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Using QPN to Model a New Routing in DTN

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***Abstract* – In order to better understand the characteristics of a new routing method, modeling of this routing method would be a good way. We have expressed the basic method in [3] for using QPN to model the routing protocol in DTNs. And, we have proposed the equivalent method in [11] for using QPN to express a new routing method under RWP mobility in DTNs. Now, we extend these studies to model the new routing method, named as "OOPFE routing" and designed by us at last years.**

In this work, not only to better understand the characteristics of the new routing method but also to get an interesting example for research the characteristics of QPN. Because QPN is a strong modeling tool for using in the performance testing of the new system begin or the new system established. This paper is a good example for using QPN to analyze new problems.

We will divide into two parts to discuss the OOPFE. The first part is that we consider no any neighbor node in “One broadcast” process of OOPFE and transfer from simple Markov state diagram to a QPN figure. The second part is that we consider the numbers of neighbor nodes in “One broadcast” process of OOPFE and transform to QPN figure.

***Keywords* – DTN, Routing, Queueing Petri Network, Inter Meeting Time, Contact Time, OOPFE, NS2.**

I. Introduction

In our previous routing studies [4], we have designed a new routing scheme to combine the advantages of multi-copy and single copy, called OOP-routing in delay tolerant mobile ad hoc networks. There are 3 main steps to process the message. The full name of OOP is OB (One Broadcast), OC (One Copy) and PS (Persistent Storage). Later, we further improve to become the OOPFE routing in [12], the new routing method suitable for the size of network scenarios is bigger or the speed of source node is slower.

In this year, we have proposed the equivalent method in [11] for using QPN to express a new routing method under RWP mobility in DTNs. So, we can choose the easier way to model.

Now, we want to use QPN to model the OOPFE routing in DTNs.

II. Related Works

There are many related analysis or application have been proposed for using PNs in Ad hoc. For instance, [9] uses PNs to model and analyze different data management schemes in sensor data storage. In [1], uses CPNs to address the problem of mobility in MANETs AODV Protocols.

In [2] uses PNs to discuss the approach of simulation and analysis in Ad Hoc network. In [7], the paper uses the tools of CPN to discuss the AODV and DSR routing. In [15], the paper uses the CPN to create a modified version of AODV routing to discuss the security for routing packets in MANETs. In [6], the paper uses CPNs to establish the AOMDV (Ad Hoc On demand Multipath Distance Vector routing) and the DSR for performance comparison in MANET.

The random waypoint mobility model (RWP, Random Waypoint) [13], is a free mobile ad hoc network (MANET), the most popular mobile mobility and most commonly be used by other routing protocols. It works as a benchmark by a new routing method. There are two important parameters in the RWP-mobility. The first parameter, IMT, has been discussed in [8], and the second parameter, CT, has been discussed in [5]. In [14], there is a very good discussion of model DTN routing.

In paper [3] is our paper to propose the basic ways for using QPN to model the routing method under RWP-mobility in DTNs. In paper [11], we have used the features of exponential distribution and have proposed the equivalent method for using QPN to express a new routing method under RWP mobility in DTNs.

III. First Case, We Consider No Any Neighbor Node in “One Broadcast” Process

In “One Broadcast” process of OOPFE routing, due to the distribution of nodes are too sparse, only very little or no neighbor node directly adjacent to the node. So, the simulation can be simplified and can be easier to understand.

Therefore, this section we consider no any neighbor node in “One Broadcast” process. Next section, we consider there are some neighbor nodes in “One Broadcast” process.

A. The basic Markov state transition diagram for OOPFE routing.

If there is not any neighbor node in the “One Broadcast” process of OOPFE routing, the simplify version of OOPFE is same as 2Hop routing.

Because the main difference between the two routings is the role replacement, we can say that: 2Hop is like a man finish 400 meters race. But, the OOPFE is like four people in the run 400 meters relay, everyone ran only 100 meters.

As shown in Figure 1 from our previous paper [11], it is a Markov chain transition diagram for 2Hop-Routing in exponential distribution of intensity λ. From this figure, we can calculate the delay time from the source node to the destination node.

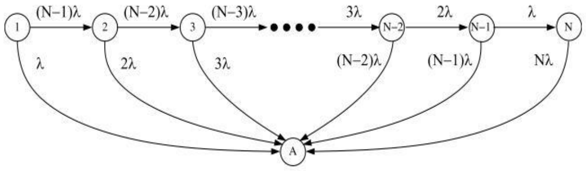

Fig.1. Two-hop multi-copy protocol transition diagram of the Markov chain for the number of copies.

In that figure, when the number of the circle is 1, which means that the source node meets other node, excluding destination node and the probability is (n-1) λ. In this condition, the 2Hop and the OOPFE are same.

The number of the circle is 2, which means that the difference between the OOPFE and the 2Hop are only one. That is change role. The source node will transform the right of copy to the first encounter node. So, the next node will obey the probability is (n-2) λ to encounter the third node, but the 2Hop will still the source node obey the same probability to encounter the third node.

Refer Figure 2; the number in circle indicates the amount of replication message has been completed. We start with a source node to know this information, so the QPME is start with a number one inside the circle. And after the average inter-meeting time, that is 1/ (λ). We can expect the source node will encounter the destination node "A". After i times copy, we use a circle contains the number i to represent. So, these i nodes can meet the node A after the time is 1/(iλ).

And the node, finally get the baton, it is also possible in 1/(N-i) λ, the average time encounter other (N-i) one does not know the message node. Once (i+1) nodes know the message, the average time to meet the destination node will be reduced to 1/((i +1) λ). Finally in addition to the destination node N nodes outside all know this message, we can expect in the time (1/Nλ) to encounter the destination node.

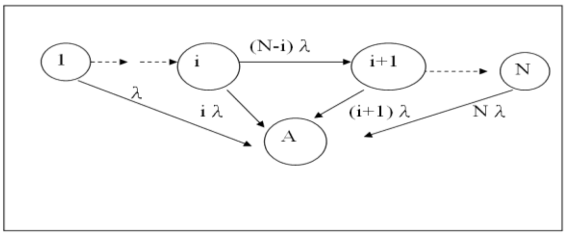

Fig.2. The Markov chain transition diagram and omit "One broadcast" process in OOPFE routing.

Although the OOPFE and the 2Hop applicable to different scenarios. However, according to Markov chain transition diagram view, the OOPFE and the 2Hop will get the same QPN.

Thus, repeated explanation is omitted. We can directly used the QPN of 2Hop to the OOPFE routing and we don't consider the "One broadcast" process.

B. The method to transfer the Markov state transition diagram into QPN for Latency

To model the Latency of OOPFE, we will transfer then basically Markov state transition diagram into QPN. In order to facilitate discussion and quickly to create model, we first omit the "One Broadcast" process and stay this discuss in later chapters. Now, only focus on the "One-Copy" process in OOPFE.

From Figure 2, the Markov state transition diagram can be converted to the simulation of 2hop. There are other methods to express. Now we present another interesting approach and show in Figure 3 (a) and Figure 3 (b). These Figures are also to model 2hop routing and completely equivalent results. We can compare the difference with earlier discuss in our paper [11].

In this case N = 2 +1, we set the parameter, in Imt1 set 1λ, in Imt2 set 2λ. And we should add a new place, named as "minSbuf1 place", to check while one is the first out between "Imt1 place" and "Subf2 place". And, the first out token must close another exit. For example: "closeSubf2 place" will close the slower "Sbuf2 place", and the "closeImt1 place" will close the slower "Imt1 place".

In the preceding Figure, about the token choice, why we choose only the arrival time of the token with the faster one? The reason is that, in the original state diagram, we can select the minimum value of Petri Net diagram the express the probability.

For example: if there are two Queueing places in QPN, the first λ = 1/10, another λ = 1/5. In other words, the first place, expect 10 seconds per token, the second place, desired 5 seconds per token. So, after 15 seconds, the average numbers of randomly generated token are 5. Also, the exports of these two places, the probability which has some token are "10:5". So, how express the probability in the QPN? In order to find the first time to encounter the destination node, so if there are two or more states, we only care about the first arrival time.

So, we add the minimum concept in QPME design. In the preceding example to illustrate that, we set a minimum mechanism at the entrance of two Queuing place, the λ = 1/10 and λ = 1/5. We look at the export of these two Queueing place, then, the first appear the token is the smallest Latency. And the place λ = 1/5, there will be the minimum value on the probability of about 10/(10 +5).

Refer to Figure 3 (a) is another method to represents the Petri Net of 2hop routing. If N = 2 +1. And, we set the parameter of "Imt1" is 1λ and "Imt2" is 2λ. We must add "minSbuf1-place". Compare the token in "Imt1"and the token in "Sbuf2", which token will be faster to run out. The faster token will be able to grab the token in "minSbuf1" and close slow token in another place. For example: the token in "closeSbuf2" can close the slower token in "Sbuf2". On the contrary, the token in "closeImt1" can close the slower token in "Imt1".

Similarly, in Figure 3 (b), shows another Petri Net to represent the 2hop and still completely equivalent expression. The N = 3 +1. And Imt1, Imt2, Imt3 set 1λ, 2λ, 3λ. We must add "minSbuf2-place" to compare the token in "Imt1" and the token in "Sbuf2". Similarly: for comparing the token in "Imt2" and the token in "Sbuf3", we must add three new places: minSbuf2, closeSbuf3, closeImt2.

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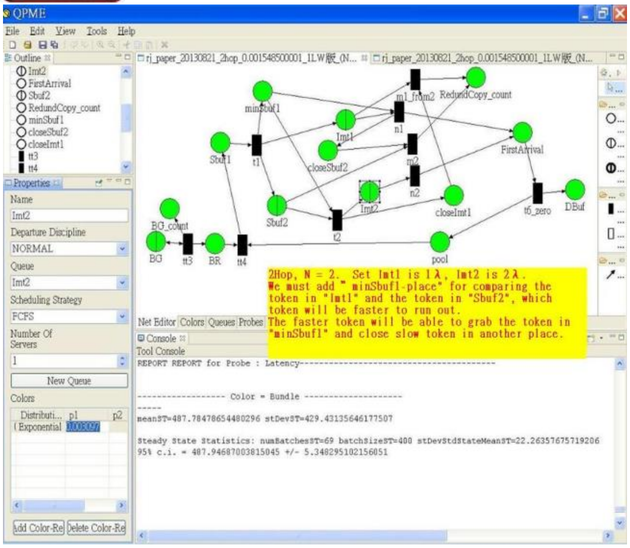

Fig.3(a). Another equivalent Petri Net expression for 2Hop. The N = 2 +1. And Imt1, Imt2 set 1λ, 2λ, 3λ.

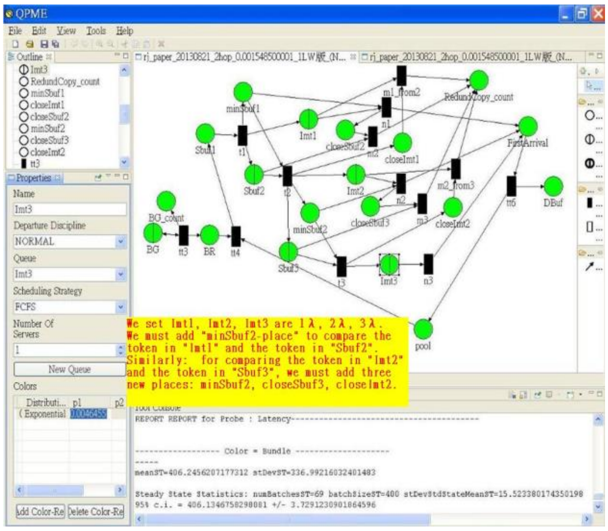

Fig.3(b). Another equivalent Petri Net expression for 2Hop. N =3 +1. And Imt1, Imt2, Imt3 set 1λ, 2λ, 3λ.

From Figure 3(a), 3(b), and previous result in paper [11], the Latency is 409.76 +/- 3.49 and the Latency is 406.13 +/- 3.73 in figure 3(b). We can find the value is more then 95% confidence interval and we get two equivalent methods to model the routing.

C. The method to simulate the Delivery ratio in QPN

After we add the new information that is message survival time (msgTTL, Time to Live of message), we can simulate the Delivery ratio. In Figure 4 (a), Figure 4 (b), Figure 4 (c), represents 2Hop, N = 2 +1, Imt1 set to 1λ and Imt2 set to 2λ. We set the msgTTL is double the average inter-meeting time. So we get the value is 484*2=968. The result of latency downs from 484.78 to 360.75. Delivery ratio and detailed figures refer to the table I.

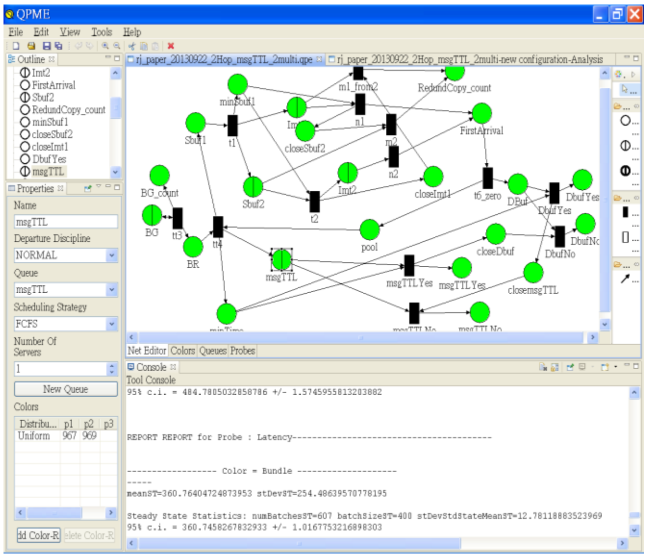

Fig.4(a) Using QPME to express the Delivery ratio for 2Hop routing. The value of msgTTL sets to twice of the average inter-meeting times. It is 968. The results of Latency fell to 358.56 from 482.24

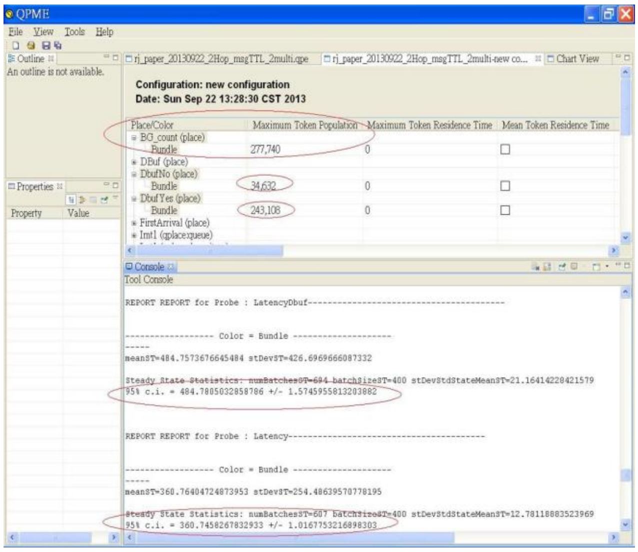

Fig.4(b): Using QPME to express the Delivery ratio for 2Hop routing. The results of Delivery ratio fell to 0.87.

Table I: Compare the Latency and Delivery Ratio changes between the msgTTL are twice of IMT or 2000 for 2Hop routing. (N=2+1, at this time, Epidemic and 2hop are same.)

msgTTL	2000 (95% c.i.)	Twice of IMT (95% c.i)
Latency	484.324424235395 +/- 1.63313448842283 ➔ 467.9316018573138 +/- 1.573258328262505	484.7805032858786 +/- 1.5745955843203882 ➔ 360.7458267832933 +/- 1.0167753216898303
Delivery Ratio	275,347/277,740 = 0.991384 = 99.13%	243,108/277,740 =87.53%

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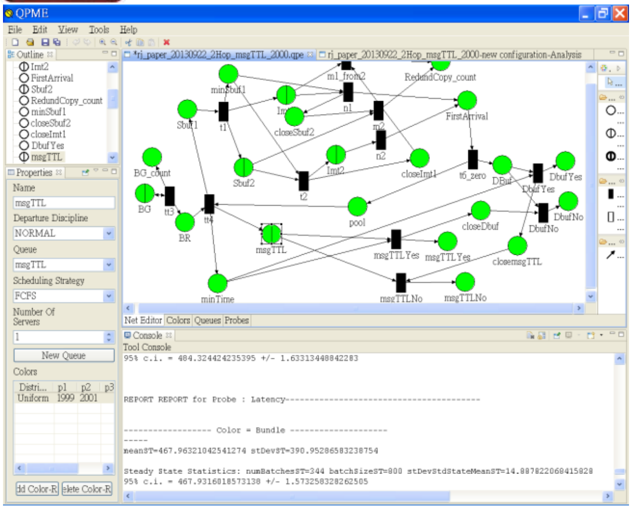

Fig.4(c): Using QPME to express the Delivery ratio for 2Hop routing. The value of msgTTL sets to 2000 sec. The results of Latency fell to 0.9913.

We use a simple text files to go into a little more detail about the preview results and show in Table II. The values of msgTTL of 2Hop routing are 2*484.3 and 2000. We observe the changes about the Delivery ratio and Latency.

In Figure 5 (a), Figure 5(b) and table III indicates the Direct-routing in the similar condition.

Table II： Observe the changes of Latency and Delivery ratio for the values of msgTTL is 2*484.3 and 2000 in 2Hop routing. (Note: the distribution of msgTTLis Uniform)

####################################
msgTTL is (2*484)
REPORT REPORT for Probe : LatencyDbuf-------------
meanST=483.6752455031011
stDevST=426.27271207336753
Steady State Statistics: numBatchesST=694 batchSizeST=400
stDevStdStateMeanST=21.78913963253408
95% c.i. = 483.6906634478864 +/- 1.621094893684816

REPORT REPORT for Probe :Latency-----------
meanST=360.74190897035413
stDevST=254.70037290186679
Steady State Statistics: numBatchesST=608 batchSizeST=400
stDevStdStateMeanST=12.429902772962917
95% c.i. = 360.72861945352014 +/- 0.9880161258883764

Maximum Token Population for Color Bundle

DbufYes (place): 243,468
BG_count (place): 277,740
DbufNo (place): 34,272

#######################################
msgTTL is 2000
REPORT REPORT for Probe : LatencyDbuf--------------
meanST=483.766831012045
stDevST=427.20858262133197
Steady State Statistics: numBatchesST=347 batchSizeST=800
stDevStdStateMeanST=14.637138109515963
95% c.i. = 483.7819987514709 +/- 1.5400666781164416

REPORT REPORT for Probe : Latency------------------
meanST=468.29297854250626
stDevST=391.98804823779017
Steady State Statistics: numBatchesST=344 batchSizeST=800
stDevStdStateMeanST=13.285346536317743
95% c.i. = 468.3049132258417 +/- 1.4039180469826342

Maximum Token Population for Color Bundle

DbufYes (place): 275,469
BG_count (place): 277,740
DbufNo (place): 2,271

Table III: Observe the changes of Latency and Delivery ratio for the values of msgTTL is 2*484.3 and 2000 in Direct-routing.

##
msgTTL is (twice of IMT)=2*484.33968356474= 968.6794
Direct msgTTL=968 sec (Uniform) Latency
REPORT REPORT for Probe : LatencyDbuf-----------
meanST=646.0621833758948
stDevST=645.1763418192512
Steady State Statistics: numBatchesST=694 batchSizeST=400
stDevStdStateMeanST=31.665574611396178
95% c.i. = 646.099867012842 +/- 2.3558939074162915

REPORT REPORT for Probe : Latency----------------
meanST=367.2672470421711
stDevST=264.9423633094522
Steady State Statistics: numBatchesST=269 batchSizeST=800
stDevStdStateMeanST=8.503917066385597
95% c.i. = 367.2841551291767 +/- 1.0162275562077803
Maximum Token Population---------------------------------------
--
DbufYes (place): 215,550
BG_count (place): 277,740
DbufNo (place): 62,190

###
msgTTL=2000sec (Uniform)Latency
REPORT REPORT for Probe : LatencyDbuf-----------------
meanST=644.757136642213
stDevST=646.2910477433467
Steady State Statistics: numBatchesST=694 batchSizeST=400

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stDevStdStateMeanST=31.52289169134141
95% c.i. = 644.7303590084815 +/- 2.3452784101081074

REPORT REPORT for Probe : Latency-------------------
meanST=550.5494212417057
stDevST=468.80930087286333
Steady State Statistics: numBatchesST=331 batchSizeST=800
stDevStdStateMeanST=15.489875939167664
95% c.i. = 550.5197573002856 +/- 1.6687144765101438

Maximum Token Population for Color Bundle

DbufYes (place): 265,272
BG_count (place): 277,740
DbufNo (place): 12,468

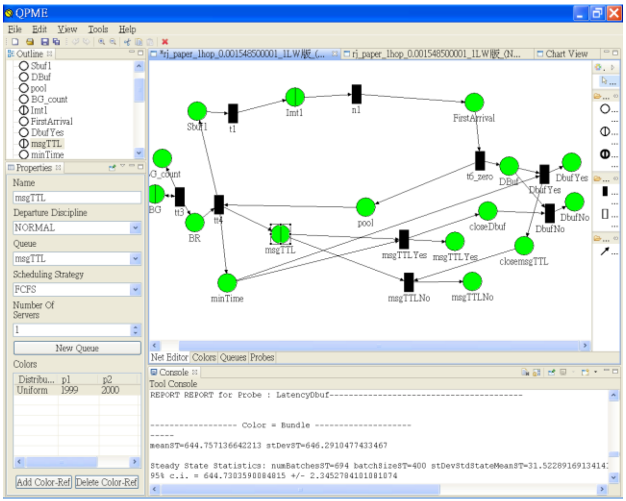

Fig.5(a): Using QPME to express the Delivery ratio for Direct-routing. The value of msgTTL sets to 2000.

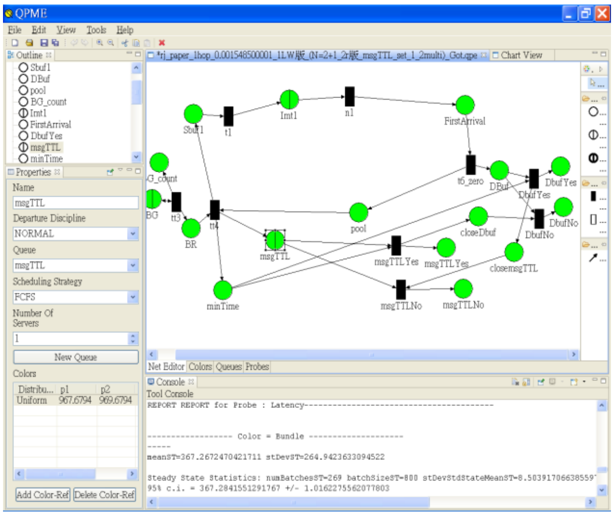

Fig.5(b): Using QPME to express the Delivery ratio for Direct-routing. The value of msgTTL sets to twice of IMT.

IV. Second Case, We Consider the Numbers of Neighbor Nodes in "One Broadcast" Process

Although the scenario is sparse and the numbers of neighbor nodes is less in the "One broadcast" process of OOPFE routing, we still consider these conditions. We assume the average numbers of neighbor nodes will receive this broadcast are m.

Compare with the previous simulation, there are some changes in this section. This section will consider the numbers of neighbor nodes is m.

A. The basic Markov state transition diagram for OOPFE routing.

AT the "One broadcast" process of OOPFE routing, we assume the average numbers of neighbor nodes will receive this broadcast are m.

We know that the numbers of neighbor nodes are related to the change of topology. In our experiments, when the transmission distance is 40 meters, the average of neighbor nodes is 0.25. Represents that, after "One broadcast" process, the average numbers of copy is 1+ 0.25 = 1.25. Therefore, the number of nodes is less than 1, and the numbers of copy is (1 + m).

We can simply divide into two cases. The first case: the probability is (1-m), still only a source node is in the scenario. The second case: the probability is m; there are two source nodes in the scenario. We can get the expect amount of copy are 1 * (1-m) +2 * (m) = 1 + m, 0.75 * 1 0.25 * 2 = 1.25. This is same as the average number of copy, so we can use this simple idea to model the routing. Figure 2 in the previous section, which means that the numbers of neighbor nodes in "One broadcast" process is zero. Now, we corrected to Figure 6. In the upper half of Figure 6, this is same as Figure 2. Meant that, there is no neighbor node. In the lower half of Figure 6, this is another case, means that there is an average of m neighbor nodes.

The upper half of the Figure, we have discussed before, so we only discuss the lower half of the Figure. There will increase one node to work as source node after "One broadcast" process.

So, a start message into the system, in the circle is marked number 1. After "One broadcast" process, There is a probability m, we can see two source nodes in the scenario.

Therefore, we mark circle with number 2 to represent that there are 2 source nodes. There are two possibilities, first case: any two nodes to encounter the destination node, the average time are 1 / (2λ). The second case: these two nodes encounter other (N-2) nodes which unknown this message, so the average time is 1 / ((N-2) * (2λ)). When the node encounters a new node, there is a role change for increasing the opportunity to pass the message out in OOPFE routing. Remained only two nodes can be copied to the node that still unknown this message.

If there are I nodes knows this message, we can split into two cases. The first case: any node i encounters the destination node, the average time is 1 / (iλ). The second

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case: the last two nodes encounter other (N-i) nodes which unknown this message, the average time is 1 / ((Ni) * (2λ)).

Repeat above process until the destination node is encountered.

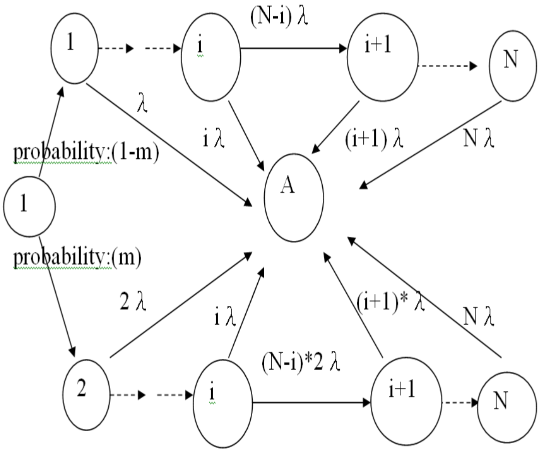

Fig.6. The Markov chain transition diagram and consider "One broadcast" process in OOPFE routing. The number of m in this figure is neighbor's nodes; the range is from 0 to 1.

B. The method to transfer the Markov state transition diagram of OOPFE routing into QPN for Latency

Refer to the previous section, we have discussed the method to transform Markov state transition diagram with QPN. Now, we will transform the previous Markov state transition diagram to QPN and model the OOPFE routing. Then, we use QPME to model the OOPFE routing and show in Figure 7. The related parameter settings and the results are presented in table IV. We assume the number of neighbors is 0.25 in this experiment. We compare these experimental results with the previous 2hop routing, the Latency of 2Hop is 406.60 and the Latency of OOPFE is 373.58.

The results show that if we can increase the neighbor nodes in "One broadcast" process, that will reduces the Latency time

Table IV：OOPFE routing, N=3+1, observe the Latency

The value of parameters: λ=0.0015485 N=3+1，The numbers of neighbor node, m=0.25 Firing Weight in S1=0.75 Firing Weight in S2=0.25 Imt1p=2λ Sbuf2p=(3-2)*2λ=2λ Imt2p=1λ BG=Uniform 36000~36010 The results: REPORT REPORT for Probe : Latency-------- meanST=373.54189464687147 stDevST=321.2321899412766 Steady State Statistics: numBatchesST=69 batchSizeST=400 stDevStdStateMeanST=14.830117152968835 95% c.i. = 373.58955803770846 +/- 3.5625831284275264 Maximum Token Population for Color Bundle -- RedundCopy_countp (place): 6,948 BG_count (place): 27,774 RedundCopy_count (place): 41,652 DBuf (place): 27,774

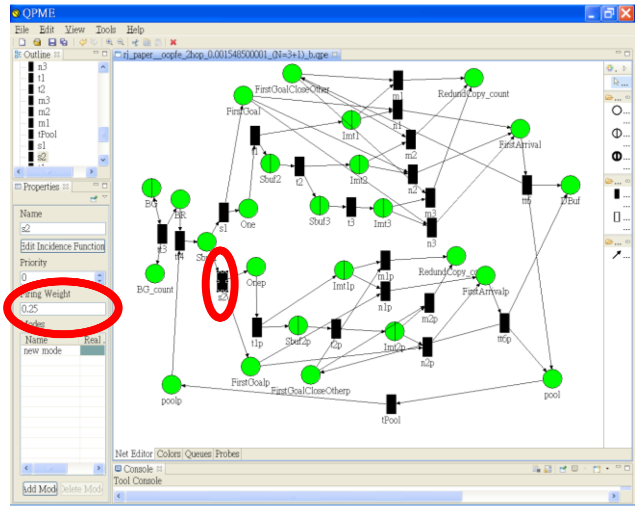

Fig.7. OOPFE Routing. Using QPME to observe the Latency in OOPFE routing

V. Conclusion and Future Works

We know the QPN simulation tool is very strong tools and can do more to further the effectiveness analysis. This is an interesting tool and we should continue to study in the future.

In this paper, we extend our preview research and create a series of simulation experiments. And, Using the SimQPN [10] tool with QPME tools, we can establish the available experimental QPN to explain our results.

Through QPN the model, we can quickly get the desired results, and we can focus the importance metrics for detailed analysis. For example, we transform the Markov state transition diagram to identify quickly create QPN approach. And perform simulations to obtain important data, for example, the Latency time and the Delivery ratio in a DTN routing protocol.

The future, through the QPN model, we can solve more advanced mathematical analysis. Moreover, not only the quantitative analysis but also qualitative analysis, for example, Reachability analysis, Liveness analysis, Boundedness analysis and so on.

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