Statistical Approach To Estimate Path Duration in Mobile Ad-Hoc Network

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***Abstract*—The performance of MANETs was greatly influenced by the routing protocols designs and the performance of routing protocols is determined by a number of factors, among which the path durations are of much importance. Path duration is defined as the time during the path is active for the communication. Estimation of path duration in MANET's is useful and it can be used in various ways to improve the performance of communication in MANET's. This paper deals with the theoretical estimation of average path duration followed by use of statistical techniques viz, Design of Experiments and Analysis of Variance for investigation of the most significant design parameter, which affect the average path duration. The design parameters include transmission range, node density, number of hops, and node velocity. This study also investigates synergetic interaction between the pair of parameters and their effect on path duration. This development will help us to emphasize on which parameter needs to be handled effectively to enhance path duration and ultimately performance of communication in MANETs.**

Random WayPoint (RWP) model has been used for the estimation of path duration as a reference. The statistical results reveled that the transmission range was the most significant parameter that contributes in estimation of path duration (94.55%) followed by number of hops (1.62%). It is also observed from the results of ANOVA that contributions of interactions between Transmission range, Node velocity and number of hops are very less. Hence it clearly indicates that those factors are independent. These findings demonstrate that Statistical techniques prove to be valuable tool for the investigation of main effect or interaction of multiple factors in estimation of path duration.

Keywords- Path duration; link duration; mathematical model; Design of Experiment; analysis of variance.

I. INTRODUCTION

An ad hoc mobile network (MANET) is a transient network formed dynamically by a collection of arbitrarily located wireless mobile nodes without the use of existing network infrastructure or centralized administration [1]. As direct communication is only possible for neighbor nodes, the transmission of information between distant devices is supported by the cooperation of intermediate nodes that retransmit and route their packets. The sequence of intermediate nodes involved in the retransmission process constitutes a route or path. The communication range and power of each node in a route is limited, so it has to form multi-hop routing when many nodes communicate with each other in a network. The routing gets complicated when mobility comes into picture. MANETs have a dynamic topology and hence the path followed by data packet to reach its destination varies frequently due to mobility or uncertainty of channels (i.e. link goes up/down). This is one of the most concerned problems which affect the performance of the network, and there are various routing protocols designed specifically for MANETs, however in every routing protocol it is a key common task to find a “good” path between a source and a destination node [1].

Routing protocols for MANETs can be categorized into table driven or on demand methods. Table driven protocols require each node to maintain routing tables to store routing information and they involve constant routing table update mechanism. A node can send information immediately to a destination whenever it wants to do so. But these protocols suffer from substantial signaling traffic and power consumption problems. The alternative to table driven protocol is on-demand routing protocols which find a route to a destination whenever a node has information to send. Though signaling and power consumption problems are minimized, they still suffer due to the fact that a node has to wait until the routing protocol finds a route in order to send data. One problem which is common to both these protocols is mobility which affects the performance of these protocols. This is due to the fact that, mobility changes connectivity graph (i.e. a link which was previously available may not be available at another point of time). Due to this, the routing protocol has to find a route once again as soon as the route becomes invalid due to mobility.

In this sense, the criterion for selecting paths plays an important role. For two communicating nodes, there may exist multiple paths among which one route must be selected for the communication. Although the criterion of the minimum number of hops is commonly utilized, diverse metric could be employed for the selection. Specifically, the consideration of the expected path duration will significantly enhance the performance of the routing protocols as well as the throughput of the MANETs.

Realizing that estimation of path duration in MANET's is useful and it can be used in various ways to improve the performance of routing protocol and ultimately communication in MANET's [18]. Also the accurate prediction of path duration will help to improve the performance of routing protocols. The prediction of path duration for a selected path is challenging task due to the dynamic nature of mobile nodes as well as it depends on several parameters such as position and number of relay nodes, their velocity, direction of movement etc. Due to complexity and high randomness, many studies and researches has been carried out based on simulations and/or empirical technique for performance evaluation in MANET lacking theoretical understanding of the ad hoc network and their behavior. Furthermore, in such studies the performance of MANET routing protocols have been addressed by the one factor at a time analysis approach [1, 18]. 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.

This paper demonstrate a theoretical understanding on estimation of path duration [6] and applied the same to analyze the performance parameter i.e. average path duration for routing protocol in MANET using several factors at a time approach by employing a Taguchi design of experiments. This will help to improve the methodology analysis aspects of evaluating the performance parameter. Further the study is extended to find out the most significant factor which impacts on average path duration and to find any interaction between two parameters exist which affect the path duration. The estimation of average path duration from mathematical model is formulated using MATLAB tool.

II. RELATED WORK

An analytical model to estimate path duration in MANET using random way point mobility model as a reference was proposed in [6]. This proposed model establishes relationship between path duration and MANET design parameters like node density, transmission range, number of hops and velocity of nodes. In this the authors mentioned that the prediction of path duration depends on position and number of relay nodes, their velocities and direction of movement. They have concluded that

- The average path duration has linear relationship with the transmission range and it can be approximated to the exponential distribution with average node velocity.
- Increasing node density results in increased path duration but has counter effect of edging with high node density.
- The path duration is much longer for one hop link, and the distribution can be approximated to exponential distribution for hops greater than 2.

Analysis of path duration statistics and their impact on reactive MANET routing protocols is studied in literature [7] & [9] which is the first attempt to formulate path duration analytically where path duration is related with protocol performance. By using simple analytical models and with the case study of DSR routing protocol, the correlation between reciprocal of average path duration and the throughput and overhead of reactive routing protocols is shown. The distribution of average path duration has been approximated to exponential distribution when the path length grows.

Distribution of path durations in mobile ad-hoc networks using palm's theorem is done in [10] in this paper they have developed a model to better explain the exponential distribution for path duration based on hop length. Palm's theorem was used to prove the emergence of exponential distribution under a set of mild conditions. The correlation between the excess life times of two neighboring links has been studied and it has been concluded that this correlation is often very weak for RWP mobility model.

A survey of mobility models for ad hoc network research is done in [5] in which they describe different mobility models like entity mobility models that represent mobile nodes whose movements are independent of each other and group mobility models that represent mobile nodes whose movements are dependent on each other. They concluded that

- The performance of an ad hoc network protocol can vary significantly with different mobility models as well as same mobility model with different parameters.
- The selection of a mobility model may require a data traffic pattern which significantly influences protocol performance.
- Random waypoint mobility (RWP) model is a free flow model where nodes are moving in random direction with a velocity chosen randomly from [0, vmax]. It uses "pause" time once between variation in direction and speed. It is used in many prominent simulation studies of ad hoc network protocols.

In [14], author Investigate DSDV protocol performance by applying Taguchi's DOE. Effect of network parameters namely terrain sizes, node speeds, network sizes, transmission ranges, transmission rates, pause times and no. of maximum connections on Packet delivery ratio and routing overhead were studied through simulations. They also analyze the response performance based on Signal to noise ratio and Analysis of Variance (ANOVA). They concluded that, most influential factor was Transmission range on PDR, followed by terrain size and transmission rates. Network size has greatest effect on routing overhead, followed by transmission range.

III. MATHEMATICAL MODEL

The model attempts to estimate the average path duration assuming a routing protocol based on shortest path principle. In the Mathematical model, the nodes are assumed to be randomly positioned due to mobility. The detail mathematical model is given in [6]. The following notation is used in Figure 3.1 as well as in the analysis.

l: Distance between the source S and the destination D

I: Point on the circle which is at the same distance as R from D.

x: Distance between the relay node R and D. So $ID=RD=x$.

y: Distance between S and R

r: Transmission range of a node in the MANET.

θ : Angle between the two straight lines SR and SD

θ_1 & θ_2 is angle between SI and SD & ID and SD resp.

z: Straight line distance between S and D

: Width of the strip shown in Fig. 1. The strip is formed by two arcs drawn from D $x \pm \Delta x$ with radii x Δx and resp. is chosen such that the probability of finding at least one node in the strip is non Δx zero.

$a_{int}(x)$: Area of intersection between two circles, one drawn at S with radius r and the other drawn at D with radius x.

$a_{arc}(x, \Delta x)$

λ : Area of the strip described above.

: The node positions are assumed to follow Poisson distribution with λ parameter

A_1+A_2: Area of intersection between circles drawn at S and D.

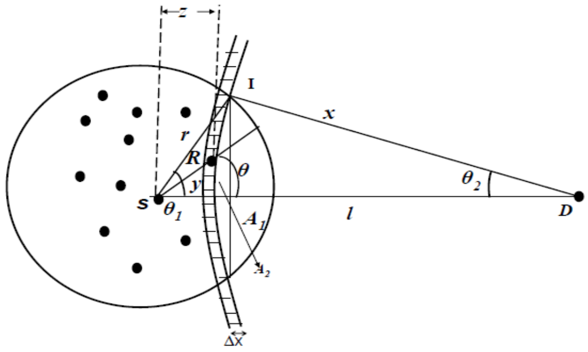

Fig.1. Network model: selection of a relay node based on the principle of shortest path or least remaining distance [1].

A. Link residual life

Link residual life (t) is defined as the time during which a link will be active once it becomes a part of a path. A link between two mobile nodes will be active as long as they are in the transmission range of each other. It can be expressed as the ratio,

$$t = \frac{d}{v_r} \tag{1}$$

Where d = distance that the neighbor (relay) node needs to travel to get out of the transmission range of its neighbor and v_r is relative velocity between the two neighbors. The PDF of X is re $f_X(x)$ted as and can be expressed as,

$$f_X(x) \approx 2\lambda\theta_2 x e^{-\lambda a_{int}(x)} \tag{2}$$

Where,

$$a_{int}(x) = r^2\left[\theta_1 - \frac{\sin(2\theta_1)}{2}\right] + x^2\left[\theta_2 - \frac{\sin(2\theta_2)}{2}\right] \tag{3}$$

$$\theta_1 = cos^{-1}\left[\frac{r^2+l^2-x^2}{2rl}\right] \; and \; \theta_2 = cos^{-1}\left[\frac{x^2+l^2-r^2}{2xl}\right] \tag{4}$$

B. Distance progress per hop

Let us define z, the distance progress per hop towards the destination, made by the choice of the relay node and expressed as,

$$f_Z(z) = 2l\lambda\theta_2(z)e^{-\lambda a_{int}(z)} \tag{5}$$

Where,

$$a_{int}(z) = r^2\left[cos^{-1}\left(\frac{z}{r}\right) - \frac{z\sqrt{r^2-z^2}}{r}\right]$$

$$+(l^2+r^2-2lz)\left[cos^{-1}\left(\frac{l-z}{l^2+r^2-2lz}\right) - \sqrt{\frac{r^2-z^2}{l^2+r^2-2lz}}\right] \tag{6}$$

$$\theta_1(z) = \cos^{-1}\left(\frac{z}{r}\right) \quad \text{and} \quad \theta_2(z) = \cos^{-1}\left(\frac{l-z}{\sqrt{l^2+r^2-2lz}}\right) \tag{7}$$

C. Relative velocity

In order to find the PDF corresponding to the relative velocity, the source node S is assumed to be fixed and the relative movement of the relay node with respect to S is considered. Assuming that all nodes move with an average (constant) velocity, the pdf of v_r, $f_{v_r}(v_r)$ is expressed as [6],

$$f_{v_r}(v_r) = \frac{1}{\sqrt{4v^2-v_r^2}}\frac{1}{\pi} \tag{8}$$

α is angle between the velocity vectors v_1, v_2.

$$v_r = 2v\,sin\frac{\alpha}{2}$$

D. Estimation of Link duration

The PDF of variable 't' from eq. (1) can be deduced by evaluating the joint probabilities of the variables 'd' and 'v_r'.

$f_T(t)$ is given by,

$$f_T(t) = \int_0^{v_{max}}[f_D(d)]_{d=v_r t}\left[\frac{v_r}{\sqrt{4v^2-v_r^2}}\frac{1}{\pi}\right]dv_r \tag{9}$$

Where v_{max} = Maximum relative velocity and v = velocity of a node. The above equation corresponds to the one hop duration of a link that a shortest path will select. It does not correspond to the average link duration of all available neighbors [6].

E. Estimation of Path Duration:

Path duration (t_{path}) is derived from the PDF of the link residual life. If the number of hops needed to reach the destination is h, then (t_{path}) can be written as,

$$t_{path} = \min\,(t_1, t_2, \ldots\ldots t_h) \tag{10}$$

Where, t_i is the link residual time corresponding to i[th] link. Using Baye's theorem [7] the PDF of T_{path} can be expressed as,

$$f(T_{path}) = hf_{T_{path}}(t_{path})C_{T_{path}}^{h-1} \tag{11}$$

Where, $C_{T_{path}} = 1 - F_{T_{path}}$ is complementary CDF of T_{path}.

Expanding $f_{T_{path}}(t_{path})$ we get,

$$f_{T_{path}}(t_{path}) = h\left[\int_0^{v_{max}}[f_D(d)]_{d=v_r t}\left[\frac{v_r}{\sqrt{4v^2-v_r^2}}\frac{1}{\pi}\right]dv_r\right] \times$$

$$\left[1 - \int_0^{t_{path}}\left[\int_0^{v_{max}}[f_D(d)]_{d=v_r t}\left[\frac{v_r}{\sqrt{4v^2-v_r^2}}\frac{1}{\pi}\right]dv_r\right]dt_{path}\right]^{h-1} \tag{12}$$

The average path duration is given by,

$$E[T_{path}] = \int_0^{\alpha} t_{path} f_{T_{path}}(t_{path})\, dt_{path} \qquad (13)$$

The above mathematical model is evaluated using MATLAB 7.6 tool.

IV. STATISTICAL DESIGN OF EXPERIMENTS

Statistical DOE refers to the process of planning the experiment so that appropriate data that can be analyzed by statistical methods will be collected, resulting in valid and objective conclusions [2]. A statistical tool is always preferred for drawing the meaningful conclusion from an experimental design data. There are two aspects to any experimental problem; the design of the experiment and the statistical analysis of the data.

The purpose of experimentation should be to understand how to reduce and control variation of product or process; subsequently, decision must be made concerning which parameter affect the performance of product or process.

The Taguchi technique is a systematical application of design and analysis of experiments for the purpose of designing and improving product or process quality [15]. The difference between a traditional full factorial design of experiment and Taguchi design of experiment is the significant reduction in size of experiments. When many factors control the performance of any system then it is essential to find out significant factors which need special attention either to control or optimize the system performance. Taguchi's concept of Orthogonal Array (OA) as a part of statistical DOE is used in such situations to plan the set of experiments and ANOVA technique is used to find out the significant factors.

For a current research we are interested in determining the effect of design parameters like transmission range, node velocity, node density and number of hops on estimation of average path duration for routing protocol in MANET. The network parameter will be referred to as main effect when the effect of that factor acting on its own from one level to another to change the outcome in a response of experiment [3]. Each network parameters has three settings to cover the range of interest. In this study the settings are referred as levels and the parameters as factors. Thus, the design of experiment for present research is a 3^4 factorial design with 4 factors each at 3 levels. The factors and their chosen levels are listed in Table I.

TABLE I. FACTORS AND THEIR LEVELS FOR EXPERIMENT

Sr. No.	Control Factors	Levels		
		1	2	3
1	Transmission range, *Tx* (m)	50	150	250
2	Node velocity, *Vel* (m/s)	5	30	60
3	Number of hops, *NoH*	2	5	8
4	Node density, *ND* per unit area	10	20	70

The first step in constructing an OA to fit a specific case study is to count the total degree of freedom that tells the minimum number of experiments that must be performed to study all the chosen control factors. Degrees of freedom (ν) is defined as the number of independent measurements available to estimate pieces of information or the number of independent comparisons that may be made within a set of data [3]. The number of degrees of freedom associated with a factor is equal to one less than the number of levels for that factor [4]. Therefore degrees of freedom (DOF) of factors are transmission range *Tx* (2), Node velocity *Vel* (2), Number of hops *NoH* (2), Node density *ND* (2). Degrees of freedom of interactions are *Tx X Vel* (4), *Tx* X *NoH* (4), and *Vel X NoH* (4). Considering all the factors and their interactions, there are 20 degrees of freedom. Thus for four factors each at 3-levels, three interactions and 20 DOF, the suitable orthogonal array is L27. In total, L27 has 26 degrees of freedom. The remaining (26-20) six degrees of freedom are used for error.

Orthogonal array L27 can be assigned with maximum 13 factors each at 3 levels is used to design the experiments for finding out the average path duration for a given protocol under the simultaneous variation of four different network parameters at three levels. Inability to distinguish effect of factors and interactions is called confounding [4]. As it is expected that factors (*Tx*), Velocity (*Vel*) and number of hops (*NoH*) to interact, no factors are assigned to columns (3, 4), (6, 7) and (8,11). This is done to avoid confounding. The trials for estimation of average path duration (T_p) for the combination of parameters are also shown in Table II. These are found by conducting experiments using MATLAB code made for the Mathematical model.

V. ANALYSIS OF VARIANCE

The results obtained for average path duration from the mathematical model analysis in MATLAB are analyzed by using the statistical tool ANOVA. It determines the relative effect of the individual factors and their interactions on the average path duration. The analysis by using ANOVA technique is done analytically. An equation for total variation may be written as,

$$SS_T = SS_{Tx} + SS_{Vel} + SS_{NoH} + SS_{ND} + SS_{TxXVel} + SS_{TxXNoH} + SS_{VelXNoH} + SS_e \qquad (14)$$

Where, SS_T is total sum of squares. SS_{Tx}, SS_{Vel}, SS_{NoH} and SS_{ND}, are sum of squares for Transmission range, node velocity, number of hops and node density respectively. SS_{TxXVel}, SS_{TxXNoH}, $SS_{VelXNoH}$ are sum of squares of *Tx X Vel*, *Tx X NoH* and *Vel X NoH* interactions respectively. SS_e is sum of square of the error. If *T* is the sum of all *(N)* average path duration, the total sum of squares is given by,

$$SS_T = \left[\sum_{i=1}^{N} T_{p_i}^2\right] - \frac{T^2}{N} \qquad (15)$$

Sum of squares of Transmission range (Tx) factor is given as,

$$SS_{Tx} = \left[\sum_{i=1}^{K_{Tx}} \frac{Txi^2}{N_{Txi}} \right] - \frac{T^2}{N} \qquad (16)$$

Where, K_{Tx} =number of levels of Tx factor. Tx_i and N_{Txi} are the sum and number of observations respectively under ith level. Similarly, sum of squares of other three factors can also be calculated. Sum of squares of interaction of Tx and velocity is given by,

$$SS_{TxXVel} = \left[\sum_{i=1}^{n} \left(\frac{(TxXVel)_i^2}{N_{(TxXVel)i}} \right) \right] - \frac{T^2}{N} - SS_{Tx} - SS_{Vel} \quad (17)$$

Where $(Tx\ X\ Vel)_i$ and $N_{(Tx\ X\ Vel)i}$ are the sum and number of observations (average path duration) respectively under ith condition of the combinations of factors Tx and Vel and n is the number of possible combinations of the interacting factors Tx and velocity (Vel). Similarly, the sum of squares for other two interactions can also be found out. The results obtained from ANOVA are given in Table III.

VI. RESULTS AND DISCUSSION

A. *Results of Mathematical model:*

The mathematical model built is validated by comparing its results obtained using MATLAB with the results obtained based on RWP mobility model presented in [6]. The comparisons are made between average path duration with Transmission range, number of hops and Node velocity. Validation is achieved by using the same values for input parameters as used in [6].

1) *Average path duration versus transmission range*

Fig. 2 shows the relationship between average path duration and transmission range. It can be seen that as transmission range increases, the average path duration also increases linearly.

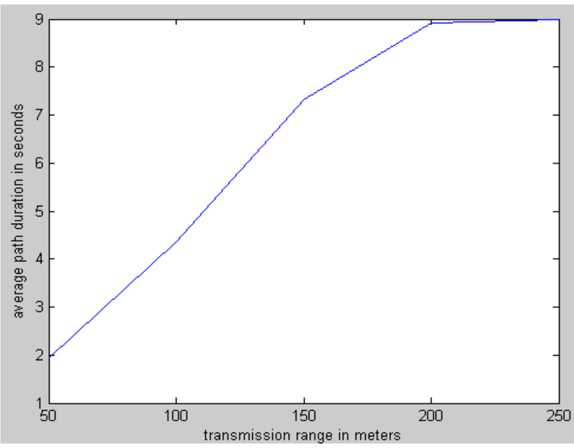

Fig.2 Average path duration versus transmission range. Parameters: Velocity=30 m/s, transmission range = 50-250m, number of nodes= 40, number of hops =2, and area = 1000m x 1000m.

2) *Average path duration versus node velocity*

Fig. 3 shows that the average path duration can be approximated to exponential distribution. Such exponential relationship has also been observed in [6].

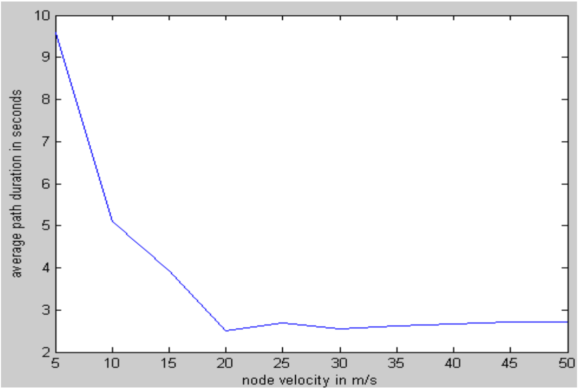

Fig.3 Average path duration versus node velocity. Parameters: Velocity=5-50m/s, transmission range = 300m, number of nodes= 40, number of hops =2, and area = 1000m x 1000m.

3) *Average path duration versus number of hops*

The plot shows that the duration is much longer for one hop link, and there is a steep fall in the average path duration when the hops increase from 1 to 2. The one hop path duration is nothing but link residual life. The distribution can be approximated to exponential distribution for hops >2.

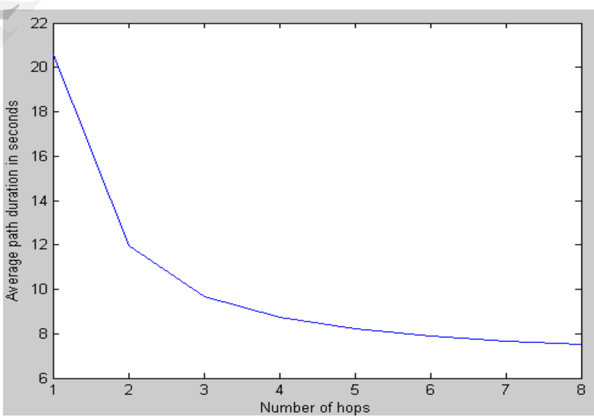

Fig.4 Average path duration versus number of hops. Parameters: Velocity=30 m/s, transmission range = 250m, number of nodes= 40, and area = 1000m x 1000m.

B. *Results of Statistical Design of experiment:*

The results obtained for average path duration from the mathematical model in MATLAB shown in Table II, are further analyzed by using the statistical tool ANOVA. It determines the relative effect of the individual factors and their interactions on the average path duration in MANETs.

The un pooled and pooled ANOVA summary table for estimation of average path duration in MANET routing protocol is shown in Tables III and IV respectively. The ANOVA calculations indicate that there are two factors which influence estimation of average path duration in MANET routing protocol.

Factor transmission range is very influential (largest Sum of square) than the factor number of hops. The ANOVA calculations do not indicate which levels of the factors are best, only that, statistically, a difference exists between the average results of the levels. The interaction is probably the interaction between node velocity and number of hops since F calculated is greater than F tabulated, but the percent contribution is relatively less.

TABLE I. ORTHOGONAL ARRAY L27 WITH MATLAB RESULTS

Expt. No.	***Tx* (1)**	***Velocity, Vel* (2)**	***Tx & Vel* (3,4)**	***NoH* (5)**	***Tx & NoH* (6,7)**	***Node density, ND* (9)**	**(10)**	***Vel & NoH* (8,11)**	**(12)**	**T_p (sec) from MATLAB**
1	50	5		2		10				3.7544
2	50	5		5		40				1.6819
3	50	5		8		70				1.2128
4	50	30		2		40				2.8701
5	50	30		5		70				1.5145
6	50	30		8		10				1.7561
7	50	60		2		70				2.5407
8	50	60		5		10				2.2718
9	50	60		8		40				1.3504
10	150	5		2		40				8.2675
11	150	5		5		70				8.09
12	150	5		8		10				5.5951
13	150	30		2		70				8.565
14	150	30		5		10				6.1261
15	150	30		8		40				7.3419
16	150	60		2		10				7.1881
17	150	60		5		40				7.6652
18	150	60		8		70				7.8233
19	250	5		2		70				9
20	250	5		5		10				8.8487
21	250	5		8		40				8.9999
22	250	30		2		10				8.8926
23	250	30		5		40				8.9999
24	250	30		8		70				9
25	250	60		2		40				8.9999
26	250	60		5		70				9
27	250	60		8		10				8.7906

TABLE II. SUMMARY OF ANOVA

Parameter	**Sum of Square**	**dof, ν**	**Variance, V**	**F, Calculated**	**F, Tabulated**	**% contribution, P**	**Remark**
Tx	231.804	2	115.902	214.049	10.9 #	94.55	$\mathbf{F_{cal} > F_{tab}}$
Node vel	0.019	2	0.0093	0.0171	3.46 +	0.0076	$F_{cal} < F_{tab}$
NoH	3.974	2	1.987	3.670	3.46 +	1.62	$\mathbf{F_{cal} > F_{tab}}$
ND	0.796	2	0.398	0.735	3.46 +	0.325	$F_{cal} < F_{tab}$
Tx X NoH	2.126	4	0.532	0.982	4.01 +	0.867	$F_{cal} < F_{tab}$
Tx X Vel	0.145	4	0.036	0.067	4.01 +	0.059	$F_{cal} < F_{tab}$
Vel X NoH	3.041	4	0.760	1.404	4.01 +	1.24	$F_{cal} < F_{tab}$
error, e	3.249	6	0.541			1.325	
Total, T	245.153	26	120.17			100	

TABLE III. POOLING ERROR VARIANCE ANOVA SUMMARY TABLE

Parameter	Sum of Square	dof, ν	variance, V	F, Calculated	F, Tabulated	% contribution, P	Remark
Tx	231.8	2	115.90	385.61	6.51 #	94.55	$F_{cal} > F_{tab}$
NoH	3.97	2	1.99	6.61	2.73 +	1.62	$F_{cal} > F_{tab}$
Tx X NoH	2.13	4	0.53	1.77	2.39 +	0.87	$F_{cal} < F_{tab}$
Vel X NoH	3.04	4	0.76	2.53	2.39 +	1.24	$F_{cal} > F_{tab}$
error, e_p	4.21	14	0.30			1.72	
Total, *T*	245.15	26	119.92			100.00	

- Note: '+' at least 90% confidence; '++' at least 95% confidence; '#' at least 99% confidence

VII. CONCLUSION

The demonstrated analytical model provides the expression for predicting the path duration of the MANETs employing LRD forwarding. In this study, an important effect of mobility on a network in the form of link breaks which affect the route life times is addressed. The developed mathematical model for path duration estimate can be used to study the limitations on path duration metric due to various parameters and to study the scalability of MANETs.

This path duration metric can be used in evaluating longer paths while making routing decisions unlike the existing routing protocols which selects path according to routing algorithms (based on certain criteria like selecting shortest path first, minimum delay etc.). A great number of previous studies for performance evaluations of routing protocols in MANET mainly focus on one-factor-at-a-time approach. This paper evaluates and quantifies the effects of for several factors (transmission range, node density, number of hops and node velocity) simultaneously using Taguchi experimental design with regards to performance metrics - path duration estimated using mathematical model.

The results are summarized as follows:

- In current study Taguchi concept has successfully applied in estimation of performance parameter i.e. path duration in MANET by quantifying the effect of four factors i.e. transmission range, node velocity, number of hops, node density and their interactions.
- Based on ANOVA results, from F-test the transmission range is the most significant parameter followed by the number of hops in estimation of path duration.
- The results obtained from ANOVA suggest that Transmission range and number of hops contribute 94.55% and 1.62% respectively in the total variation of average path duration. Together these two factors account for 96.17% of total variation in estimation of average path duration in MANET. Hence these two parameters are critical in predicting the average path duration of a route.
- It is also concluded from the results of ANOVA that contributions of interactions between Transmission range, Node velocity and number of hops are very less. Hence it clearly indicates that those factors are independent.

This work could be extended in future to focus on mobility model dependent factors that contribute to average path duration. The future work can also focus on to determine the protocol dependent factors that contribute to path duration. This would help in the accurate prediction of average path duration for various routing protocols. Once the relation between path duration and mobility model dependent factors developed, the Taguchi design of experiment and ANOVA concept can be applied to identify the significant factors among those factor under consideration.

REFERENCES

[1] Stefano Basagni, Marco Conti, Silvia Giordano, and Ivan Stojmenovic, "Mobile Ad-Hoc Networking" *IEEE Press, Wiley India.*

[2] Douglas C. Montgomery, "Design and analysis of experiments" fifth edition, John Wiley & sons, INC.

[3] Ross PJ (1996) Taguchi Techniques for Quality Engineering. New Delhi: Tata McGraw-Hill.

[4] Phadke MS (1989) Quality Engineering and Robust Design. New Delhi: Tata McGraw-Hill.

[5] Montgomery DC (2006) Design and Analysis of Experiments. New Delhi: Wiley India (P) Ltd.

[6] Kamlesh Namuduri and Ravi Pendse (June 2012), "Analytical Estimation of Path Duration in Mobile Ad Hoc Networks" IEEE sensors journal, vol.12, No.6.

[7] F. Bai, N. Sadagopan, B. Krishnamachari, and A. Helmy (Sep. 2004), "Modelling path duration distributions in MANETs and their impact on routing performance," IEEE J. Select. Areas *Commun., vol. 22, no. 7*

[8] L. Kleinrock and J. Silvester, "Optimum transmission radii for packet radio networks or why six is a magic number," in Proc. IEEE Nat. Telecomm. Conf., 1978.

[9] N. Sadagopan, F. Bai, B. Krishnamachari, and A. Helmy (2003), "Paths: Analysis of PATH duration statistics and their impact on reactive MANET routing protocols," in Proc. MobiHoc Proc. 4th ACM Int. Symp. Mobile Ad Hoc Netw. Comput.

[10] Y. Han, R. J. La, and A. M. Makowski (2003), "Distribution of path durations in mobile ad-hoc networks - palm's theorem at work," in Proc. ITC Special. Seminar Perform. Eval. Wireless Mobile Syst., 2004

[11] X. Hong, M. Gerla, G. Pei, and C.-C. Chiang, “A group mobility model for ad hoc wireless networks,” in Proc. 2nd ACM Int. Workshop Modeling Anal. Simul. Wireless Mobile Syst., 1999.

[12] S. De, A. Caruso, T. Chaira, and S. Chessa, “Bounds on hop distance in greedy routing approach in wireless ad hoc networks,” Int. J. Wireless Mobile Comput., vol. 1, no. 2, Feb. 2006.

[13] T. Camp, J. Boleng, and V. Davies (Aug. 2002), “A survey of mobility models for ad hoc network research,” Wireless Commun. Mobile Comput., vol. 2, no. 5

[14] Hazura Mohamed, Muhammad Hisyam Lee, Mazalan Sarahintu, Shaharuddin Salleh & Bahrom Sanugi “Application of Taguchi’s Design of Experiment in Performance Analysis of Destination Sequenced Distance Vector (DSDV) Routing Protocol in Mobile Ad-hoc Networks,” Sains Malaysiana 38(3), 2009.

[15] Hazura Mohamed, Muhammad Hisyam Lee, Shaharuddin Salleh, Mazalan Sarahintu & Bahrom Sanugi “Taguchi Approach for Performance Evaluation of Routing Protocols in Mobile Ad Hoc Networks,” Journal of Statistical modeling and analytics, vol. 1 No. 2, 2010.

[16] Hazura Mohamed, Muhammad Hisyam Lee, Shaharuddin Salleh, Mazalan Sarahintu & Bahrom Sanugi, “The use of Taguchi method to determine factors affecting the performance of Destination Sequenced Distance Vector routing protocol in mobile Ad-hoc networks.”*Journal of Mathematics & statistics 4, 2008 ISSN, science publications.*

[17] Y.-B. Ko and N. H. Vaidya. “Location-Aided Routing (LAR) in Mobile Ad Hoc Networks,” in Proceedings of the 4th ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), pp. 66–75, Dallas, Texas, October 1998.

[18] Alicia Triviño-Cabrera, Jorge García-de-la-Nava , Eduardo Casilari, Francisco J. González-Cañete “Application of path duration study in multihop ad hoc networks” Telecommunication System DOI 10.1007/s11235-008-9094-0