

A New Approach to Overcome the Count to Infinity Problem in DVR Protocol Based on HMM Modelling

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Abstract

Due to low complexity, power and bandwidth saving Distance Vector Routing has been introduced as one of the most popular dynamic routing protocol. However, this protocol has a serious drawback in practice called Count To Infinity problem or slow convergence. There are many proposed solutions in the literature to solve the problem, but all of these methods depend on the network topology, and impose much computational complexity to the network. In this paper, we introduce a new approach to solve the Count To Infinity using hidden markov model (HMM), which is one of the most important machine learning tools. As the modelling results show, the proposed method is completely independent from the network topology and simple with low computational complexity.

Keywords: Count To Infinity, Distance Vector Routing (DVR), Hidden Markov Model (HMM), Network Routing Protocol, Slow Convergence.

1. Introduction

At the beginning of the 1990s the wireless communication society witnessed a rapid growth of interest in mobile ad-hoc network (MANET) technology. Because of the dynamic behaviour of the MANETs, in order to improve the efficiency of communication networking, new strategies and protocols were required. MANETs utilize the conventional TCP/IP protocol [1,2]. However, the dynamic entity of these networks (i.e., mobility and resource constraints) needs the modification of TCP/IP protocol in different layers. One of the most challenging research topics of the MANETs is in the network layer known as MANETs routing. There are many routing protocols developed based on the properties of the MANETs. In packet-switched based communication theory, there are two major classes of routing protocols known as Link State Routing (LSR) and Distance Vector Routing (DVR) algorithms.

The link-state routing protocol, periodically broadcasts the link-state costs of its one hop neighbours to other nodes in a flooding manner. Each node in the network by receiving the update packets, updates its routing table. Using the link state information and employing a shortest path algorithm the LSR protocol determines the next hop node [3].

In the DVR protocol, each node maintains a routing table giving the shortest distance to each destination based on some metrics. Different metrics, such as number of hops, time delay, the number of packets queued in the routing queues, can be used to show the nodes distance. DVR protocol utilizes the Bellman-Ford algorithm to

calculate the cost of each path, and chooses a path with the minimum cost as a best route to the destination. In DVR protocol, as each node makes its routing table according to information received from its neighbours, it provides less traffic, compared to LSR protocol which broadcasts the node information throughout the network in flooding manner. Furthermore, memory, bandwidth and power saving, are other prosperities that make the protocol more attractable routing protocol for network managers. Notwithstanding the mentioned benefits of the DVR, there is a serious drawback for this protocol called the *Count To Infinity* or slow convergence problem. The Bellman-Ford algorithm used in the DVR protocol does not prevent routing loops from happening and suffers from the count-to-infinity problem. When a node disconnects from the network due to a link failure, its neighbours cannot be informed about this *bad* news. Hence, they get the wrong routing information to reach the disconnected node. The wrong information propagates in the network slowly and all the node update their routing table for a long time until the routing table entry belongs to disconnected node reaches to an unacceptable amount (say infinite) according to the selected metrics in the protocol. In these conditions, the disconnected node information is removed. In section 3.2 this process is explained through an example.

There are several proposed techniques to overcome this drawback of the DVR protocol. However, all of the proposed methods in the literature are designed based on the topology of the network. This fact results in not completely solving of the problem for any random network topology. Furthermore, most of the proposed

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methods increase the complexity and computations of the routing algorithms (Section 2 is devoted to investigate some of these methods). In this paper, we introduce a new method to solve the Count to Infinity problem based on the concepts of system modelling and machine learning techniques. We use the Hidden Markov Model (HMM) as one of the most powerful machine learning tools in the field of system modelling to model the behaviour of the Count to Infinity problem in communication networks. After that we proposed a method to detect link failure in the network (which results in Count to Infinity) based on the structure of the HMM. The proposed method is completely independent of the network topology and the modelling results show that the proposed method can detect the Count to Infinity problem fast. Furthermore, using the HMM in routing managing of DVR protocol does not impose many computations to routers.

The rest of the paper is organized as follows. Section 2, reviews some related works about the Count to Infinity problem in DVR. In section 3 the Hidden Markov Model (HMM) and count to infinity problem are explained. The proposed method is introduced in section 4 and modelling and results are shown in the section 5. Section 6 presents some practical discussion about the proposed method and the last section concludes the paper.

2. Literature Review

There are several proposed methods to avoid count to infinity problem in literature [4,5,6,7]. However, all of them depend on network topology. [5] has proposed, CF-DVRP protocol to prepare backup set for each node when a link failure happens. A backup set is a set of nodes in the network selected to avoid updating the routing table of each node via loops in the network. However, in general, the availability of a backup set in a random network cannot be guaranteed. As mentioned in [6,8] four concepts, triggered update, split horizon, poison reverse and path hold-down have been suggested to solve count to infinity, but they did not solve this problem completely, due to their dependency to the network topology. To avoid routing loop, [6] classified possible self-passage or updating via loops, in nine different combinations of nodes. This classification and checking the self-passaging of each node can increase the complexity of algorithm and the delay of route selection in each router. In [7], slow convergence of networks is known the result of, Two-Node Loop Instability, Three-Node Loop Instability and more than Three-Node Instability, and proposed some solution to avoid the loops might integrate through groups of nodes. It is obvious that the same as [6], the main idea to prevent the Count to Infinity is based on classifying the network topology to some classes which might cause the updating the routing tables via loops. Based on their solution if any of these network topologies occurs in the network, the routing algorithm is aware that the Count to Infinity problem can happen in routing. Therefore, the

routing scheme tries to avoid these topologies to find the path to destination. All these proposed methods are dependent on network topology, and cannot solve count to infinity problem when the topology changes. Also these methods cause message overhead and more complexity in routing tables by adding some parameters, adding sequence of numbers in header of each packet or using test packet to get information about topology of network [8,9]. As mentioned before, we use a new approach based on modelling the behaviour of the Count to Infinity problem. The main advantage of the proposed method is independency of the method to the network topology with a simple structure.

3. Background Information

In the two following subsections, some background information about the Hidden Markov Model (HMM) and the count to infinity problem in the DVR protocol is explained.

3.1 Hidden Markov Model (HMM)

To analyze a random sequence with the finite state structure, the Hidden Markov Model (HMM) is one of the most powerful machine learning techniques [10,11]. Generating random sequences which follows a certain pattern and detecting a particular pattern of random sequences are some of important applications of HMM model. The HMM can be considered as a generalization of a mixture model where the hidden variables which manage the mixture component to be selected for each observation, are related through Markov chains. Two main parts of the HMM are the hidden state and observation states. Observable sequence depends on the hidden states and each state has a probability distribution over the observation sequence which controls the interaction between these states. The only way to evaluate the sequence of hidden states is to observe the observation sequence. The transition between hidden states follows the Markov process in which the current state only depends on the previous state.

To construct a (A,B,π) HMM model, first hidden and observation states, state transition probability matrix (A), in hidden states, observation sequence emission probability matrix (B) and initial vector (π) showing transitions start points are determined. Fig. 1 shows an example of HMM structure, with the initial vector, transition and emission probability matrices defined in the Equation 1. In this figure, two states S and T are the hidden states which interact via the transition probabilities (i.e. $P(S,T)$, $P(T,S)$, $P(S,S)$ and $P(T,T)$). Furthermore, this figure shows the hidden states can emit different observations with different probabilities (i.e. A , C and T).

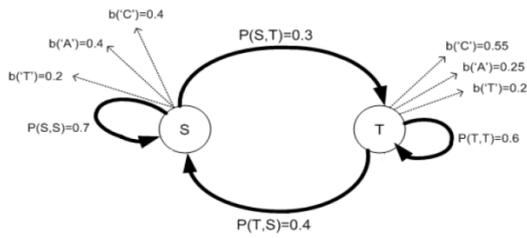


Fig. 1: An example of hidden states and observation sequences in HMM. S and T are hidden states, and C, A, T are observable option emitted from hidden states.

$$A = \begin{pmatrix} 0.7 & 0.3 \\ 0.4 & 0.6 \end{pmatrix}, B = \begin{pmatrix} 0.40 & 0.40 & 0.20 \\ 0.55 & 0.25 & 0.20 \end{pmatrix}, \pi = (1,0) \quad (1)$$

Estimation of transition and emission probability is one of the most important problems in HMM modelling. In fact the estimation of the HMM model expresses the behaviour and the hidden pattern in a random sequence. Therefore, in order to estimate the HMM parameters, HMM model is trained using enough numbers of observation sequences. Baum-Welch Algorithm is used to estimate transition and emission parameters. In this algorithm, if the number of observation sequences is too much (maybe infinite) acceptable results cannot be achieved and there is no guarantee that HMM can satisfy global results. In such a case, a heuristic algorithm is utilized to estimate the HMM parameters. Furthermore, transition and emission probabilities can be estimated based on the problem conditions without using any algorithm.

One of the most important usages of HMM model is in the decoding problems, which means HMM-decoding, computes the most probable sequence of the hidden states, according to the observation sequence, transition and emission probabilities. In other word, the HMM decoding determines if a random sequence can be emitted from the HMM model after enough training. In this paper, we use the HMM-decoding to introduce criteria to detect link failure in a network.

3.2 Count to Infinity Problem

In this subsection the Count to Infinity problem is explained through an example. Suppose in the network shown in Fig. 2, node A wants to join to the network. As it is illustrated in Fig. 2-a [6], after four information exchange, all nodes know their distance to the node A. Showing that the information of a new node propagates very fast throughout the network. However, when a node leaves the network or a link failure happens, it might take a long time that the nodes to be informed about a node disconnection. In the Fig. 2-b, suppose that the node A is disconnected. In the first step, node B updates its routing table entities according to the node C's routing table which has old information to reach the node A. Therefore, node B supposes that it can reach to the node A through the node C by the three hops. The node C and E distance information does not change. In second step according to routing table of the neighbours C the table entity in C is revised to four. A similar scenario continues, until the

distance between A and other nodes reach to infinity, the definition of infinity depends on the metric and the number of the node in the network. Finally, nodes recognize the node disconnection and delete the node as information from their routing table [6].

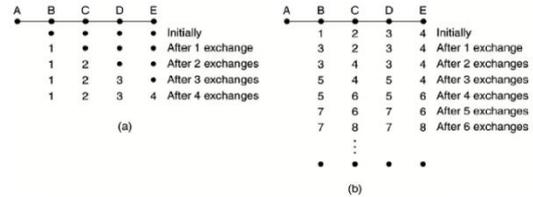


Fig. 2: (a) before and (b) after count to infinity problem.

It is obvious that the bad news, initiated due to a link failure, propagates very slowly in the networks. Hence, the nodes that are far from the broken link position are awarded very late resulting in weak network stability. The main reason of the slow convergence of the routing table in the DVR protocol is the table updating via loops that propagate the wrong routing information in the network. As mentioned there are several methods to avoid this wrong updating procedure which are so complex and not completely efficient. In the next section we present our approach to solve the problem based on the HMM-decoding with a simple structure and expandable to any network architecture.

4. Proposed Method

As mentioned in section 3.1 to establish the HMM model, first, two states of sequence, hidden and observation sequence, are defined. To model the Count to infinity problem, two hidden states are considered state 1, presents no disconnected node in the network and state 2 shows a node disconnection event moreover, the observation sequence is the sequence of hop numbers that is observed in the routing table showing the nodes distance which can change by topology changing. To simplify the observation sequence it is converted to a binary sequence, which identifies any changing in the amount of routing table entity. Therefore, after each updating, the amount of routing table entities is checked. If the certain entity has increased, the associated element in the binary observation sequence changes to 1, otherwise associated element is set to 0. In fact, by introducing binary observation sequence we try to model the behaviour of count to infinity by a string of ones and zeros. Therefore when series of ones are observed, the probability of link failure will increase.

In order to detect a link failure in the network the HMM-decoding is used to calculate the most probable hidden states sequence. It utilizes Viterbi algorithm according to observation sequence, transition and emission probabilities. Therefore HMM acts like a decision box and according to the binary observation sequence it finds any node disconnection by the HMM-

decoding. As the output of HMM-decoding is a probability of staying in each state, the decision making is a statistical model. In order to evaluate the method we run 100 different topologies with the introduced structure. The results are presented in the next section.

5. Modelling and Results

To show that how the proposed scheme can solve the count to infinity problem, suppose a network with 8 nodes which are connected to each other as shown in Fig. 3. Now, let us assume that the link between node A and B is broken and count to infinity problem happens.

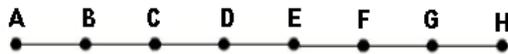


Fig. 3: Network with 8 nodes to simulate count to infinity problem

Fig. 4 denotes routing table and related binary observation sequence after breaking the link. Notice that the binary observation sequence shows the style of changing in the nodes distances. For example nodes B, D, F and H update their table at odd exchange times, as described in section 3.2.

A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H
1	1	0	0	0	0	0	0	3	4	3	4	5	6	7	
1	1	1	1	0	0	0	0	5	4	5	4	5	6	7	
1	1	1	1	1	1	0	0	5	6	5	6	5	6	7	
1	1	1	1	1	1	1	0	7	6	7	6	7	6	7	
1	1	1	1	1	1	1	1	7	8	7	8	7	8	7	
1	1	1	1	1	1	1	1	9	8	9	8	9	8	9	
1	1	1	1	1	1	1	1	9	10	9	10	9	10	9	
1	1	1	1	1	1	1	1	11	10	11	10	11	10	11	
.
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Fig. 4: (a) distance of each node to node A after each update and (b) related binary observation sequence.

To demonstrate a link failure in the network, the number of the binary observation sequence updates is limited by 3. This number in a large network should be larger. According to the updating times, 8 different possible observation sequences 000, 001, ..., 111, determined by O1, O2, ..., O8 respectively, are possible.

Fig. 5 illustrates the hidden states and observation sequences for the HMM model. To reduce the complexity of HMM model, observation sequence that leads to the same result in HMM-decode can be considered as one observation sequence, because these observation sequences present almost the same emission probability. Therefore, the observation sequences O2, O3, O5, O6 and O7, showing a normal changing in the network with no link failure, are assumed as one observation sequence. Fig. 6 shows the modified model in the assumed network.

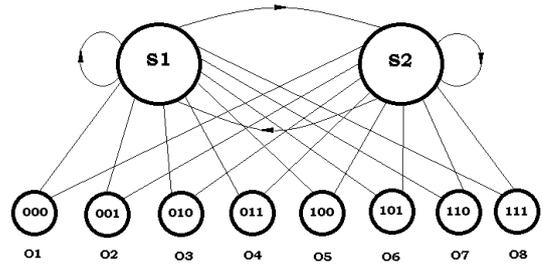


Fig. 5: Hidden states and observation sequences for HMM model.

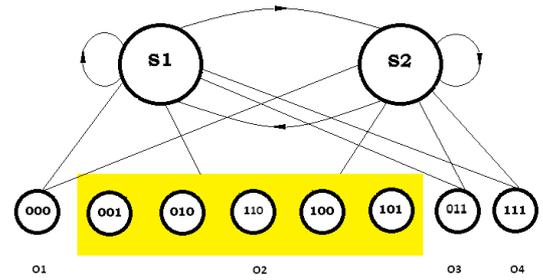


Fig. 6: Modified observation sequence for HMM model.

The next step is estimation of transition and emission probabilities. To estimate these parameters, a heuristic idea is employed. It is obvious that observation state O4 (in Fig. 6), showing 3 continuous increments in the updating table, is more likely to result count to infinity than the state 2, because, count to infinity is modelled with a string of many consecutive ones in observation sequence. Also O1, showing 3 continuous decrements or no changing in the routing table distances, has lower probability than the state 2 to result count to infinity. In this case, emission, transition and initial probability of HMM are estimated as follows.

$$A = \begin{pmatrix} 0.5 & 0.5 \\ 0 & 1 \end{pmatrix} \tag{2-1}$$

$$B = \begin{pmatrix} 0.5 & 0.20 & 0.15 & 0.15 \\ 0 & 0.15 & 0.30 & 0.55 \end{pmatrix} \tag{2-2}$$

$$\pi = (1 \ 0) \tag{2-3}$$

$\Theta=(A,B,\pi)$ shows HMM model of count to infinity problem. It is assumed that network starts at state 1.

As mentioned in the section 1, HMM provides a suitable criterion and a scale to evaluate the status of the network. Table I, shows the results of the HMM analysis which is evaluated according to the following procedure. After three updating, the status of the network is checked and the link failure probability is determined. To determine the current status of the network a threshold level is considered. If the output of HMM-decoding (probability of link failure) is less than 0.5, we assume that no link failure is occurred and normal changing is happened in the network topology. For probability of link failure more than 0.5 and less than 0.9 next three updating

and related binary observation sequence are checked to make sure that the increments is not due to the normal changing in the network topology when there is no link failure. Finally, for the probability more than 0.9, it can be assumed a link failure has occurred in the network. These threshold of decision making depends on HMM parameters introduced in Equations (2-1), (2-2) and (2-3).

Table 1: probability of link failure and status of the network based on binary observation sequence using HMM-decoding

Time/node	A	B	C	D	E	F	G	H
1	...	1	1	0	0	0	0	0
2	...	1	1	1	1	0	0	0
3	...	1	1	1	1	1	1	0
Probability	...	0.7857	0.7857	0.6667	0.6667	0.4286	0.4286	0
Status	...	Wait and check next	No link failure	No link failure	No link failure			
4	...	1	1	1	1	1	1	1
5	...	1	1	1	1	1	1	1
6	...	1	1	1	1	1	1	1
Probability	...	0.9683	0.9683	0.9483	0.9483	0.7857	0.7857	0.7857
Status	...	Link failure	Link failure	Link failure	Link failure	Wait and check next	Wait and check next	Wait and check next
7	...	1	1	1	1	1	1	1
8	...	1	1	1	1	1	1	1
9	...	1	1	1	1	1	1	1
Probability	...	0.9956	0.9956	0.9928	0.9928	0.9861	0.9861	0.9683
Status	...	Link failure						

According to above discussion, the status of defined network in Fig. 3 is presented in the Table 1, however the slow convergence problem still exist. It means, it will be taken a long time for the nodes that are far from the link failure position to be aware of the bad news (in this example after 9 updating, the node H realizes that the node A is disconnected).

To solve this problem, the following equation is defined to compute a new probability (Pnew) based on the neighbours link failure probability.

$$P_{new} = \begin{cases} P_{old} & P_{old(ni)} < 0.5 \\ \alpha P_{old} + (1-\alpha)P_{old(ni)} & 0.5 < P_{old(ni)} < 0.9 \\ 0.5 + P_{old} & P_{old(ni)} > 0.9 \end{cases} \quad (3)$$

which P(ni) denotes the link failure probability of the neighbours and α is a constant number between 0 and 1 which is assumed $\alpha=(2/3)$. Each node checks the link failure probability of its neighbours. If there are two or more neighbours, maximum probability will be selected, and new probability is computed using Equation (3). For the decision making the same algorithm is performed as shown in Table 2. By using the modified probability defined in the Equation (3) if a link failure is detected the news propagates in the network very fast, which results in a fast convergence in the network. Table 3 shows the results based on the modified probability of the link failure.

Table 2: decision making based on Pnew

Pnew	Status
0 < Pnew < 0.5	No link failure
0.5 < Pnew < 0.9	Wait and check next 3 update
0.9 < Pnew < 1	Link failure

As it is obvious, according to Table 3, link failure between the node A and the network is detected very fast in comparison with results in the Table 1. Fig. 7 compares

two defined models, model using HMM and model using modified probability, for the node H that is in the worst conditions to converge, because it has the biggest distance to the position of link failure. Fig. 8 denotes link failure probability for normal changing in the network topology (a random change is considered in the topology), where no link failure happens in network.

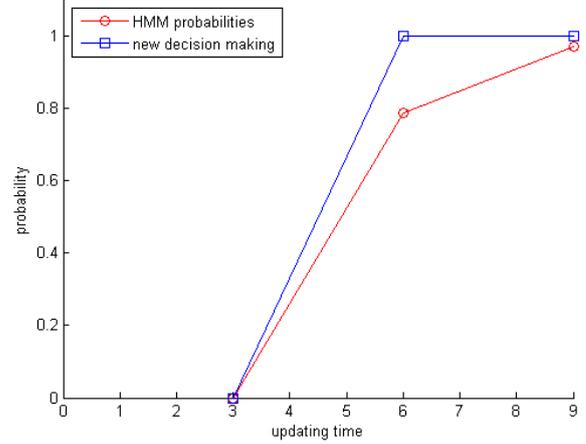


Fig. 7: Comparison of HMM probability and HMM using modified probability.

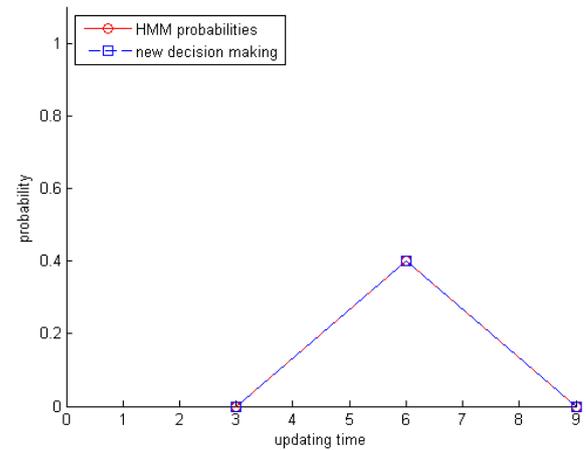


Fig. 8: HMM probability and HMM using modified probability when no link failure occurs.

Table 3: probability of link failure and status of network based on HMM-decoding and computation of modified probability in Equation (3)

Time/node	A	B	C	D	E	F	G	H
1	...	1	1	0	0	0	0	0
2	...	1	1	1	1	0	0	0
3	...	1	1	1	1	1	1	0
Old_p	...	0.7857	0.7857	0.6667	0.6667	0.4286	0.4286	0
New_p	...	0.7857	0.7857	0.7063	0.6666	0.5079	0.4286	0
Status	...	Wait and check next	No link failure	No link failure	No link failure			
4	...	1	1	1	1	1	1	1
5	...	1	1	1	1	1	1	1
6	...	1	1	1	1	1	1	1
Old_p	...	0.9683	0.9683	0.9483	0.7857	0.7857	0.7857	0.7857
New_p	...	0.9683	0.9683	1	1	1	1	1

Time\Node	A	B	C	D	E	F	G	H
Status	...	link failure						
7	...	1	1	1	1	1	1	1
8	...	1	1	1	1	1	1	1
9	...	1	1	1	1	1	1	1
Old_p	...	0.9683	0.9683	0.9683	0.9683	0.9683	0.9683	0.9683
New_p	...	0.9683	1	1	1	1	1	1
Status	...	link failure						

According to Equation (3) and Table 2 the same results will be achieved for both methods when there is no link failure in the network. These results are presented in the defined network with 8 nodes. The results for larger network with more nodes can even be better because of using modified probability introduced in Equation (3). The probability of link failure propagates in network much faster than the news of link failure by other nodes.

6. Discussion

As we explained, our approach for fast convergence in the DVR protocol is to detect the specific pattern of routing information tables for any link failure in the network. At first step of the proposed method introduces a probability value for link failure based on the HMM concepts. After that the method by using the link failure probability of its neighbours can detect any link failure in the network so fast. One of the main advantages of the method is the independency from the network topology. Other proposed methods in the literature, to avoid the Count to Infinity problem perform some modifications on the network topology which could decrease the network performance. However, the proposed scheme detects the link failure in the network without any changing in the topology.

There are some practical points while using the proposed method which must be considered. One of the main issues of designing the HMM model is the interaction between the structure complexity and the link failure detection in the network. The number of the bits generating the observation sequences in the HMM model determines the structure complexity of the model and the accuracy of the model to detect the link failure. By increasing the number of the bits in the model the complexity of the model increases. For example, a 4-bit HMM model has 16 observation states. According to this number of states the training stage to determine the emission probabilities is more complex and cannot be computed easily. However, for larger numbers of bits generating the observation states, different status of the network can be detected with more accuracy. In other word, a 4-bit HMM model demonstrates that checking the link

failure status of the network is performed with the accuracy twice the accuracy of a 2-bit HMM model. Therefore, in order to use the proposed model to detect the link failure effectively, one must be able to balance a trade-off between the complexity and the time accuracy of link failure detection. The following table shows different scenarios and how different number of bits can determine the time accuracy of the link failure in the network.

Table 4: the performance of the HMM model for different bit HMM modelling.

Bit no.	State no.	Updating time to detect link failure	Numbers of node in the network
2	4	8	8
3	8	6	8
4	16	2	8

As the modelling results demonstrate, 4-bit HMM model can detect the link failure faster than other model. The problem of high structure complexity can be solved by joining the observation states which have similar status for link failure in the network to one observation state. An example of joining is presented in Fig. 6 where states that have similar status for link failure are classified in one observation state. This joining can reduce the complexity of the model without decreasing the model performance.

7. Conclusion

In this paper, we introduced a new method to solve the slow convergence or Count To Infinity problem in DVR protocol. This model determines the existence of link failure based on a binary observation sequence. Count to infinity problem is modelled as certain behaviour of binary observation sequences based on nodes distances, therefore the other topology information like updating through loops or different form of node combination is not necessary. Since this method is independent of the network topology it can also detect multi-link failure easily. When multi-link failure happens in the network the status of link failure according to proposed model will be observed in routing table in number of broken link in the network. Therefore detecting link failure in such cases will be more easily and confident.

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