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Identifying Factors Affecting Data Delivery Performance in Mobile Ad-Hoc Network Routing Protocol Using A Systematic Approach

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Abstract A mobile ad hoc network (MANET) is a collection of mobile nodes dynamically forming temporary network without the use of any existing network infrastructure or centralized administration. Due to the mobility of the nodes, as well as the continual arrival and departure of nodes, the topology of the network changes constantly. To manage the data transmission, routing protocols are needed. Therefore, analyzing performance of the protocols becomes crucial to finding an efficient routing protocol. Many performance evaluation of routing protocols have done through trial-and-error simulation experiment. This paper shows a systematic procedure of using Taguchi parameter design in analyzing Destination Sequence Distance Vector (DSDV) routing protocol performance. The affect of terrain size, node speed, network size and pause time on the performance of DSDV routing protocol is identified. Performance is evaluated with respect to packet delivery ratio. Based on the simulation data, it was found that the network size and the terrain have significant impact on the performance.

Keywords Taguchi parameter design; ANOVA; mobile ad hoc networks; performance evaluation; packet delivery ratio.

1 Introduction

A mobile ad hoc network is a collection of mobile wireless nodes that can dynamically form a network without necessarily using any fixed infrastructure. Such network can be useful in all those situations in which conventional networking cannot be applied, because of difficult terrain, or economical reasons, such as military activities in enemy territory, disaster recovery operations or big conference rooms. Due to the mobility of nodes, the topology of the networks changes constantly. Therefore, routing protocols play a significant role for efficient data transmissions in mobile ad hoc networks.

As a best solution in process transmitting data or information, many routing protocols for mobile ad hoc networks have been proposed, for instance [1]–[4]. They may be categorized as proactive and reactive, according to the way the mobile host exchange routing information. The proactive protocols, such as Destination Sequenced Distance Vector (DSDV), periodically disseminate routing information among all the hosts in the network, so that every host has the up-to-date information for all possible routes. In contrast, reactive routing protocols, such as Ad-Hoc On-Demand Distance Vector Protocol (AODV) and Dynamic Source Routing (DSR), query a route when there is a real need for it.

Several performance comparisons have been reported for mobile ad hoc routing protocols over the past few years. Most of previous studies evaluate the performance of routing protocols used simulation based [5]–[10]. As stated in [11], 75.5% of MANET research published in the 2000–2005 proceedings of the ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc) used simulation to test their research. Simulations of proactive and reactive routing protocols demonstrate that the packet delivery ratio degrades when mobility is high because of route instability and frequent network partitions [12]. When DSDV detects a broken route, it stores the packet until the next route update at which time it tries to resend the packet. In DSDV, each mobile node keeps a routing table that indicates all possible destinations, along with their next hop and a distance metric, which is the number of hops to the destination. Each routing entry has a sequence number assigned by the destination node, allowing distinguishing out of date routes from new ones and avoiding the routing loops.

Through simulation experiment, it provides a vital alternative for conducting cheap and repeatable evaluations prior to actual deployment. However, every experimenter or researcher has to plan and conduct experiments or in another words in systematic approach to obtain enough and relevant data so that he can infer the science behind the observed phenomenon. Most previous researches have done the simulation experiment by trial and error approach, which is costs time and money. However, in recent years, there are few researchers using design of experiment in perform the simulation experiments [13]–[15].

In this paper, we present how Taguchi parameter design could be used in identifying the significant factors: terrain, node speed, network size and pause-time that may affect the performance of DSDV routing protocol. Specifically, this paper evaluates the impact of these factors on the packet delivery ratio as a performance metric.

2 Taguchi Method

There are many ways to conduct experiment to obtain enough data to give desired result. The Taguchi method is one of the best robust design methods. The basic principle of this method is to develop an understanding of the individual and combined effects of various design parameters from a minimum number of experiments. In this methodology, the desired design is finalized by selecting the best performance under conditions that produce consistent performance. The Taguchi method provides systematic, simple and efficient methodology for the optimization of the near optimum design parameters with only a few well-defined experimental sets [16]–[17].

Two important tools used in taguchi parameter design are orthogonal arrays and signal-to-noise ratio. Specific orthogonal array should be carefully selected largely based on the factors quantities and their value differentiation. The greatest influence factor to the performance of DSDV routing protocol will be determined after deeper analysis. The signal-to-noise ratio is an indicator to quantify the present variation by which the effect of changing a particular design parameter on the performance of the process can be evaluated.

3 Selection of the Quality Characteristic, Experimental Factors and Orthogonal Array

There are three types of quality characteristics in Taguchi methodology, namely smaller-the-better, larger-the-better and nominal-the-best. In this paper larger-the-better was used to get the maximum packet delivery ratio (PDR) of the DSDV routing protocol. Larger PDR values represent better or improved data packet delivered.

In order to get the higher percentage of delivered packet, we have to concern on the size of environment network where nodes move randomly and communicate with each other in a square region of medium scale size network like an indoor stadium. In this study we term it as terrain. The terrain was selected as 150m x 150m and 200m x 200m, approximated based on the largest indoor stadium in the world, the Superdome in New Orleans, 207 meters in diameter and 83 meters high [18]. In general, indoor environment has low mobility. The range of the speed node was set as 0.5 m/s and 1.0 m/s pedestrian [19]. The network size refers to the number of nodes in the terrain specified. This work is considered moderate network size, so that, we set 100 and 200. Pause time is a time, in seconds, for which mobile nodes pause between their consecutive movements. The less this time is, the more active the mobile nodes are in moving. Table 1 listed all the factors and levels used in the experiment.

Table 1: Process parameters with their value levels

Factor	Level 1	Level 2
A - terrain (m^2)	150 x 150	200 x 200
B - speed (m/s)	0.5	1.0
C - network size	100	200
D - pause time (s)	10	150

There are 18 basic types of standard orthogonal arrays (OA) in the Taguchi parameter design. The selection of a suitable orthogonal array design is critical for the success of an experiment. Since there are four network parameters with each two levels were studied in this research, the L_8 (2^7) orthogonal array is used. The use of the L_8 OA allows the full factorial design of 128 experiments (which would have been time consuming even with present day computing power) to be examined with just 8 experiments. This is a significant saving of computer analysis time. Each row of the matrix represents one trial. However, the sequence in which these trials are carried out is randomized. Each experiment was repeated three times, resulting in 24 simulations runs which were conducted for analysis in this study. The experimental layout for the screening experiment is shown in Table 2.

4 Conducting the Simulation Experiments

Our simulations were run on network simulator-2, version 2.29 [20] which provide implementation of DSDV routing protocol. This simulator is the most used in MANET research.

Table 2: Orthogonal Array (L_8 (2^7))

Experiment no.	1 (A) Terrain (m)	2 (B) Speed (m/s)	3 (C) Network size	4 (D) Pause time	5	6	7
1	150x150	0.5	100	10	1	1	1
2	150x150	0.5	100	150	2	2	2
3	150x150	1.0	200	10	1	2	2
4	150x150	1.0	200	150	2	1	1
5	200x200	0.5	200	10	2	1	2
6	200x200	0.5	200	150	1	2	1
7	200x200	1.0	100	10	2	2	1
8	200x200	1.0	100	150	1	1	2

35 out of 80 (43.8%) simulation papers that state simulator used in the simulation study used ns-2 [14]. All simulations are run for 4800 simulated seconds.

The radio transmission range of each node is 100 meter corresponding to a radio range of standard Wi-Fi. In this study, we used constant bit rate (CBR) sources that continuously transmit 512 bytes data packets at a rate of 4 packets per second for the duration of the simulation. The Random Waypoint mobility model [21] is used in our evaluations. In the Random Waypoint model, each mobile node starts from a randomly chosen position in the simulated area (terrain) and stay for the length of pause time. When a pause time expires, a destination and moving speed are randomly picked. The mobile node will move towards the destination at a speed uniformly chosen between zero and maximum speed. Once it reaches the destination, the process of pausing, choosing destination and speed start over again.

Three measured packet delivery ratio (PDR) were computed from the simulation experiment. Packet delivery ratio is the number of data packets received by the destination nodes divided by the number of data packets transmitted by the source nodes. Lets x is the total number of packets received by the nodes and y is the total number of packets transmitted times the number of receivers, so PDR equation can be written as

$$\text{PDR} = \frac{x}{y} \times 100.$$

Packet delivery ratio is a “the larger the better” type of quality characteristic. So, the S/N ratio for that type of response was used and is given by

$$S/N \text{ ratio} = -10 \log \left[\frac{1}{r} \sum_{i=1}^{r} \frac{1}{{y_i}^2} \right] \tag{1}$$

where r is the number of simulation repetitions under the same design parameter conditions, y_i represents the ith PDR computed. The higher the signal-to-noise ratio, the greater the performance becomes. The PDR computed and S/N ratios of each experimental run are shown in Table 3.

Table 3: Experimental results for packet delivery ratio (%) and its corresponding S/N ratio

Experiment no.	Repetition 1	Repetition 2	Repetition 3	Average	S/N ratio
1	98.27	99.27	98.71	98.75	39.89
2	99.37	97.81	99.85	99.01	39.91
3	50.73	41.52	46.55	46.27	33.22
4	47.96	42.91	47.54	46.14	33.25
5	42.34	39.76	41.29	41.13	32.27
6	36.75	41.51	40.75	39.67	31.93
7	95.74	84.46	94.28	91.49	39.26
8	88.39	84.57	95.33	89.43	38.99

5 Analyzing the Result

Based on the data presented in Table 3, the corresponding S/N response table and S/N response graph can be derived, as presented in Table 4 and Figure 1 for the packet delivery ratio, respectively. The calculation of average S/N ratios for each factor at ith level, $\overline{S/N}_{factor_i}$ was based on the following equation:

$$\overline{S/N}_{factor_i} = \frac{1}{n_{factor}} \sum_{j=1}^{n_{factor}} [(S/N)_{factor_i}]_j \tag{2}$$

where n_{factor} is the number of appearances of each factor in each level in the orthogonal array table, and $(S/N)_{factor_i}$ is the signal-to-noise ratio of each factor in level i. The effect of each factor is then calculated by absolute difference between the two average S/N ratios (two levels).

In accordance with the principles of the Taguchi method, the present study assumes that the best performance is indicated by the maximum S/N ratio. It is clear from Figure 1 that the factor C (network size) is the most dominant factor effect, followed by factor effects A (terrain), B (speed) and D (pause-time). Figure 1 also shows that the maximum of packet delivery ratio is at the first level of factor A, C and D and at the second level of factor B.

Table 4: Mean effect response table for S/N ratio

Factor	A	B	C	D
Level 1	36.566	36.002	39.516	36.161
Level 2	35.617	36.181	32.667	36.022
Effect Estimate	0.95	0.178	6.849	0.14
Rank	2	3	1	4

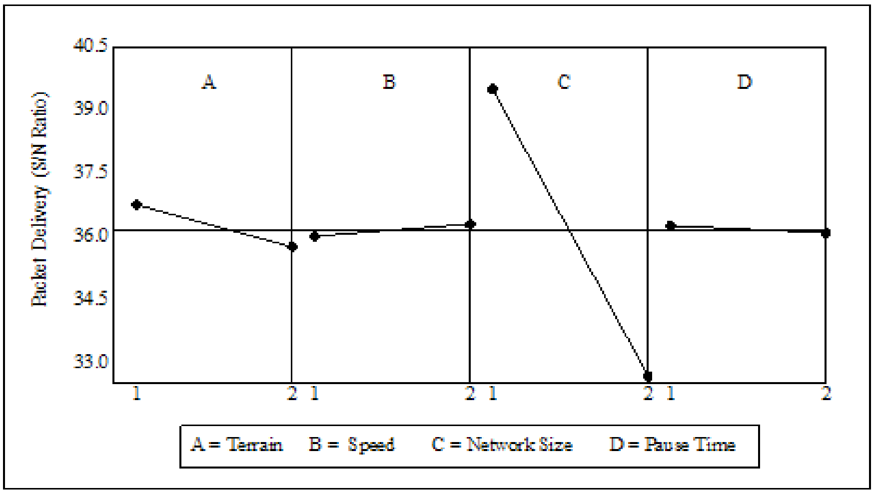

Figure 1: Larger-the-better S/N ratio response graph

In order to study the significance of parameters, Analysis of Variance (ANOVA) was performed. The purpose of the ANOVA is to determine which network parameters significantly affect the quality characteristic (PDR). ANOVA analysis was performed using equation from (3) to (7) as below [16].

$$SS_{total} = \sum_{i=1}^{n} \left[(S/N)_i - \overline{S/N} \right]^2, \tag{3}$$

$$SS_{factor} = n_{factor} \sum_{i=1}^{L} \left[(\overline{S/N}_{factor_i} - \overline{S/N} \right]^2, \tag{4}$$

$$V_{factor} = \frac{SS_{factor}}{df_{factor}}, \tag{5}$$

$$F_{factor} = \frac{V_{factor}}{V_e}, \tag{6}$$

$$P_{factor} = \frac{SS_{factor} - (df \times V_e)}{SS_{total}}, \tag{7}$$

where SS_{total} is the total sum of squares, SS_{factor} the factorial sum of squares, n is the number of experiments, V_{factor} is the variance of the factor, F_{factor} is the F ratio of the factor, n_{factor} is the number of appearance of each factor in OA, $\overline{S/N}$ is the overall mean of S/N ratio, L is the number of levels and P_{factor} is the percent contribution for each factor.

Table 5 shows the result of ANOVA analysis of S/N ratio for the packet delivery ratio. The last columns of the ANOVA table is percent contribution, which reflects the portion of the total variation observed in an experiment to each network parameter. It signifies that the parameters with substantial percent contributions are the most important for reducing variation. From Table 5, it is clear that the network size (97.929%) is the most influential factor followed by terrain (1.863%), speed (0.046%) and the least influential factor is pause-time (0.019%). Table 5 showed that the terrain and network size have a significant impact on the performance of packet delivery. Conversely, the results indicate that the speed and pause-time have a less significant influence upon the packet delivery ratio.

Table 5: ANOVA table of S/N ratio

Factors	Degrees of freedom	Sum of Squares	Variance	F-ratio	Percent Contribution (%)
Terrain	1	1.803	1.803	93.700**	1.863
Speed	1	0.063	0.063	3.313	0.046
Network size	1	93.809	93.809	4872.698**	97.929
Pause-time	1	0.038	0.038	1.981	0.019
Error	3	0.057	0.019		0.143
Total	7	95.773			100.00

From F-tables: $F_{0.05,1,3} = 10.13$ and $F_{0.01,1,3} = 34.12$
**Factor is significant at both 1% and 5% significance levels.

6 Conclusion

Extensive researches have been done in performance evaluation of routing protocols in mobile ad hoc networks. Due to the high cost of deploying and testing new mobile ad hoc network architecture in real world, performance evaluation has been mostly simulation based. However, most of the simulation experiment was done by trial-and-error approach. This requires making measurements after every experiment so that analysis of observed data will allow researcher to decide what to do next and which parameters should be varied and by how much. Consequently, some cost and time involved in perform the experiment especially in laboratory experiment.

This study, we used the systematic procedure in designing the simulation experiment. Taguchi's design of experiments is used to study the impact of network parameters on the performance of DSDV routing protocol. There are several networks parameters that could potentially impact the performance of DSDV routing protocol. In this study, we considered the factors of terrain (A), node speed (B), networks size (C) and pause time (D) and each factor is examined at two different value levels. The L_8 (2^7) orthogonal array is used for designing the simulation experiment. From the simulation experiment we measured the packet delivery ratio as a performance metric and analyzed the data. The analysis found that the network size and the terrain have a significant effect on the performance. Nevertheless, speed and pause-time have a less impact on the performance of DSDV routing protocol.

Further study could consider sparse and dense network in setting the value level of network size. Also, further study could consider more factors (e.g. maximum connection, transmission range, etc) in the research to see how the factors would affect the performance of DSDV routing protocol.

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