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Optimum Reliability Analysis of Mobile Adhoc Networks using Universal Generating Function under Limited Delivery Time and Cost

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Abstract: *The emphasis in this paper is on executing the optimum MANET reliability subject to the constraints delivery time and cost. This work is devoted to assess the MANET reliability in a Universal Generating Function (UGF) paradigm. By introducing different composition operators over UGF, the physical happening of the network can be predicted. An algorithm has been proposed to execute the system reliability.*

Keywords: *MANET, Network Reliability, Universal Generating Function, Group Communication Application, Multicasting, delivery time, transmission cost*

1. Summary and Motivation

Network reliability is an important part of planning, designing and controlling network. Designing, developing and testing real applications for ad hoc network environments still deserves particular attention by the MANET research community. A MANET is a dynamic multi-hop wireless network that is established by a group of mobile nodes on a shared wireless channel. Mobile ad hoc networks can be in military use, rescue operations, remote site construction, and communication among a group of islands or ships. The efficiency of the MANET is executed with the parameters reliability, transmission time and cost. This work instantiates an algorithm to obtain the optimum MANET reliability achieved by any of the sub MANET in a dynamic environment. The proposed Algorithm is validated using a numerical example in a battlefield environment.

This work concentrates on calculating the MANET reliability subject to the constraints time and cost using UGFT. The first UGFT was proposed by Ref [1] and was improved by Ref [2] using some simplified techniques. Ref [3,4] extended the UGFT further for general multistate network reliability, which is more practical and reasonable than acyclic multistate networks. UGFT is applied to obtain MANET reliability by Ref [5,6]. The goal of this paper is to find which combination of the sub MANET provides the optimum reliability with minimum cost and delivery time.

2. Mathematical Modeling

The Universal Generating Function Technique is considered as an important tool to evaluate the reliability assessment of a multi-state system. Composition operators are introduced to composite different universal generating functions.

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Definition 2.1 The individual UGF for the source node (S) is denoted by u(S) and is defined as $u(S) = \sum_{N \subseteq \theta_S} P_{S:N} X^N$. Here the exponent N represents the state and the coefficient of X denotes the event probability of the set of nodes ($N \subseteq \theta_S$) that receive information directly from the source node S.

Definition 2.2 The individual UGF for neighbouring nodes denoted by u(n) is defined as a polynomial function of X by $u(n) = \sum_{N \subseteq \theta_n} P_{n:N,T} X^T$ where $P_{n:N,T}$ refers to the probability of sending messages from the node n to a set of nodes N, ($N \subseteq \theta_n$) where they get transmitted within the group (only one time repetition is permitted) and finally reaches the terminal T.

Definition 2.3 The path UGF via node n, denoted by $U(n) = U(S) \otimes u(n), n = 1,2,3,\ldots$.. is the composition of node UGF and its source UGF. It is defined as $U(n) = \sum_{N \subseteq \theta_n} P_{S:n,N,T} X^T$. Here $P_{S:n,N,T}$ denotes the probability of transmitting the received information by the node n from the source S, to the destination node T through the neighbours of node n. For a source node, the node UGF and path UGF are the same that is, U(S) = u(S).

Definition 2.4 Reliability of a sub MANET is defined as the probability of the event that the transformed message received at the sub source from the main source has been passed among the group members (nodes) and reached the sub source again. R_{SM} is obtained from $\sum_{n \subseteq \theta_n} U(n)$. Reliability of the MANET reliability from source node (headquarters) to the target node T is given by $R_M = \sum R_{SMi}$.

The cost and time for a particular transmission is included at the subscript. $u(S) = \sum_{N \subseteq \theta_S} P_{S:N::T} X^T_{(c,t)}$. The first subscript denotes the cost and the latter one denotes the time constraint (sec). The cost and time factors are added consecutively for any information initiated from the source node and transmitted through any path and reached the target successfully.

3. Reliability Calculation Algorithm

Step 1: Define the UGF for each sub source (source) of the available SMs as

$$u(S) = \sum_{N \subseteq \theta_s} P_{S:N} X_{(c,t)}^{N}$$

Step 2: Define the UGF for all neighbouring nodes except the source in each SMs as $u(n) = \sum_{N \subseteq \theta_n} P_{n:N,T} X_{(c,t)}^{N}$

Step3: Obtain the path UGF U (n) as a polynomial in X using the composition operator $U(n) = u(s) \otimes u(n)$.

Step 4: Compute the reliability, the transmission cost and delivery time of SMs. Select the reliable sub MANET with optimum reliability.

4. Numerical Analysis

Forming a fixed wired network is highly impossible in a war zone. The military applications have to respect time constraint in order to update positions of wounded soldiers, get enemy map position or find medical assistance etc. Providing time constrained services can highly benefit the MANET environment. Hence this particular work considers the MANET reliability with time as one of the major constraints.

In order to validate the efficiency of the proposed algorithm an example network given in Figure 1 has been considered. An intelligent team at headquarters has decided to check the efficiency of their three platoons of soldiers. For that they design an assignment which consists of destruction of a terrorist camp with in a fixed time of 10 minutes and fixed budget of $350. They disseminate this information to all the group leaders at a time (multi casting). After getting the information, the group leaders of three platoons will

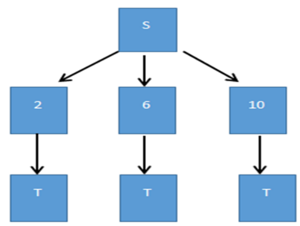

Figure 1 Message transmission in MANET

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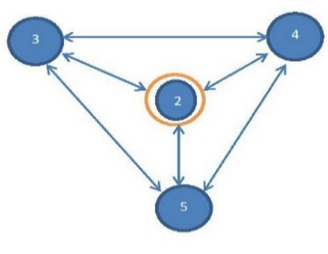

Figure. 2 Sub MANET 2

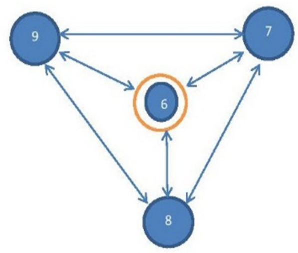

Figure 3 Sub MANET 3

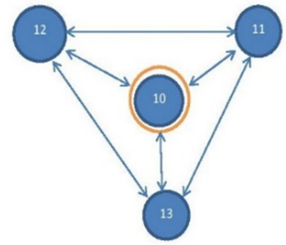

Figure 4 Sub MANET 3

pass it to their group members and destroy the target within the fixed cost and stipulated time. The MANET environment of this scenario is expounded in Figure 1 In that, S stands for the headquarters and T represents the target [terrorist camp] and the intermediate nodes 2,6 and 10 denote the group leaders (sub sources). Each sub source together with some participating nodes can be treated as sub MANETs (Shown in Figures 2 to 4). For the numerical analysis, the working states, state dependent probabilities, delivery cost and delivery time of various sub MANETs are considered from the table 2

Table 2: Sub MANET numerical data

Groups	Working States	SDP	Delivery Cost ($)	Delivery Time (sec)
I	2-3	0.09	0.50	1.0
	2-4	0.05	1.00	2.0
	2-5	0.20	0.75	1.0
	3-4	0.40	1.00	2.5
	3-5	0.06	0.50	1.0
	4-5	0.70	1.00	1.0
II	6-7	0.30	0.5	1.0
	6-8	0.10	0.5	0.5
	6-9	0.05	0.5	2.0
	7-8	0.04	1.0	2.0
	7-9	0.02	2.0	2.0
	8-9	0.07	0.5	1.0
III	10-11	0.20	0.25	0.5
	10-12	0.40	1.00	1.0
	10-13	0.05	0.50	1.0
	11-12	0.10	1.00	1.0
	11-13	0.06	0.25	2.5
	12-13	0.07	0.25	1.5
Source	H-2,6,10	1	0.5	0.05
Target	T-2,6,10	1	0.5	0.05

4.1 Reliability Calculation for Sub MANET 1

The node UGF for source node 2 of SM 1 is obtained by considering all possible member nodes that receives information directly from it. The node UGF for nodes 3,4 and 5 defined by considering all chances of transmitting messages via them to reach the target.

Step 1: The UGF for SM 1 is defined as $U(i) = U(S) \otimes u(i)$ here $S = 2; i = 3,4,5$
Step 2: The node UGF for sub source and neighbouring nodes with the corresponding time and cost can be obtained as follows:

$$u(2) = U(2) = P_{2:3}X^{3}_{(0.5,1)} + P_{2:4}X^{4}_{(1,2)} + P_{2:5}X^{5}_{(0.75,1)} + P_{2:\{3,4\}}X^{\{3,4\}}_{(1.5,3)} + P_{2:\{3,5\}}X^{\{3,5\}}_{(1.25,2)} + P_{2:\{4,5\}}X^{\{4,5\}}_{(1.75,3)} + P_{2:\{3,4,5\}}X^{\{3,4,5\}}_{(2.25,4)}$$

$$u(3) = P_{3:2}X^{2}_{(0.5,1)} + P_{3:4,2}X^{2}_{(2,4.5)} + P_{3:5,2}X^{2}_{(1.25,2)} + P_{3:4,3,2}X^{2}_{(2.5,6)} + P_{3:4,5,2}X^{2}_{(2.75,4.5)} + P_{3:5,4,2}X^{2}_{(2.5,4)} + P_{3:\{4,5\}::\{\varphi,2\}}X^{2}_{(2.25,4.5)} + P_{3:\{4,5\}::\{2,\varphi\}}X^{2}_{(2.5,4)} + P_{3:\{4,5\}::\{2,2\}}X^{2}_{(3.25,6.5)} + P_{3:5,3,2}X^{2}_{(1.5,3)}.$$

$$u(4) = P_{4:2}X^{2}_{(1,2)} + P_{4:3,2}X^{2}_{(1.5,3.5)} + P_{4:5,2}X^{2}_{(1.75,2)} + P_{4:3,4,2}X^{2}_{(3,7)} + P_{4:3,5,2}X^{2}_{(2.25,4.5)} + P_{4:5,3,2}X^{2}_{(2,3)} + P_{4:\{3,5\}::\{\varphi,2\}}X^{2}_{(2.75,4.5)} + P_{4:\{3,5\}::\{2,\varphi\}}X^{2}_{(2.5,4.5)} + P_{4:\{3,5\}::\{2,2\}}X^{2}_{(3.25,5.5)} + P_{4:5,4,2}X^{2}_{(3,4)}.$$

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$$u(5)=P_{5:2}X^{2}_{(0.75,1)}+P_{5:3,2}X^{2}_{(1,1)}+P_{5:4,2}X^{2}_{(2,3)}+P_{5:3,5,2}X^{2}_{(1.75,3)}+P_{5:3,4,2}X^{2}_{(2.5,5.5)}+P_{5:\{3,4\}::\{2,\varphi\}}X^{2}_{(2,3)}+$$
$$P_{5:\{3,4\}::\{\varphi,2\}}X^{2}_{(2.5,4)}+P_{5:\{3,4\}::\{2,2\}}X^{2}_{(3,5)}+P_{5:4,5,2.}X^{2}_{(2.75,3)}+P_{5:4,3,2}X^{2}_{(2.5,4.5)}$$

Considering all possible communications (which includes transmission of messages from 2 to 3, {3,4}, {3,5}, {3,4,5}) and reaches again 2, the path UGF for SM 1 is calculated.

Step 3: The path UGF is obtained by introducing the composition operator over the node UGF. For example U(3) = U(S) ⊗u(3) =

$$U(2)\otimes u(3) = \sum_{N\subseteq\theta_3} P_{2:3,N,2}\ X^{2}_{(c,t)}$$

$$=[P_{2:3X}{}^{3}_{(0.5,1)}+P_{2:4}X^{4}_{(1,2)}+P_{2:5}X^{5}_{(0.75,1)}+P_{2:\{3,4\}}X^{\{3,4\}}_{(1.5,3)}+P_{2:\{3,5\}}X^{\{3,5\}}_{(1.25,2)}+P_{2:\{4,5\}}X^{\{4,5\}}_{(1.75,3)}+$$
$$P_{2:\{3,4,5\}}X^{\{3,4,5\}}_{(2.25,4)}]\otimes[P_{3:2}X^{2}_{(0.5,1)}+P_{3:4,2}X^{2}_{(2,4.5)}+P_{3:5,2}X^{2}_{(1.25,2)}+P_{3:4,3,2}X^{2}_{(2.5,6)}+$$
$$P_{3:4,5,2}X^{2}_{(2.75,4.5)}+P_{3:5,4,2}X^{2}_{(2.5,4)}+P_{3:\{4,5\}::\{\varphi,2\}}X^{2}_{(2.25,4.5)}+P_{3:\{4,5\}::\{2,\varphi\}}X^{2}_{(2.5,4)}+$$
$$P_{3:\{4,5\}::\{2,2\}}X^{2}_{(3.25,6.5)}+P_{3:5,3,2}X^{2}_{(1.5,3)}]$$

$$U(3)=4[P_{2:3,2}+P_{2:3,4,2}+P_{2:3,5,2}+P_{2:3,4,3,2}+P_{2:3,4,5,2}+P_{2:3,5,4,2}+P_{2:3,\{4,5\}::\{\varphi,2\}}+P_{2:3,\{4,5\}::\{2,\varphi\}}+$$
$$P_{2:3:\{4,5\}::\{2,2\}}+P_{2:3,5,3,2}]X^{2}_{(98,192)}$$

By continuing the same procedure, U(4) and U(5) are given by U(4) = U(2)⊗u(4) and U(5) = U(2)⊗u(5),

$$U(4)=4[P_{2:4,2}+P_{2:4,3,2}+P_{2:4,5,2}+P_{2:4,3,4,2}+P_{2:4,3,5,2}+P_{2:4,5,3,2}+P_{2:4,\{3,5\}::\{\varphi,2\}}+P_{2:4,\{3,5\}::\{2,\varphi\}}+$$
$$P_{2:4,\{3,5\}::\{2,2\}}+P_{2:4,5,4,2}]X^{2}_{(128,226)}$$

$$U(5)=4[P_{2:5,2}+P_{2:5,4,2}+P_{2:5,3,2}+P_{2:5,4,5,2}+P_{2:5,4,3,2}+P_{2:5,3,4,2}+P_{2:5,\{4,3\}::\{\varphi,2\}}+P_{2:5,\{4,3\}::\{2,\varphi\}}+$$
$$P_{2:5,\{4,3\}::\{2,2\}}+P_{2:5,3,5,2}]X^{2}_{(147,168)}$$

The probability, transmission cost and time for the successful transition of message via nodes 3, 4 and 5 of SM 1 are calculated as follows:

Via node 3, TP = 4[0.0206982] = 0.0827928 Cost = 98$ Time = 4[48] =192 sec

Via node 4, the TP **= 0.089624**, Cost = 128$, Time = 226 sec

Via node 5, the TP = 0.3248872, Cost = 4[36.75] =147 $, Time =168 sec.

Considering all the possible TP's via nodes 3,4 and 5, the reliability of SM 1 is obtained as 0.497304, with a transmission cost of 373 $ and transmission time of 9.7 mins.

4.2 Reliability Calculation for Sub MANET 2

For sub MANET 2, the path UGF is defined as U(i)=U(S) ⊗u(i) here S = 6,i = 7,8,9

$$u(6)=U(6)=P_{6:7}X^{7}_{(0.5,1)}+P_{6:8}X^{8}_{(0.5,0.5)}+P_{6:9}X^{9}_{(0.5,2)}+P_{6:\{7,8\}}X^{7,8}_{(1,1.5)}+P_{6:\{7,9\}}X^{7,9}_{(1,3)}+P_{6:\{8,9\}}X^{8,9}_{(1,2.5)}+P_{6:\{7,8,9\}}X^{7,8,9}_{(1.5,3.5)}$$

$$U(7)=U(6)\otimes u(7)=4[P_{6:7,6}+P_{6:7,8,6}+P_{6:7,9,6}+P_{6:7,8,7,6}+P_{6:7,8,9,6}+P_{6:7,9,8,6}+P_{6:7,\{8,9\}::\{\varphi,6\}}+P_{6:7,\{8,9\}::\{6,\varphi\}}+$$
$$P_{6:7,\{8,9\}::\{6,6\}}+P_{6:7,9,7,6}]X^{6}_{(106,196)}$$

$$U(8)=4[P_{6:8,6}+P_{6:8,7,6}+P_{6:8,9,6}+P_{6:,8,7,8}+P_{6:8,7,9,6}+P_{6:8,9,7,6}+P_{6:8,\{7,9\}::\{\varphi,6\}}+P_{6:8,\{7,9\}::\{6,\varphi\}}+P_{6:8,\{7,9\}::\{6,6\}}+P_{6:8,9,8,6}]X^{6}_{(72,162)}$$

$$U(9)=4[P_{6:9,6}+P_{6:9,8,6}+P_{6:9,7,6}+P_{6:9,8,9,6}+P_{6:9,8,7,6}+P_{6:9,7,8,6}+P_{6:9,\{8,7\}::\{\varphi,6\}}+P_{6:9,\{8,7\}::\{6,\varphi\}}+P_{6:9,\{8,7\}::\{6,6\}}+P_{6:9,7,9,6}]X^{6}_{(104,216)}$$

4.3 Reliability Calculation for Sub MANET 3

The path UGF for sub MANET 3 is defined as U(i) = U(S) ⊗ u(i) here S = 10, i= 11,12,13

$$u(10)=U(10)=P_{10:11}X^{11}_{(0.25,1)}\ P_{10:12}X^{12}_{(1,1)}+P_{10:13}X^{13}_{(0.5,1)}+P_{10:\{11,12\}}X^{11,12}_{(1.25,2)}+P_{10:\{11,13\}}X^{11,13}_{(0.75,2)}+$$
$$P_{10:\{12,13\}}X^{12,13}_{(1.5,2)}+P_{10:\{11,12,13\}}X^{11,12,13}_{(1.75,3)}$$

$$U(11)=U(10)\otimes u(11)=4[P_{10:11,10}+P_{10:11,12,10}+P_{10:11,13,10}+P_{10:11,12,11,10}+P_{10:11,12,13,10}+P_{10:11,13,12,10}+$$
$$P_{10:11:\{12,13\}::\{\varphi,10\}}+P_{10:11:\{12,13\}::\{10,\varphi\}}+P_{10:11:\{12,13\}::\{10,10\}}+P_{10:11,13,11,10\}}]X^{10}_{(69,154)}$$

$$U(12)=4[P_{10:12,10}+P_{10:12,11,10}+P_{10:12,13,10}+P_{10:11,12,11,10}+P_{10:12,11,13,10}+P_{10:12,13,11,10}+$$
$$P_{10:12:\{11,13\}::\{\varphi,10\}}+P_{10:12:\{11,13\}::\{10,\varphi\}}+P_{10:12:\{11,13\}::\{10,10\}}+P_{10:12,13,12,10\}}]X^{10}_{(88,154)}$$

$$U(13)=4[P_{10:13,10}+P_{10:13,12,10}+P_{10:13,11,10}+P_{10:13,12,13,10}+P_{10:13,12,11,10}+P_{10:13,11,12,10}+$$

$P_{10:13:\{12,11\}::\{\varphi,10\}} + P_{10:13:\{12,11\}::\{10,\varphi\}} + P_{10:13:\{12,11\}::\{10,10\}} + P_{10:13,11,13,10\}}]X^{10}_{(66,180)}$

The reliability of nodes and Sub MANETs are listed in table 3.

Table 3: Reliability for nodes and sub MANETs

Node	Reliability	Cost($)	Time (sec)
3	0.0827928	98	192
4	0.089624	128	226
5	0.3248872	147	168
$R_{SM\,1} = P_{S:2:T}X^{2}_{(0.5,0.05)}$	0.497304	373	586 = 9.7 mins
7	0.38736	106	196
8	0.05367	72	162
9	0.14385	104	216
$R_{SM\,2} = P_{S:6:T}X^{6}_{(0.5,0.05)}$	0.455415	282	574 = 9.6 mins
11	0.2302	69	154
12	0.726	88	154
13	0.0264	66	180
$R_{SM\,3} = P_{S:10:T}X^{10}_{(0.5,0.05)}$	0.9826	223	488 = 8 mins

The UGF for the source node in terms of the heads of the SMs are given by

$u(S)=U(S) = P_{S:2,T}\, X^{T}_{(0.1,0.01)}$, $u(S)=U(S) = P_{S:6,T}\, X^{T}_{(0.1,0.01)}$ and $u(S)=U(S) = P_{S:10,T}\, X^{T}_{(0.1,0.01)}$

By assuming the SDP of transferring message from source node S to heads of SMs and from SM's heads to target (T) as 1, the performance measure of the system through the SM's are given by $P_{S:2,T}$, $P_{S:6,T}$ and $P_{S:10,T}$ respectively and the obtained values are given in table 4.

Table 4: Performance via sub MANETs

Sub MANETS	**Reliability**	**Cost**	**Time (min)**
1	0.497304	374	9.8
2	0.455415	283	9.7
3	0.9826	224	8.1

From the table 3.4, it is clear that out of the three platoons; the third one is highly reliable compared with the other two. Also the time and cost factor is advantageous for third one. For the first group, the total cost has crossed the limit. Hence the optimum reliability of the MANET is 0.9826. This reliability is achieved with in the budget of $224 and the delivery time of 8.1 mins.

5 Discussions and Conclusion

Reliability is used as the performance measure for various networks. Due to the dynamic nature of nodes, MANETs do not have any fixed infrastructure. Hence the traditional methods will not be successful to obtain the reliability of MANETs. To overcome these kinds of situations, UGFT has been considered to achieve the reliability of a MANET. The suggested technique allows one to obtain the probability that the information gathered at the source node of a MANET reaches the target node though any of the sub MANETS within a fixed cost and stipulated time. As a future focus, this UGFT may be applied to a heterogeneous sensor networks.

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