

NSNCR: a Non-Source Non-Certain Routing Strategy for Ad Hoc Networks

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Abstract—In order to suit high mobility and limited resources of ad hoc networks, a new hybrid routing strategy named Non-Source Non-Certain Routing (NSNCR) is proposed. This paper designs a multi-path judgment method for handling request message in route discovery process. A next hop selecting mechanism used for forwarding packets is proposed, and the mechanism is based on series of collective concepts like forward-list and neighbor table. NSNCR could provide increased stability and reliability of routes for its flexible choice of uncertain route, instead of the fixed route in traditional protocols. Moreover, the strategy can decrease the network congestion and balance the network energy since next hop selecting mechanism takes current surroundings like node degree, congestion, energy, relative mobility into consideration. Simulations are conducted to evaluate the performance comparison of NSNCR with Dynamic Source Routing (DSR) and ad hoc On-demand Multipath Distance Vector (AOMDV) using ns-2 network simulator. The results show that NSNCR is efficient to decrease the drop packet ratio and average end-to-end delay under high load and mobility conditions.

Keywords—ad hoc networks; NSNCR; competition utility function; multi-path; neighbour table

I. INTRODUCTION

Ad hoc networks are mobile, multi-hop wireless networks with no fixed infrastructure or centralized administration, and the networks have characteristics such as independence, self-configuration, highly dynamic topology and limited resources etc. Due to the mobility of nodes, routing protocol in ad hoc networks is highly complicated. The design of an effective routing protocol has been an active research field in recent years. The effective routing protocol means it should be critical for adapting to node mobility as well as possible channel error to provide a feasible path for data transmission [1]. Among them, one notable class is called “on-demand protocols”, such as Dynamic Source Routing (DSR) and Ad hoc On-demand Distance Vector (AODV). Another class is named “proactive protocols”, e.g. Destination Sequenced Distance Vector (DSDV) and so on. It’s important to realize that lots of prior studies have shown that “on-demand protocols” perform better in saving limited energy and available bandwidth [2].

Several multi-path routing protocols were proposed in [3], [4], [5], and most of them design that the destination or the source selectively chooses proper routes from received

messages. Reference [6] proposes an opportunistic routing protocol (WAOR) based on forward-list. However, in WAOR every data packet is sent by broadcast among the networks which brings collision and waste of bandwidth. Reference [7] focuses on the evaluation of different controlled message flooding schemes over large-scale, sparse mobile networks and proposes a definition named “node willing” in the schemes which includes Beacon Interval, Times-to-Send and Retransmission Wait Time. Some of the concepts are worth learning although the schemes in [7] are just fit for sparse mobile networks. Reference [8] proposes weighted clustering algorithm (WCA), which takes the ideal degree, transmission power, mobility and battery power of a mobile node into consideration for selecting cluster-head.

Based on those protocols and schemes, this paper describes a new strategy named NSNCR (Non-Source Non-Certain Routing), which combines “on-demand protocols” with “proactive protocols”. Firstly, source node launches a process called “route discovery”. Then, destination node constructs a forward-list based on multi-path judgment method used by intermediate nodes. At the same time, parts of nodes of the forward-list will transmit HELLO (TTL=1) message in order to found their own neighbor table. Finally, when packet is sent, it chooses the next hop among the neighbor table according to selecting mechanism which takes several parameters into consideration, rather than the fixed route in traditional protocols. NSNCR could balance energy usage of the networks, prolong lifetime of the entire ad hoc networks and mitigate network congestion, due to the parameters in selecting mechanism include congestion queue and energy conservation. In addition, NSNCR is more suitable for the mobility of ad hoc networks, because the neighbor table is a concept of relative real-time due to periodic HELLO message and the optional next hop in the neighbor table is not unique commonly.

The rest of the paper is organized as follows. An overview of the NSNCR and specific mechanism used in routing process are presented in the next section. In section 3, we evaluate the performance of NSNCR by using ns-2 simulations. Section 4 presents the conclusion

II. NON-SOURCE NON-CERTAIN ROUTING(NSNCR)

NSNCR is a hybrid routing protocol which combines “on-demand protocols” by borrowing the basic mechanism of

route discovery and “proactive” protocols plus the use of periodic beacons.

Firstly, a process of route discovery begins on demand and at the same time, it makes a distributed judgment of multi-path in order to establish a forward-list. Then, parts of nodes of the forward-list are supposed to send HELLO message to learn surroundings, and tell others their own nodes’ information including competition utility function, which presents forwarding priority of node. Every node in the forward-list can built their neighbor table by sending and receiving HELLO message. Based on neighbor table, when a node receives a packet, it will choose a neighbour node as the next hop whose competition utility function is largest, rather than fixed next hop like pre-classical routing protocols. Through multi-path judgment method to limit range of available nodes and receiving HELLO message to learn real-time conditions, the strategy gets a series of collective concepts to delivery packets, which not only tackles the link failure brought about by mobile ad hoc network, but also lowers the blocking rate.

A. Multi-path Judgment Method

To be illustrated that, first of all, the distinguishing of multi-path should take commands from two main aspects. On the one hand, low coupling multi-path can effectively avoid negative effect of the high mobility of ad hoc networks, because a more independent path set offers more aggregate physical resources between a node pair [9], thus guarantees the independence of the route and efficiency of the forward-list. On the other hand, obviously, the independent route consumes more time to discovery multi-path. We should balance these two opposite aspects.

Therefore, NSNCR designs a judgment method that distributes the disposal of multi-path during broadcast request messages. That can bring two advantages: first, it can eliminate redundant copies of the flooding messages to the greatest extent; second, it can alleviate burden of the destination node. To achieve high path independence and prevent the unlimited flooding messages, the intermediate nodes in NSNCR are required to accept a valid request message then broadcast at most 3 times. A received message can be considered to be accepted only if:

- 1) The next hop of source node in request message received this time is different from that received last time. That requirement is to guarantee that source node will not meet independent bottleneck, which is to say, the nodes around the source node should take part in the delivery packets as much as possible.
- 2) The last hop of the present node in request message received this time is different from that received last time. That requirement is to prevent hotspots in the networks. It cannot only make the route independent, but also reduce partial redundant flood. According to the test, requirement 2 could make sure that every node of the route can attain link-independent route.
- 3) The difference of distance, which is from the source node to the present node in request message received this and last time, is less than 2 hops. The requirement is able to prevent multi-path from scattering. In this paper, we

design that there is a shortest route in the request message between source nodes to the present node when the node firstly receives.

$$\text{If } \left\{ \begin{array}{l} (source_next_index_{before} \neq source_next_index_{now}) \text{ and} \\ (last_index_{before} \neq last_index_{now}) \text{ and} \\ (|dis_{source_index, index}^{now} - dis_{source_index, index}^{before}| \leq 2) \end{array} \right\} \text{ then}$$

broadcast require message;

Else

drop require message;

endif

Figure 1. Pseudo code of multi-path judgment method in NSNCR

According to the three requirements above, as shown in Figure 1, intermediate nodes, unlike traditional protocols will receive a required message and examine the message’s validity. If the result shows that the message is valid, the node will store some information, and then continue to broadcast the request message. In contrast, if the result is proved invalid of message, the node will immediately discard it.

B. Route Discovery

Source node will launch a route discovery process on demand. The first step of the route discovery in NSNCR is to broadcast request messages. Once mid-node receives flooding messages, it will handle the message according to the multi-path judgment mechanism, as we just presented. Destination node will receive lots of messages by sequences via different routes some time later. In NSNCR, destination node is responsible for establishing forward-list. Specifically, destination node will add these nodes in flooding messages received to forward-list without reduplication. What is more, destination node still transmits reply when its timer expires.

When the forward-list is ready or timer expires, destination node will broadcast request reply with it. Once every node receives the reply, it will judge whether itself is in the list. If the result is yes, the node will label itself; if no, it will discard the flood reply at once.

C. Next Hop Selecting Mechanism

In order to select the optimal next hop, we will firstly introduce several related concepts.

Definition 1: Distance serial number. This concept is property of node, which depends on the nodes’ location in the multi-path received by destination node. NSNCR sets the distance serial number of source node as 1, so that the number of node will add 1 with the node in the link approaching destination node one hop.

Definition 2: Special nodes. The special nodes are parts of nodes in forward-list which is decided by the distance serial number. In NSNCR destination node and nodes with odd number are regarded as special nodes which have right to transmit HELLO message.

According to the above concepts, it is obvious that a node in the forward-list can be in two modes in the NSNCR,: special nodes and non-special nodes. Special nodes can send

HELLO message to demand information of neighbours, and non-special nodes just wait for HELLO message and reply the sender. Consequently, every labelled node can establish its own neighbor table though sending or receiving HELLO message.

After neighbor table is completed, the node can choose next hop by comparing the competition utility function, which synthetically considers several parameters. We notice that every node in the neighbor table should have its own competition utility function.

Nodes labelled will calculate the competition utility function which presents their forward quality. The competition utility function $\psi(i)$ of the node i playing a key role in delivery of packets and takes connectivity、energy、relative mobility、congestion into consider. $\psi(i)$ is described as:

$$\psi(i) = \alpha \times L_{is} + \beta \times k_i + \gamma \times D_{ave_i} + \chi \times E_i + \delta \times (Q_i - q_i) + \kappa \times M_i \quad (1)$$

Where L_{is} denotes the distance series number of node i and α is a weighting factor.

In the $\psi(i)$ above, k_i is degree of the node i , which means the number of neighbor table of the node i and β is a weighting factor.

D_{ave_i} denotes the distance arithmetic sum of all neighbors of node i where γ is a weighting factor. D_{ave_i} in NSNCR represents the transmission range of long range radios of node i as:

$$D_{ave_i} = \sum_{i' \in n(i)} [d(ii')] / k_i \quad (2)$$

Where $n(i)$ is the neighbor table of the node i and $d(ii')$ is the distance from node i to node i' .

Obviously, only special node can calculate D_{ave_i} in NSNCR because the $d(ii')$ is equal to the time gap between sending HELLO message and receiving HELLO-REPLY message. Therefore, non-special node just set γ to 0 in the above competition utility function formula.

E_i is current remainder energy of node i and χ is a weighting factor.

Q_i is buffer of node i while q_i is reminder of buffer of node i . We introduce these to this function where node sends packets through a neighbor with the fewer amounts of data packets waiting to be transmitted. δ is a weighting factor.

M_i is a parameter which represents the relative mobility of node i to its neighbors, firstly, we define the relative mobility of node i to node j as

$$M_i(j) = 10 \lg \frac{P_{j-i}^{new}}{P_{j-i}^{old}} \quad (3)$$

Where P_{j-i}^{old} and P_{j-i}^{new} respectively are signal strength of neighbor node j to node i this time and the former one.

The average mobility of node i in NSNCR employs an estimated method in [10], and the average mobility is defined as:

$$M_i = \{ \sum_{n=1}^{k_i} [M_i(j_n)]^2 \} / k_i = E\{[M_i(j)]^2\} \quad (4)$$

This function is the mean value of the relative mobility, of all the neighbors of node i , squared. Finally, κ denotes a weighting factor.

Furthermore, all of the weighting factors must meet the requirement of $\alpha + \beta + \gamma + \chi + \delta + \kappa = 1$, and the specific value is up to the specific applied situations.

Apparently, the higher of node's priority, the larger of the node's competition utility function, and the node's higher priority is equivalent to the higher probability of node being chosen as the next hop.

D. Neighbor Table Update Rule and Advertisement Scheme

Given the dynamic ad hoc networks where link failures and route breaks occur frequently, the forward-list update and advertisement are needed. We will analyse and redesign NSNCR to deal with three cases below:

1) Add node: NCNSR designs a specialized judgment mechanism when a node accesses to area of forward-list covered, but the node is not in forward-list originally. This node is considered as node p . In the first place, p will be regarded as "suspicious node" if it has received three HELLO messages from different nodes. Secondly, "suspicious node" transmits HELLO message once to try to establish its own neighbor table. Finally, p will label itself if there are at least four labelled nodes in the neighbor table. Furthermore, new node is in the special mode initially, meaning that it can periodically transmit HELLO message. It should be noticed that the distance series number which is determined by those of its neighbours. The number, NSNCR designing, is the intermediate value (distance series number required to be an integer) between the largest number and the second largest number.

2) Delete node: a node will delete the label and its own neighbor table, and will not transmit HELLO message any more since it is far away the area of forward-list covered. It is believed that a special node will meet the condition if it cannot receive HELLO-REPLY message any longer. In the similar way, as a non-special node, the node will delete all the information for not receiving any HELLO message for a period of time. Moreover, all of labelled nodes will delete the counterpart, information of node a , in the neighbor table for

not receiving the any HELLO message or HELLO-REPLY message of node a .

3) Update distance series number: If the node moves a certain range but not up to area of delete node demanding, the serial number needs to be updated. Each time when accepting the HELLO-REPLY message or HELLO message, it updates the distance serial number according to the numbers of the neighbours from time to time. If the former serial number is between the maximum and minimum number of the neighbour nodes, the change is unnecessary. If it is greater than or less than all of the neighbours' serial number, appropriate change is needed. NSNCR strategy's updating rule is as follows:

$$Z = \{L_{1s} \dots L_{ks}\} \quad (5)$$

$$L_{is} = \begin{cases} L'_{is} & \min Z \leq L'_{is} \leq \max Z \\ \min Z & L'_{is} < \min Z \\ \max Z & L'_{is} > \max Z \end{cases} \quad (6)$$

Where Z is the list of the distance series numbers of neighbor nodes of node i and the L'_{is} is the distance series number of node i at a moment before.

E. Delivery of Packets

As described above, parts of the labelled nodes transmits HELLO message to establish and update its own neighbor table, which is similar to "proactive protocols".

When a data packet reaches a node (or data packets sent by source node), it needs to choose next hop by the competent mechanism as said in above chapter C. That is to say, each node will choose the node in its neighbor table, whose competition utility function, as the next hop to unicast data packets until packets arrive at the destination node.

Obviously, when selecting, it flexibly combines with the current surrounding, rather than fixed route link in the tradition protocol. Therefore, it can be realized that NSNCR adapts to the mobility and uncertainty of ad hoc networks. In addition, the route picked one by one in NSNCR is more flexible and reasonable for the competition utility consists of congestion, mobility, node degree and other parameters. Therefore, NSNCR could balance energy usage of the networks, prolong lifetime of the entire ad hoc networks and mitigate network congestion.

Normally, the optional node in the neighbor table is not only one. Therefore, the node can continue to choose next-best node in the neighbor table as next hop when the original best hop chosen doesn't reply to ask of the forwarding data packets. All in all, NSNCR can eliminate complicated and routine maintain process in traditional protocols.

III. SIMULATION AND RESULTS

We have evaluated the performance of NSNCR and compared it with DSR which is classical "on-demand" protocol and AOMDV which is widely used as multi-path protocol. In order to simplify the simulation, we deformalize

the competition utility function $\psi(i)$. Our simulation sets $\alpha = 0.7$, $\beta = 0.1$, $\chi = 0.2$, $\gamma = 0$ and each node's original energy=3 in condition of waste energy=0.002 at forwarding packet one time.

Specifically, we quantified the difference between these three protocols using two metrics:

- 1) **Average end-to-end packet delays:** the delays between time when a packet enters the system and the time when the packet finally arrives.
- 2) **Drop packet ratio:** the ratio between the number of packets originated by the sources and the number of packets dropped by all of the nodes in networks.

A. Simulation Environment

A 25 node random mesh topology network in a field with dimensions 1000m*1000m is used in the simulation.. We use traffic sources are CBR (continuous bit-rate) and 512 byte data packets. The Monarch research group in CMU developed support for simulation multi-hop wireless networks complete with physical, data link and MAC layer models on ns-2. The DCF (distributed coordination function) of IEEE802.11 for wireless LANs is used as the MAC layer [3]. Simulations are run for 10 simulated seconds.

B. Varying Offered Load

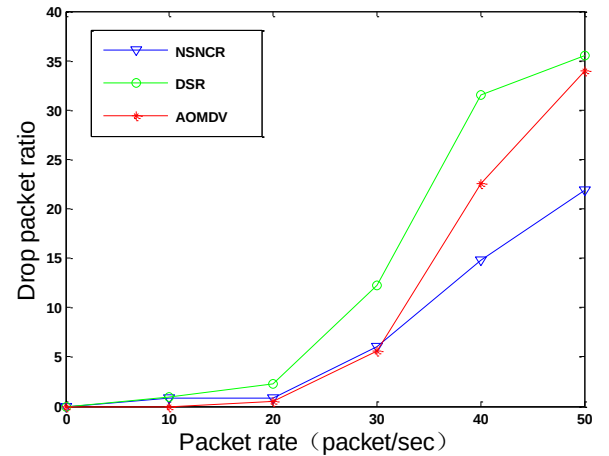


Figure 2. Comparison between the three protocols of the drop packet ratio as a function of varying sending packet

Figure 2 illustrates that the drop packet ratio with varying sending packet rate of source at the max speed of nodes being 20m/s. We vary the source sending rate from 1 to 50 packet/s. As we can see, all of the protocols deliver a great percentage of the originated data packets when there is small traffic loads (packet rate under the 20 packet/s). However, the drop packet ratio of all protocols is increasing as the load increases (along the x-axis). In DSR and AOMDV, all of packets just go through only one link, like single-plank bridge. In contrast, in NSNCR, the drop packet ratio is lower than other protocols for its multi-path and flexible selection. There are more accessory nodes which have a chance to take part in forwarding packets. Therefore, node will avoid to choice a

congested hotspot since the hotspot's competition utility function is lower. The node prefers to choose other idle nodes around hotspot, which can balance burden of networks. Through this way, another benefit is that NSNCR can protect the hotspot from early death. In a word, Figure3 proves the NSNCR performs better at heavier load.

C. Varying Mobility

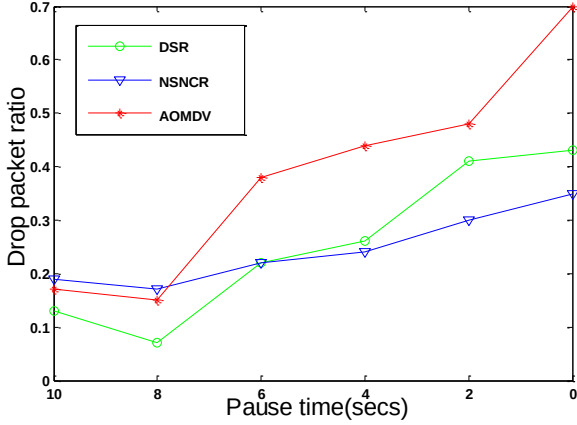


Figure 3. Comparison between the three protocols of the drop packet ratio as a function of pause time. Pause time 0 represents constant mobility.

Figure 4 shows the three protocols perform at drop packet ratio as a function of mobility. We can find that the protocols deliver a greater percentage of the originated data packets when there is little node motion. The very first point of Figure 4 is that drop packet ratio is not 0%, because the source sending packet rate is fixed at 30 packet/s. The drop packet ratio of NSNCR is higher than others on account of control packets, periodic HELLO message designed by NSNCR. However, as expected, these three protocols' performance differences become more apparent, but the ratio goes up for all protocols at higher speeds. Rise of mobility of nodes implies that probability of original link broken will increase. In other words, the source may launch route discovery more often. During the waiting time of discovery process, lots of packets will be dropped. In addition, the multi-path in AOMDV will become invalid so that packet delivery fraction sharp decline to hardly bear [11] at high mobility. In contrast, there is own update rule and advertisement scheme in NSNCR to guarantee the forward-list and neighbor table available for a long time. Therefore, mobility of nodes in ad hoc networks takes less effect on drop packet ratio of NSNCR. What's more, when a node of route moves, DSR or AOMDV may consider this route failed, and recover route or use reserved route. However, in NSNCR, mostly, there are more than one optional choose, and last hop may choose the node, whose function is the second largest, as the next hop. If every neighbour's function is less than the current node, this node will forward the packet to last hop.

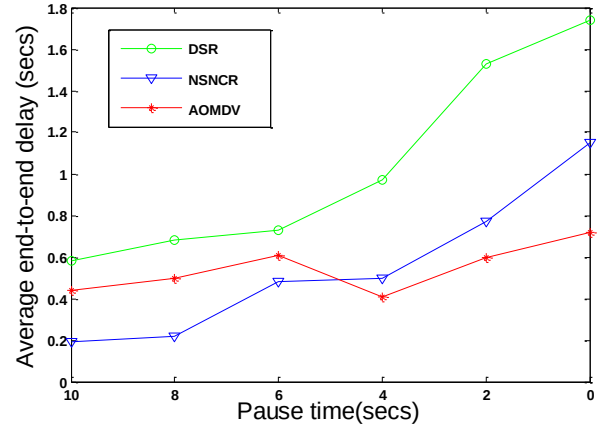


Figure 4. Comparison between the three protocols of the average end-to-end delay as a function of pause time. Pause time 0 represents constant mobility.

Figure 4 describes the performance of these three protocols in average end-to-end delay with average mobility of nodes. In addition, with increasing nodes' mobility, poor performance of DSR with large delay, because the route failures arouse route discovery latency that contributes to the delay. We can find in ns-2 network simulator that lots of packets will stay at intermediate nodes for a while once link failure and these packets maybe continue to be forwarded if intermediate nodes find another path to destination node again. In other words, these waiting packets enlarge the delay. Interestingly, the least delay protocol is AOMDV, but that is because most of packets have been dropped according to the Figure3. Therefore, the performance of NSNCR is slightly less at average end-to-end delay but least at packet drop ratio.

In conclusion, NSNCR performs better for its adequate consider of mobility of ad hoc networks.

IV. CONCLUSIONS

In this paper we propose a novel strategy named NSNCR which could effectively reduce the impact of high mobility and congestion in ad hoc networks. NSNCR is a hybrid protocol which combines "on-demand" and "proactive" protocols. The strategy designs a multi-path judgment method used by intermediate nodes. In most of traditional multi-path protocols, source node or destination node is responsible for path calculation, however, in NSNCR, intermediate nodes balance this judgment burden. Moreover, traditionally, routing protocols has to forward packets through the fixed route. In contrast, NSNCR gets a series of collective concepts like forward-list and neighbour table to flexibly deliver packets. When current node selects next hop for forwarding packets, NSNCR takes congestion, relative mobility, node degree and battery power into consideration. Finally, in order to optimize NSNCR, we redesign neighbour table update rule and advertisement scheme for its self-improving. Our simulation results show that NSNCR strategy is very efficient in high load and mobility ad hoc networks. In the high load condition (source sending rate 50packet/sec in Figure2), source node delivers more packets over 15% than DSR and AOMDV. In

addition, the average end-to-end delay of NSNCR is less 30% than DSR and the packet drop ratio of NSNCR is less than half of AOMDV in high mobility.

Our future work will include the transmission of a message to multiple destinations and rational set of weighting factor in competition utility function.

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