern, and also required to set the target performance. The planning phase starts by identifying a problem, test conditions, and area of concern, and then target performances are set. Control factors are the controllable parameters in designing a product/process, while noise factors are factors that may influence the selected quality characteristics and cannot be adjusted in the design. In the Experiments, Phase experiments efforts are carried out using a simulator. The goal of the simulation is to examine and quantify the effects of those factors selected in the planning phase on the performance of the product/process. The analysis Phase determines the effect of each factor on the output.

In this article, the authors attempt to incorporate the Taguchi method to design Experiments to conclude parameters, which make an impact on the QoS of the packet delivery. The realistic packet delivery dataset from CRAWDAD is considered for analysis purposes. The OA is designed in consideration of the number of nodes, nodes mobility, and routing algorithm as a controlling factor. The signal Noise Ratio, Transmission speed, and Packet Load are considered Noise factors, which may influence the selected quality characteristics and cannot be adjusted in the design. The Network Simulator-2 (NS-2) is used to conduct the designed experiments. To analyze the contribution of individual factors ANOVA test is carried out.

2. Footprints of the TAGUCHI method

To achieve better design parameters, the Taguchi method follows a systematic, simple, and efficient approach that requires only a few well-defined experimental sets.[10] A traditional full factorial design of experiments can be significantly reduced in size, which speeds up the experimentation process. As long as a robust experimental design is used to reduce process variation, the Taguchi method can produce a high-quality product at a lower cost. How different parameters affect the mean and variance of a process performance characteristic is examined by the Taguchi method. The Taguchi method also identifies that to improve a product's quality, an experiment in quality assurance is required just before the product is put into production.[11] The Taguchi method ensures minimal process iteration and compares the effects of multiple factors and their interactions simultaneously. This kind of robust parameter design method has been successfully applied in a wide range of fields such as environmental sciences, agriculture sciences, manufacturing processes, basic sciences, engineering, and medicine.

A review by Ng Chin Fei [12] on the streamlining of processing attributes for injection molding, where a huge number of molding attributes are involved, and the possible interaction between them needs to be optimized. Streamline processing attributes through numerical simulation necessarily requires a series of trial runs in the absence of a well-planned design of experiments. By integrating the Taguchi method with numerical simulation, this problem has been alleviated. In the case of Miroslav R.,[13] the Taguchi approach is used to determine optimal surface roughness while turning 316-LVM stainless steel with a coated carbide tool. Surface roughness is used as a response factor to optimize four control attributes: depth of cut, insert radius, cutting speed, and feed. The effect of control attributes on surface roughness was experimentally investigated.

To forecast the combination of conditions that will result in the lowest survival of malignant cells, M. ilea[14] used Taguchi's approach. A mower's highest cutting quality can be achieved with little waste and energy consumption by using the Taguchi method developed by S. Saeid Hosseini.[15] Anam Asghar[16] compared the central composite design (CCD) and Taguchi approach for Fenton oxidation in several applications of chemical engineering. Messias Borges Silva uses the Taguchi Method[17] in environmental engineering to improve the treatment conditions of polyester-resin effluent utilizing advanced oxidative processes (AOPs) and chemical oxygen demand (COD) as response parameters.

The Taguchi technique of experimentation is commonly used in evaluating the performance of routing protocols for Manet and wireless networks, according to the literature. A study by Pushpraj Patel[18] used Taguchi's loss function to determine which of the 10 parameters affected the performance of the AOMDV routing protocol and concluded that Queue size was the most important. Taguchi's loss function was used in another study by Dheeraj Rawat[19] to quantify the performance of a network.

Using Taguchi's experimental design, S. Ajjaj [20] examines how factors affect the AODV protocol's routing overhead. The transmission range was shown to have the greatest impact on routing overhead, followed by the maximum connection and network size at various factor levels. According to[11] Mohamed E.'s experimental study, the Taguchi method is used to reduce energy consumption by optimizing four design factors as routing protocol(s), counter area size, server position, and transmission power with three noise factors such as packet size, traffic generation density, and mobility speed.

3. Design of experiments with the Taguchi method

The DoE starts with identifying data set for decision-making, simulation condition, and parameters. To quantify the effects on the performance control factors and noise factors are taken into consideration while setting the simulation environment. Depending on these Control factors and their appropriate level, select the appropriate OA. Experiments are conducted in alignment with an obtained orthogonal array with the simulator. Simulation results are fed into the ANOVA test for the analysis phase. The optimum level of the performance metric under various control factors is analyzed.

3.1 Identify the data set for decision making

The CRAWDAD realistic packet delivery data set is used for analysis. For each stack parameter configuration, packet delivery metadata information such as acknowledgment, Link Quality Indicator, and Radio Signal Strength Indicator are captured. The stack parameter configuration is a composite of seven parameters associated with different layers of the TCP/IP protocol layer that represent network characteristics that affect packet delivery.[21]

3.2 Simulation conditions and parameter

Network Simulator (NS) -2[22] is used for the simulation of DSR, PA-DSR, and AMQoS routing protocol to quantify effects on the performance of three control factors: 'Number of Nodes', Routing protocol, and mobility speed. For the simulation in a 500 m × 500 m area, Random Way Point Mobility Model has been incorporated.

Control Factors: It has been observed that the performance of the DSR routing protocol varies with a variable number of nodes and mobility speed. So, it is evident to capture and analyze the performance of PA-DSR and AMQoS against the DSR for a variable number of nodes and mobility speed. The MANET control factors considered in the design of the experiment are represented in Table 1.

Noise Factors: The Rough Set Theory (RST) is incorporated to propose optimization guidelines, which analyze the impact of the multilayer stack parameter on QoS metrics. This analysis will identify a trade-off point for configuring the stack parameter to achieve better QoS in packet delivery. The outcome of this analysis will be helpful for identifying noise factors. The sequence of RST methodologies from discretization to derive decision rules are applied in a rough set exploration system (RSES). The MANET noise factors considered in the design of the experiment are represented in Table 2.

Table 1. MANET control factors.

Control Factors	Levels									
No. of Nodes	25	30	35	40	45	50	55	60	65	70
Mobility Speed	5		19		15		20		25	
Routing Algorithm	DSR			PA-DSR				AMQoS		

Table 2. MANET Noise factors.

Noise Factors	Level
Signal to Noise Ratio (SNR)	17
Transmission Speed (Tx)	11
Packet Load (Ld)	110

3.3 Orthogonal array for the design of experiments

The OA is considered for Taguchi's DoE obtained by considering the control factor and noise factor. A total of 48 experiments are planned by the NS-2 simulator for different configurations of control and noise factors as shown in Table 3.

3.4 Experiment phase

The AMQoS, PA-DSR, and DSR have been simulated in NS-2.36. The experiment is conducted for varying numbers of nodes from 25 to 70 nodes; these nodes are randomly positioned in a 1000 m × 1000 m area. Every node is installed with a single network interface card and has a transmission range of 80 meters. The transmission power and receiving power are set in such a way that two neighboring nodes can communicate within their transmission range. The distributed coordination function of IEEE 802.11 for wireless LAN is used as the MAC layer protocol. The channel bandwidth limit for the radio propagation model is 2 Mbps and the traffic generated will be of type CBR. Node mobility is fixed to random waypoint mobility with varying speeds of 5 to 25 m/s. The initial energy of all nodes is set to 100 joules, along with this energy consumption for transmission and receiving will be set to 0.7 and 0.3 joules respectively. The range of values set for the attributes of the network setup are mentioned in Table 4.

Table 3. Orthogonal Array of design of experiments.

Experiment Number	Number of Nodes	Mobility Speed	Routing Algorithm	Experiment Number	Number of Nodes	Mobility Speed	Routing Algorithm
1	25			33	25		
2	30			34	30		
3	35			35	35		
4	40			36	40		
5	45			37	45		
6	50	10		38	50	10	
7	55			39	55		
8	60			40	60		
9	65		DSR	41	65		AMQoS
10	70			42	70		
11	75			43	75		
12		5		44		5	
13		10		45		10	
14	40	15		46	40	15	
15		20		47		20	
16		25		48		25	
17	25						
18	30						
19	35						
20	40						
21	45						
22	50	10					
23	55						
24	60						
25	65		PA-DSR				
26	70						
27	75						
28		5					
29		10					
30	40	15					
31		20					
32		25					

Table 4. Varying simulation parameters.

Parameters	Values
Terrain dimensions	1000m × 1000m
No. of nodes	25, 30, 35, 40, 45, 50, 55, 60, 65, 70
MAC	IEEE 802.11
Transmission range	80 mtr
Mobility model	Random Way Point Mobility
Initial Energy	100 Jouls
Radio Tx power	0.7j
Radio Rx power	0.3j
Routing Protocol	AMQoS
Channel Bandwidth	2 Mbps

4. Results and discussion

The measured performance characteristic from each experiment can be used to analyze the relative effect of the different parameters once the experimental design has been selected and the experiments have been carried out. It should be noted that the Taguchi technique, rather than using repeated trials, allows for the introduction of noise factors and control factors that affect the process outcome. In this study, 48 experiments were designed to conization the number of nodes, mobility speed, and routing algorithm. Since the Taguchi method is incorporated in the design of the experiment, without any repeated experiments were able to cover each and all elements of control factors as planned. To determine the effect of each factor on the experiment, an ANOVA test is carried out on different QoS metrics like energy, goodput, delay, and Packet Delivery Fraction.

4.1 Analysis of results with ANOVA

Analysis of variance (ANOVA) is a group of statistical models used to examine the difference between group means and their associated procedures, in which the observed change in the dependent variable is partitioned into components contributed to different sources of variation. A 1-way ANOVA test is carried out to analyze the performance variation of AMQoS, DSR, and PA-DSR against the different QoS parameters. The results against every QoS parameter are classified into two categories. In the first category results of AMQoS, DSR, and PA-DSR for a number of nodes, and in the second category results of AMQoS, DSR, and PA-DSR for a number of nodes are considered. The significance of both categories is compared to prove the performance of AMQoS improves as the number of nodes and mobility increases against the DSR AND PA-DSR.

4.1.1 ANOVA test on energy

Hypothesis 1: The performance of AMQoS against DSR and PA-DSR is higher as the number of nodes in the network increases in terms of energy.

Interpretation 1: The F-value implies the significance of the hypothesis. The significance of AMQoS for a number of nodes is 0.07101 and the significance of AMQoS for a number of nodes is 1.64939 as shown in Table 5. The F-value indicates the significance of the AMQoS for more nodes is higher compared to the significance of AMQoS for a number of nodes. So, the performance of AMQoS in terms of energy consumption against DSR and PA-DSR is higher as the number of nodes in the network increases can be inferred from the result.

Hypothesis 2: The performance of AMQoS against DSR and PA-DSR is higher as the mobility of nodes increases in terms of energy.

Interpretation 2: The F-value implies the significance of the hypothesis. The significance of AMQoS for low node mobility is 0.3972 and the significance of AMQoS for high node mobility is 0.798 as shown in Table 6. The F-value indicates the significance of the AMQoS for high mobility is higher compared to the significance of the AMQoS for low mobility. So, the performance of AMQoS in terms of energy consumption against DSR and PA-DSR is higher as the node mobility increases can be inferred from the result.

The ANOVA test on other QoS metrics like goodput, delay, and Packet Delivery Fraction is available in the Supplementary file.

5. Conclusions

Routing protocol designs and quantity parameters such as the number of nodes, node mobility, transmission range, traffic load, end-to-end delay, and throughput can all have a significant impact on the performance of multi-constrained QoS routing protocols. These elements, along with the fundamental properties of MANET, may cause uncertainty in overall network performance. The Taguchi method is a powerful approach for quantifying multiple elements at the same time. It is an iterative optimization process that uses an OA to discover near-optimal settings. As a result, the Taguchi approach is a systematic and efficient way of identifying effective components that influence the process when a robust experimental design is used. The robust parameter design method has been successfully applied in many areas such as environmental sciences, agriculture sciences, manufacturing processes, basic sciences, engineering, medicine, management sciences, biological science, physical science, power

Table 5. ANOVA test for energy consumption variation against no. of nodes.

	Source of Variation	SS	Df	MS	F	p-value
Significance of AMQoS for less no. of nodes	Between groups	1.763	2	0.8815	0.07101	0.931837
	Within groups	148.9542	12	12.4129		
	Total	150.7172	14			
Significance of AMQoS for more no. of nodes	Between groups	163.7603	2	81.8802	1.64939	0.232888
	Within groups	595.7134	12	49.6428		
	Total	759.4738	14			

Table 6. ANOVA test for energy consumption variation against the mobility of nodes.

	Source of Variation	SS	Df	MS	F	p-value
Significance of AMQoS for low mobility	Between groups	2.4162	2	1.2081	0.3972	0.6887
	Within groups	18.2503	6	3.0417		
	Total	20.6665	8			
Significance of AMQoS for high mobility	Between groups	11.7242	2	5.8621	0.798	0.4928
	Within groups	44.0773	6	7.3462		
	Total	55.8015	8			

electronics, wireless communications, and many more where optimization is required to minimize process iteration and compare the elapsed time.

Conflict of interest

The authors declare no conflict of interest.

Supporting information

Available.

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