Volume: 07 Issue: 03 Pages: 2771-2778 (2015) ISSN: 0975-0290

Cost Effective Routing Protocols Based on Two Hop Neighborhood Information (2NI) in Mobile Ad Hoc Networks

Dr. Anuradha Banerjee, Dr. Paramartha Dutta

ABSTRACT

Ad hoc networks are collections of mobile nodes communicating with each other using wireless media without any fixed infrastructure. During both route discovery and traversal of route-reply packets from destination to source, broadcast of packets is required which incurs huge message cost. The present article deals with the message cost reduction during transmission of route-reply from destination to source. Also the redundancy that is visible within the 2-hop neighborhood of a node is minimized during broadcasting of route-reply. This improves the average lifetime of network nodes by decreasing the possibility of network partition. The scheme of 2NI can be used with any reactive routing protocol in MANETs.

Keywords – **Ad hoc networks, Broadcast Balloon, Cost-Effective, Route-request, Route-reply, Two-hop neighborhood information.**

Date of Submission: Nov 30, 2015 Date of Acceptance: Dec 04, 2015

I. INTRODUCTION

Ad hoc networks are multi-hop wireless networks consisting of radio-equipped nodes that may be stationary or mobile. They communicate with each other in a collaborative way mostly over multi-hop wireless links without the help of any fixed network infrastructure or centralized administration. These are deployed mainly in battlefields and disaster situations such as earthquakes, floods etc. Many routing protocols have been proposed for ad hoc networks. They can be categorized as proactive and reactive routing protocols.

Among proactive routing protocols, destination-sequenced distance vector (DSDV) [1], wireless routing protocol (WRP) [2], global state routing (GSR) [3] and cluster-based gateway switch routing (CGSR) [4] are well known. In all proactive routing protocols the nodes proactively store rout information to every other node in the network. In general, the proactive routing protocols suffer from extremely huge storage overhead because they store information both about active and non-active routes. This inculcates the unnecessary complexity of discovering routes to the destinations with which a node rarely communicates. Reactive or on-demand routing protocols are designed to reduce this overhead. In reactive routing protocols, when a source node needs to communicate with a destination, it floods route-request packets throughout the network to discover a suitable route to the destination. Dynamic source routing (DSR) [5], ad hoc on-demand distance vector routing (AODV) [7], adaptive communication aware routing (ACR) [8], flow-oriented routing protocol (FORP) [9] and associativity-based routing (ABR) [10] are well-known among the reactive routing protocols. AODV builds routes using a route-request, route reply query cycle. When a source node desires to send packets to a destination for which it does not already have a route, it broadcasts a route-request (RREQ) packet across the network. Nodes receiving this packet update their information for the source node and set up pointers backward to the source node in their routing tables. A node receiving the route-request (RREQ) packet sends a route-reply (RREP) if it is either the destination or has a recently established route to the destination with. Dynamic source routing (DSR) is similar to AODV in that it forms a route on-demand when a source node requests one. It uses source routing instead of relying on the routing table at each device. Determining source routes require accumulating the address of each router in the route-request message. In FAIR [11], the source node transmits RREQ packets that arrive at the destination through multiple paths. Depending upon the locations, residual energy, velocity etc. various characteristics of the routers, the destination node evaluates performance of the paths by considering their stability and agility. Then communication from source to destination begins through one of the best paths. FORP and ABR are link stability based routing protocols that also rely on the flooding of RREQ packets for route discovery. So, if the number of RREQ packets can be reduced then much lesser number of routers will be involved in the route discovery process. As a result, network throughput or data packet delivery ratio enhances with decrease in energy consumption in nodes. This part is taken care of by efficient reactive routing protocols like FORP, ABR, FAIR etc. However these protocols do not focus on the message cost incurred by the broadcast of route-reply packets while discovering a route from destination to source. If reuse of a hop is possible during the transmission of both RREQ and RREP packets, then that will increase weight of the hop in selection of a path from source to destination.

In the present article, a cost effective scheme 2NI is proposed that can be used with any reactive routing protocol for performance enhancement. In 2NI we have rigorously studied the eligibility of each hop in the path options from source to destination, in the context of traversal of route-reply from destination to source. Weight of a hop increases if that can be used for route-reply also. Otherwise, a broadcast operation will be required to discover a route from that router to source. During this broadcast of route-reply, redundancy within two-hop downlink neighborhood of a node is examined and eliminated. Each node within the two hop neighborhood of a router receives RREP packet from exactly one node among the 1-hop and 2-hop downlink neighbors of the same router. This significantly reduces message cost in the network increasing packet delivery ratio and the number of alive nodes preserving network connectivity. Simulation results firmly illustrate these advancements in favor of 2NI embedded reactive routing protocols compared to the ordinary versions of those protocols.

II. PROBLEM DESCRIPTION AND OVERVIEW OF 2NI

During route discovery process, source node broadcasts RREQ packets towards the destination node according to a balloon broadcast structure (described in section III). These packets reach the destination through multiple paths. Among those paths, exactly one is elected for communication depending on different criteria in different protocols. Generally, all the links in a communication route in ad hoc networks are not bidirectional. Therefore in most of the cases, the path that is used for communication from source to destination cannot be completely reused for transmission of acknowledgements or RREP packets from destination to source. In the routing protocols existing in literature, the destination node floods RREP packets towards the source. This incurs huge message overhead. Automatically the energy consumption in the network nodes becomes high. As a result, the number of alive nodes reduce giving rise to network partition. Hence, nodes residing in one part of the network become unreachable for the others decreasing packet delivery ratio up to a great extent.

2NI extracts and utilizes some structural benefits of ad hoc networks arising from advantageous node positions. It encourages the inclusion of bidirectional links in the communication route from source to destination provided it is energy-efficient (remaining energy is high in battery of the two nodes involved in the link) and stable (nodes in the link are presently close enough and have high possibility of staying close in future due to small relative velocity). Sometimes it is also seen that a node cannot reach its immediate predecessor in 1-hop but can directly reach some of the predecessors of its immediate predecessor in the communication route from source to destination.

This can be seen in figure 1 where n_m and n_{m+2} are 1-hop downlink neighbors of n_i although the link from n_p to n_i is not bidirectional. Selection of this kind of links in the route from source to destination enhances the reusability of the route during transmission of RREP from destination to source. Sometimes these cannot be achieved in 1-hop but in 2 hops. For example, in figure 2 it can be seen that n_k acts as the router from n_i to n_{m+1}; Similarly, n_l acts the bridge from n_i to n_p.

If no such advantage can be extracted, then RREP packet has to be broadcasted. For example, consider figure 1. The node n_{m+1} does not have any 1-hop or 2-hop downlink neighbor which is a predecessor of n_{m+1} in the communication route from source to destination. Then 2NI will advise inclusion of the hop from n_m to n_{m+1} in the communication route from source to destination provided n_{m+1} has high residual battery power and huge number of downlink neighbors towards source n_s to which if RREP is forwarded then RREP packets will traverse a great distance to the source. Cost of messages incurred here is worth the advancement towards the source. Moreover this waives out the requirement of more intermediate nodes to reach n_s, saving message cost and energy consumption in network nodes. Weight of the hop from n_m to n_{m+1} increase if n_{m+1} has less number of downlink neighbors that move RREP away from n_s. These movements are mere distractions for RREP packets and even if RREP reach n_s through these downlink neighbors it will have to traverse an unnecessary long path.

III. ROUTE DISCOVERY PROCEDURE OF 2NI

Assume that, in a route S, the link from a node n_a to n_b is broken where the destination is n_d. In order to repair the broken link, n_a initiates a route discovery session to n_d. The last known location of n_d to n_a is at time t1 and its value is $(x_d(t1),y_d(t1))$. Maximum velocity of n_d is vm_d. Since R_{max} is the maximum possible radio-range in the network and H is the maximum possible number of hops, so the maximum possible distance a route-request packet can traverse in its entire lifetime, is HR_{max}. The time required to traverse this distance, is $(HR_{max})/vs$ where vs is the signal speed. Let MQ be the maximum possible size of message queue in a node and tm be the smallest possible time required to forward a message. Then maximum waiting time of a route request packet in a path is H.tm.(MQ-1). So, the total lifetime TL of a route-request packet is formulated as,

$$TL=H[R_{max}/vs+ tm\ (MQ-1)] \qquad (1)$$

The movement of n_d by this time, is bound by a circle $C_d(t1)$ with center $(x_d(t1),y_d(t1))$ and radius $R=(TL\ .\ vm_d)$. 2NI suggests that, instead of broadcasting route-request packets in every direction in the network, it is broadcast in a balloon kind of structure. The route-request packets are bound by the straight lines which are tangents to the circle $C_d(t1)$ drawn from location of n_a at time t i.e. $(x_a(t),y_a(t))$, and the rest portion of the circle itself not covered by those tangents. For example, consider figure 3.

As seen from figure 3, route-requests are broadcast from point A; they remain within the two straight lines AC and AB where tangents from point A touch $C_d(t)$ at points B and C. As B or C is reached, route-request packets traverse within the sector CDB towards O which is center of the circle. Coordinate of O is $(x_d(t1),y_d(t1))$. So, the broadcast balloon is ACDBA.

Area of the broadcast balloon = area of the $\triangle$ ABC + area of $C_d(t1)$ bound by the line CB and arc CDB (2)

On the other hand, area of $C_d(t1)$ bound by the line CB and arc CDB = area of $C_d(t1)$ – area of region CEB
area of region CEB = area of OCEB–area of OCB $\triangle$ (3)

Let the coordinate of C be (h,z). Then,

$$(x_a(t)-h)^2+(y_a(t)-z)^2= C^2 \quad (4)$$

And

$$(x_d(t1)-h)^2+(y_d(t1)-z)^2=R^2 \quad (5)$$

$$\text{Where } C^2=(x_d(t1)-x_a(t))^2+ (y_d(t1)-y_a(t))^2 \quad (6)$$

From (4),

$$h^2+z^2-2hx_a(t)-2zy_a(t)+z1(t)=0 \quad (7)$$

Similarly, from (5),

$$h^2+z^2-2hx_d(t1)-2zy_d(t1)+z2(t)=0 \quad (8)$$

$$\text{here } z1(t)=x^2{}_a(t)+ y^2{}_a(t) - C^2 \quad (9)$$
and
$$z2(t)=x^2{}_d(t1)+y^2{}_d(t1) - R^2 \quad (10)$$
Subtracting (8) from (7),

$$h=(z2(t)-z1(t)-2z(y_d(t1)-y_a(t)))/\{2(x_d(t1)-x_a(t))\} \quad (11)$$

Simplifying from (11),

$$h=p- rz \quad (12)$$

$$\text{where } p=(z2(t)- z1(t)) /\{2(x_d(t1)-x_a(t))\} \quad (13)$$

$$r=(y_d(t1)-y_a(t))/\{(x_d(t1)-x_a(t))\} \quad (14)$$

Putting (12) in (4),

$$z^2(r^2+1)+2zM+ V = 0 \quad (15)$$

$M = r(x_a(t) - p) - y_a(t)$ and

$$V = -2rzp+ (x_a(t) - p)^2 + y^2{}_a(t) - C^2$$

From (15),

$$z = (-2M\pm\sqrt{(4M^2-4(r^2+1)V)})/\{2(r^2+1)\}$$

Let $z\_st = (-M+\sqrt{(M^2-(r^2+1)V)})/\{(r^2+1)\}$ and

$$z\_en = (-M-\sqrt{(M^2-(r^2+1)V)})/\{(r^2+1)\}$$

Corresponding to these possible values z_st and z_en of z, the values of h are h_st and h_en, s.t.

$h\_st = p - r\, z\_st$ and $h\_en = p - r\, z\_en$

Length of CO is denoted as l_co and defined as,
$l\_co = \sqrt{\{(h\_st-x_d(t1))^2+(z\_st-y_d(t1))^2\}}$

Similarly, length of BO is denoted as l_bo and defined as,
$l\_bo = \sqrt{\{(h\_en-x_d(t1))^2+(z\_en-y_d(t1))^2\}}$

Length of CB is denoted as l_cb and defined as,
$l\_cb = \sqrt{\{(h\_st-h\_en)^2+(z\_st-z\_en)^2\}}$

Let θ be the angle ∠COB. Then,

$$\theta = \cos^{-1} \{(l\_co^2+l\_bo^2-l\_cb^2) / (2\, l\_co\, l\_bo)\}$$

So, area of the region OCEB=$(\theta/360)\pi\, l\_co^2$ (16)

Area AR of $\triangle$OCB $=\sqrt{\{Q(Q-l\_co)(Q-l\_bo)(Q-l\_cb)\}}$ (17)

Where $Q = (l\_co+l\_bo+l\_cb)/2$

So, area AR_1 of region CBE = $(\theta/360)\, \pi\, l\_co^2$ - AR

From figure 3, it is evident that area AR_2 of CDB is given by,

$$AR\_2=\pi l\_co^2 - AR\_1 \quad (18)$$

Area of the $\triangle$ABC is denoted by AR_3 and defined by,

$$AR\_3=\sqrt{\{Q1(Q1-l\_ca)(Q1-l\_cb)(Q1-l\_ab)\}} \quad (19)$$

where l_ca, l_bc and l_ab denote the lengths of the arms CA, BC and AB, respectively, of the triangle ABC in figure 3.
So, $l\_ca = \sqrt{\{(h\_st-x_a(t))^2+(z\_st-y_a(t))^2\}}$
$l\_ab = \sqrt{\{(h\_en-x_a(t))^2+(z\_en-y_a(t))^2\}}$

Hence, area AR_4 of the broadcast balloon ACDBA in figure 3 is given by,

$$AR\_4 = AR\_2 + AR\_3$$

IV. HOP SELECTION IN 2NI

Let the hop from n_p to n_i be a part of the route S from source n_s to destination n_d. If n_p is a direct downlink neighbor of n_i, then it is easiest for n_i to send the RREP from n_i to n_p. If n_p is a downlink neighbor of some downlink neighbor of n_i (i.e. 2-hop downlink neighbor) then also it is cost-effective to include the hop from n_p to n_i during communication from source n_s to destination n_d.

Below we illustrate different situations that can take place during computation of weight of each hop.

Case – 1

If n_p or any predecessor of n_p is a direct downlink neighbor of n_i (illustrated in fig. 1), then weight $w_{pi}(t)$ of the hop from n_p to n_i at time t is given by,

$$w_{pi}(t)=\mathrm{MAX}[fr_{pij}(S,t) \exp sd_{pi}(S,t)] \quad \forall\, n_j \in M_i(S,t) \tag{20}$$

where $fr_{pij}(S,t)=W_{pi}(S,t)\{(e_i(t)/E_i)\beta_{pi}(t)\ \beta_{ij}(t)\}$ (21)
and $sd_{pi}(S,t) = (1/(4\times\Phi_{pi}(S,t)))$
Where $M_i(S,t)$ is the set of downlink neighbors of n_i that have been included in S. $W_{ip}(S,t)$ is weight of the hop from n_p to n_i in route S at time t according to the underlying routing protocol. If the routing protocol does not assign any weight to the hop, $W_{pi}(S,t)$ acquires the value 1. $e_i(t)$ and E_i denote the residual charge of n_i at time t and the maximum battery power of the same node, respectively. $\Phi_{pi}(S,t)$ is the number of direct downlink neighbors of n_i in the route S at time t. $\beta_{pi}(t)$ specifies the affinity between the two nodes n_p and n_i in terms of relative velocity, distance radio-range, their history of communication till time t etc. Similarly the significance of $\beta_{ij}(t)$ can also be understood.

$w_{pi}(t)$ will acquire a high value (between 0 and 1) if n_i is not exhausted much already i.e. $(e_i(t) / E_i)$ is high (n_p is already included in the communication route, so its energy need not be considered now; similar case with n_j, it is a predecessor of n_p in the route S), n_p and n_i share a strong wireless bond ($\beta_{pi}(t)$ is high), similarly n_i and n_j are strongly connected ($\beta_{ij}(t)$ is high) and n_p has a significant number of downlink neighbors who have already been included in the route S (i.e. $\Phi_{pi}(S,t)$ is high; this is a measure of reusability of the hop during transmission of RREP packets).

$\beta_{ij}(t)$ denotes affinity of the node n_j w.r.t. n_i at time t and $NE_i(t)$ is the set of 1-hop downlink neighbors of n_i at time t. In (22), n_j has been continuously residing within the 1-hop downlink neighborhood of n_i from $(t - \varpi_{ij}(t))$ to current time t in the present session.

$$\beta_{ij}(t) = \begin{cases} (f1_{ij}(t) \exp f2_{ij}(t)) & \text{if this is the first time the link from } n_i \text{ to } n_j \text{ has been established or } |\psi1_{ij}(t)| = 0 \\ \{\varphi_{ij}(t)\ \ pl\_rt_{ij}(t)\ (f1_{ij}(t) \exp f2_{ij}(t))\}^{1/3} & \end{cases} \tag{22}$$

Where $f1_{ij}(t)=\{1-(|\nu_i(t) - \nu_j(t)| + 1)^{-1}\}$ (23)

$$f2_{ij}(t)=\{d'_{ij}(t) / (R_i + 1)\} \tag{24}$$

$$\varphi_{ij}(t)=[|\psi1_{ij}(t)|f3_{ij}(t)]^{1/2} \tag{25}$$

$$f3_{ij}(t)=((\sum_{\sigma \in \psi1_{ij}(t)} T_{ij}(\sigma))/|\psi1_{ij}(t)|-\varpi_{ij}(t))/(\psi2_{ij}(t)\times\Gamma max_{ij}(t)) \tag{26}$$

$$pl\_rt_{ij}(t)=1- tot\_pkt\_lost_{ij}(t) / (tot\_pkt\_sent_{ij}(t) + 1) \tag{27}$$

Relative velocity of n_i w.r.t. n_j at time t is given by $(\nu_i(t) - \nu_j(t))$. Its effect on $\beta_{ij}(t)$ is modeled as $f1_{ij}(t)$. Please note that $f1_{ij}(t)$ always takes a fractional value between 0 and 1, even when $\nu_i(t) = \nu_j(t)$. As the magnitude of relative velocity of n_i w.r.t. n_j at time t increases, it leads to the reduction in the value of $f1_{ij}(t)$, which in turn, contributes to increase the link stability. $f2_{ij}(t)$ expresses the dependence of $\beta_{ij}(t)$ on the distance between the nodes n_i & n_j at time t. As n_i is the predecessor of n_j at time t, n_j must be within the transmission range (or radio-range) of n_i at that time. Since R_i denotes the radio-range of n_i, upper limit of the distance $d'_{ij}(t)$ between n_i and n_j at time t is R_i. As per the expression of $f2_{ij}(t)$, it also acquires a fractional value between 0 and 1. As $d'_{ij}(t)$ decreases, $f2_{ij}(t)$ decreases enhancing the link performance. As per the history of communication between n_i and n_j till time t is concerned, $\Gamma max_{ij}(t)$ indicates the maximum duration of the link from n_i to n_j in earlier communication sessions occurring between the two nodes till time t. In the formulation of $\varphi_{ij}(t)$, $\psi1_{ij}(t)$ is the set of communication sessions till time t in which n_j resided within the radio-range of n_i for a time duration higher than $\varpi_{ij}(t)$. $\psi2_{ij}(t)$ is the total number of communication sessions that took place between n_i and n_j till time t. $T_{ij}(\sigma)$ is the duration of the link between n_i and n_j in the communication session σ. It is evident that $T_{ij}(\sigma) \le \Gamma max_{ij}(t)$ and $|\psi1_{ij}(t)|$ is less than or equal to $\psi2_{ij}(t)$. So, $\varphi_{ij}(t)$ ranges between 0 and 1. If $\varphi_{ij}(t)$ is high then it signifies that according to the history of communication between n_i and n_j till time t, $(T_{ij}(\sigma) - \varpi_{ij}(t))$ is high in a large number of communication sessions that took place between the two nodes till time t. Hence, the remaining life of the present link between those two nodes is also expected to be high.

$tot\_pkt\_lost_{ij}(t)$ and $tot\_pkt\_sent_{ij}(t)$ denote the total number of packets lost in the link from n_i to n_j till time t and the total number of packets actually sent in that link till time t. So, $(tot\_pkt\_lost_{ij}(t) / tot\_pkt\_sent_{ij}(t))$ is the packet loss rate in the link from n_i to n_j till time t. Lesser is the packet loss rate greater will be reliability of the link. 1 is added to $tot\_pkt\_sent_{ij}(t)$ in (27) to avoid 0 value in the denominator when the link is completely new i.e. $tot\_pkt\_sent_{ij}(t)$ is equal to 0. Since all of $\varphi_{ij}(t)$, $f1_{ij}(t)$, $f2_{ij}(t)$ and $pl\_rt_{ij}(t)$ take positive fractional values, $\beta_{ij}(t)$ is between 0 and 1. This kind of formulation inculcates energy and relative velocity consciousness in route selection even if the underlying protocol does not consider these important factors.

Case – 2

If n_p or any predecessor of n_p in route S is a direct downlink neighbor of any downlink neighbor of n_i (consider fig. 2), then weight $w_{pi}(t)$ of the hop from n_p to n_i at time t is given by,

$$w_{pi}(t)=\mathrm{MAX}[fr1_{pijk}(S,t) \exp sd_{pi}(S,t)] \quad \forall\, n_j \in M'_i(S,t),\ n_k \in NE_i(t) \cap UP_j(t) \tag{28}$$

$$fr1_{pijk}(S,t) = W_{pi}(S,t)\{(e_i(t)/E_i)\ (e_k(t)/E_k)\ \beta_{pi}(t)\ \beta_{ik}(t)\ \beta_{kj}(t)\}$$
$$sd_{pi}(S,t) = (1/(6\times\Phi 1_{pi}(S,t)))$$

$M'_i(S,t)$ is the set of 2-hop downlink neighbors of n_i that have been included in the route S. $UP_j(t)$ is the set of uplink neighbors of n_j at time t. $\Phi 1_{pi}(S,t)$ is the number of two hop downlink neighbors of n_i in S. Significance of all other symbols are explained earlier.

$w_{pi}(t)$ acquires a high value if both n_i and n_k have sufficiently high residual battery power (battery power of n_j has no role to play here since it is already included in the communication route S), stable bonds exist between the pairs n_p and n_i, n_i and n_k, and n_k and n_j. The effect increases if n_i has a high number of 2-hop downlink neighbors included in S.

Case – 3

If both case 1 and case 2 are applicable (illustrated in figure 4), the one that produces more weight is taken into account.

Case – 4

If none of the above cases is applicable, then n_i broadcasts the RREP packet mentioning n_s as destination. If the broadcasted RREP packet arrives at a node n_a which has ns as one of its direct (1-hop) or 2-hop downlink neighbors, then n_a stops further broadcasting and sends the RREP to n_s if n_s is its 1-hop downlink neighbor or to an uplink neighbor of n_s which is a downlink neighbor of n_a. If any node receives same RREP from more than one node, it forwards RREP on the first occasion and discards it in subsequent cases.

Let ST(i,t) denote the set of all 1-hop and 2-hop downlink neighbors of n_i at time t including n_i. Also assume that q-th member of the set $(ST(i,t) – n_i)$ is denoted as n_q and its distance from n_s at time t is $d'_{qs}(t)$. If $d'_{qs}(t) < d'_{is}(t)$, then movement from n_i to n_q (1 or 2 hop whatever) is advantageous because the movement is an advancement towards n_s which is the ultimate goal of RREP packets. The movement will be more cost effective if the movement from n_i to n_q is stable enough in terms of relative velocity, distance and history of communication between the nodes.

$$w_{pi}(t)=(W_{pi}(S,t)\times a1_{pi}(t) \times (e_i(t)/E_i)\ ) / (a2_{pi}(t) \times b_{pi}(t)) \quad (29)$$

$$a1_{pi}(t) = \begin{cases} \Big[\prod\limits_{n_q \in AS(i,t)} \{(1-d'_{qs}(t) / d'_{is}(t))\ \beta_{iq}(t)\}^{1/2}\Big]^{1/|AS(i,t)|]} & \text{if } |\ AS(i,t)| > 0 \text{ and } n_q \text{ is a} \\ & \text{1- hop downlink neighbor of } n_i \\ \Big[\prod\limits_{n_q \in AS(i,t)}\{(1-d'_{qs}(t)/d'_{is}(t))\ (\beta_{im}(t)\ \beta_{mq}(t))^{1/2}\}^{1/2}\Big]^{1/|AS(i,t)|]} & \text{if } |\ AS(i,t)| > 0 \text{ and } n_q \text{ is a} \\ & \text{2- hop downlink neighbor of } n_i \\ & \text{where } n_m \text{ is the intermediate} \\ & \text{node that produces maximum} \\ & \text{value of } (\beta_{im}(t)\ \beta_{mq}(t))^{1/2} \\ & \text{among all the bridge nodes} \\ & \text{from } n_i \text{ to } n_q \\ 0.01 & \text{Otherwise} \end{cases}$$

$$a2_{pi}(t) = 1 -\Big[\prod_{n_q \in (ST(i,t) – n_i - AS(i,t))}\{(1- d'_{is}(t) / (1+d'_{qs}(t)))\Big]^{1/|(ST(i,t) – n_i - AS(i,t))|}$$

$$b_{pi}(t) = \Big(\prod_{n_q \in ST(i,t)} |\kappa_{q,i}(t)| / (|ST(i,t)|-1)\Big)^{1/|(ST(i,t))|}$$

Let AS(i,t) denote the set of such nodes to which movement from n_i is advantageous. Higher is the value of $(d'_{is}(t) - d'_{qs}(t))$ and $|AS(i,t)|$, higher will be weight of the hop from n_p to n_i. So, $|(ST(i,t) – n_i) - AS(i,t)|$ is the set of nodes to which movement from n_i is not advantageous. So if $n_q \in (ST(i,t) – n_i - AS(i,t))$ then $d'_{qs}(t) \geq d'_{is}(t)$. Lesser is the value of $(d'_{qs}(t) - d'_{is}(t))$ and $|(ST(i,t) – n_i - AS(i,t))|$ better for weight of the hop from n_p to n_i. Keeping in mind all these dependencies, $w_{pi}(t)$ for this case is formulated below: $b_{pi}(t)$ deals with the redundancy in two hop downlink neighborhood of n_i. $\kappa_{q,i}(t)$ denotes the set of members of ST(i,t) of which n_q is a direct downlink neighbor at time t. Therefore, $\kappa_{q,i}(t) \subseteq (ST(i,t) – n_q)$. Hence, $|\kappa_{q,i}(t)| \leq (|ST(i,t)|-1)$. If redundancy in two hop downlink neighborhood of n_i is high, then it will decrease weight of the hop from n_p to n_i.

V. SIMULATION RESULTS

Experimental Setup

Simulation of the mobile network has been carried out using ns-2 [15] simulator on 800 MHz Pentium IV processor, 40 GB hard disk capacity and Red Hat Linux version 6.2 operating system. Graphs appear in figures 5 to 12 showing emphatic improvements in favor of cost effective route discovery. Number of nodes has been taken as 20, 50, 100, 300 and 500 in different independent simulation studies. Speed of a node is chosen as 5m/s, 10 m/s, 25 m/s, 35 m/s and 50 m/s in different simulation runs. Transmission range varied between 10m and 50m. Used network area is 500m ×500m. Used traffic type is constant bit rate. Mobility models used in various runs are random waypoint, random walk and Gaussian. Performance of the protocols AODV, ABR and FAIR are compared with their 2NI embedded versions 2NI-AODV, 2NI-ABR and 2NI-FAIR respectively. In order to maintain uniformity of the implementation platform, we have used ns-2 simulator for all the above-mentioned communication protocols. The simulation matrices are data packet delivery ratio (total no. of data packets delivered×100/total no. of data packets transmitted), message overhead (total number of message packets transmitted including data and control packets) and per node delay in seconds in tracking destination (total delay in tracking the destination in different communication sessions / total number of nodes). Simulation time was 1000 sec. for each run.

Experimental Results

Figure 5 shows that the initially the data packet delivery ratio improves for all the protocols with increase in number of nodes and then it starts reducing at least for those protocols that are not immune much to link breakages generated by great increase in number of nodes or increased node speed. For eg, ABR and FAIR are much more immune to this, compared to AODV, as per the underlying functioning logic of the protocol. The reason is that the network connectivity improves with increase in number of nodes, until the network gets saturated or overloaded with nodes. When the overloading occurs, cost of messages become very huge and the packets hinder one another from reaching their destinations by colliding. Figure 7 shows that for all the protocols cost of messages increase with increase in number of nodes. This is quite self-explanatory. Both the route discovery procedure and communication saves a lot of messages. From figure 11 it may be seen that as the number of nodes increase, the communication The reason is that more number of communications is initiated with increased number of nodes and due to better network connectivity more destinations can be tracked now which are far apart. Also the phenomenon of more packet collision increases the delay in tracking destinations. Figures 6,8,10 and 12 are concerned with the influence of node speed on these metrics. As the node speed increases, many links break increasing the network congestion and message collision. Those links need to be repaired using link repair mechanism. This requires a new route discovery session to find a route to n_d from n_b where the broken link is from n_b to n_a. Route discovery once again means the injection of a huge number of route-request packets into the network. Colliding messages are unable to reach their respective destinations; hence they need to be retransmitted. This causes additional delay in the process and injects some more messages. As a result, packet delivery ratio decreases with increased cost and delay.

2NI reduces the injection of route-request packets to a great extent since an intermediate node that has recently communicated with the destination, broadcasts the route-request only to those downlink neighbors from which it is possible to drive the RREQ to the actual destination within the lifetime of RREQ packet generated by the source of the communication session. This increases the node lifetime and reduces the packet collision. The improvements are evident from figures 7, 8, 9 and 10. As far as delay in tracking the destination is concerned, 2NI embedded versions show significant improvement. The reason is that RREQ packets in 2NI embedded versions face much less hindrances due to lesser amount of packet collisions compared to the ordinary versions of those protocols. Therefore, those RREQ packets are driven to their respective destinations much sooner in protocols with 2NI facility.

Please note that the improvement produced by 2NI-AODV over ordinary AODV is more than those produced by 2NI-ABR over ordinary ABR and 2NI-FAIR over ordinary FAIR. The reason is that in AODV, among all discovered routes from source to destination, the one with minimum hop count is elected for communication, without considering stability of the links (stability is expressed mainly in terms of relative velocities between the two nodes forming a link). On the other hand, in ABR, the route with maximum number of stable links is elected as optimal. FAIR is even more conscious on link stability as well as agility. Hence, the phenomenon of link breakage is more frequent in AODV than ABR as well as FAIR. In order to repair the broken link, more RREQ messages are injected into the neighborhood of the broken link in case of ABR and FAIR whereas in AODV a new route discovery session is initiated altogether which requires generation of a huge number of RREQ packets once again. Actually, link breakage in all protocols increases message overhead decreasing the network throughput with different intensity determined by the logic of the protocol itself. Note that, the phenomenon like route discovery and link repair are less devastating in ABR and FAIR than in AODV. So, performance enhancement of 2NI-AODV over AODV is more than that produced by 2NI-ABR over ABR and 2NI-FAIR over FAIR.

Conclusion

2NI proposes a two hop neighborhood information based technique of route discovery as well as route selection, among all available options. This technique can be applied along with any routing protocol for enhancing it's performance i.e. increasing data packet delivery ratio, reducing message cost, energy consumption and communication delay. It gives weight particularly to the bidirectional links so that a route that is used for transmitting data packets to the destination, can be used to transmit acknowledgement packets back to the source. This saves the message cost that would otherwise have been required for discovering a route from destination to source.

REFERENCES

[1] C.E. Perkind & P. Bhagat,"Highly Dynamic Destination Sequenced Distance Vector Routing (DSDV) For Mobile Computers" *Computer Communications Review,* vol. 24 no. 4 1994, pp. 234–244.

[2] S. Murphy, J.J. Garcia-Luna-Aceves, "An Efficient Routing Protocol for Wireless Networks", ACM Mobile Networks and Applications Journal, pages 183-197, Nov.1996. http://citeseer.nj.nec.com/10238.html

[3] T.W. Chen, M. Gerla, "Global State Routing: A new routing scheme for wireless ad hoc networks" , *IEEE Conference On Information, Communication and Control, 1998*

[4] C.C. Chiang et. Al.,"Routing in clustered multi-hop wireless networks with fading channel", *IEEE Conference on Innovative Systems.* 1997, Singapore

[5] Broch, J., Maltz, D., Johnson, D., Hu, Y., , And Jetcheva, J. A performance comparison of multi-hop wireless ad hoc network routing protocols. In

Proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom '98) (Dallas, Texas, USA, Aug. 1998).

[6] A. Kodole, P.M. Agarkar, "A survey of routing protocols in mobile ad hoc networks", Multi-disciplinary Journal of Research in Engg. & Tech, vol.2 no. 1, pg – 336-341, 2015

[7] C.E. Perkins, E.M. Royer, "Ad Hoc On-demand Distance Vector Routing" *IEEE Wokshop on Mobile Computing Systems and Applications.*, 1999

[8] T. Ueda, "ACR: An adaptive communication aware routing through maximally zone-disjoint shortest paths in ad hoc wireless networks with directional antenna", *Journal of Wireless Communication and Mobile Computing, vol. 16 no. 3,* 2007

[9] T.X. Brown, H.N. Babow & Q. Zhang, "Maximum Flow Life Curve for Wireless Ad Hoc networks" *ACM Symposium on Mobile Ad Hoc Networking and Computing*, USA, 2001

[10] C.K. Toh & P. Bhagwat, "Associativity based routing for mobile ad hoc networks", *Wireless Personal Communications, 1997,* vol. 4 no. 2., pp. 1-36

[11] A. Banerjee, P. Dutta, "Fuzzy-controlled adaptive and intelligent route selection (FAIR) in ad hoc networks", *European Journal of Scientific Research*, vol. 45 no. 3, 2010, pp. 367-382

[12] S. Corson,"Ad Hoc Networks: Routing, Performance Issues and Evaluations", *Internet draft, IETF Mobile Ad Hoc Networking Group.* 1999

[13] R. Parasher, Y. Rathi, "A-AODV: A modern routing algorithm for mobile ad hoc networks", International Research Journal of Engg. And Technology, vol. 2 issue 1, 2015

[14] S. Prakash, J.P. Saini, S.C. Gupta, "Methodologies and Applications of Wireless Mobile Ad Hoc Networks Routing Protocols", International Journal of Applied Information Systems, vol. 1, no. 2, 2012

[15] http://www.isi.edu/nsnam/ns/tutorial/

Figures:

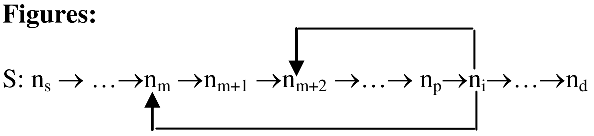

Figure 1: Some predecessors of n_i in S are its 1-hop downlink neighbors

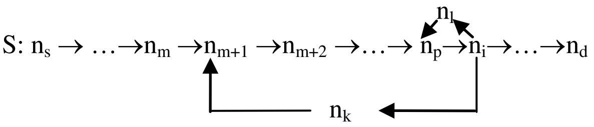

Figure 2: Some predecessors of n_i in S are its 2-hop downlink neighbors

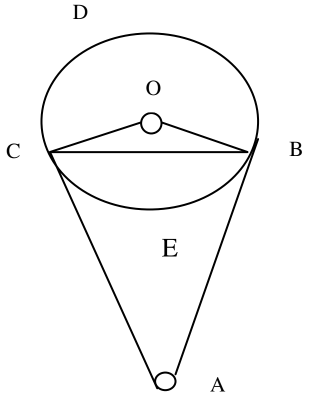

Figure 3: Illustration of broadcast balloon

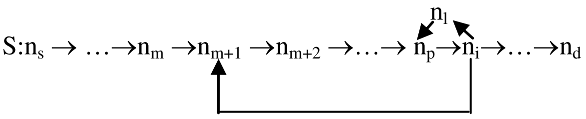

Figure 4: Some predecessors of n_i in S are its 1-hop or 2-hop downlink neighbors

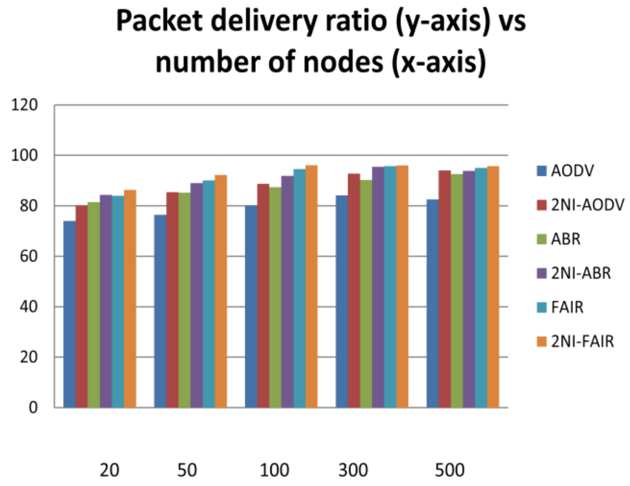

Figure 5: packet delivery ratio vs number of nodes

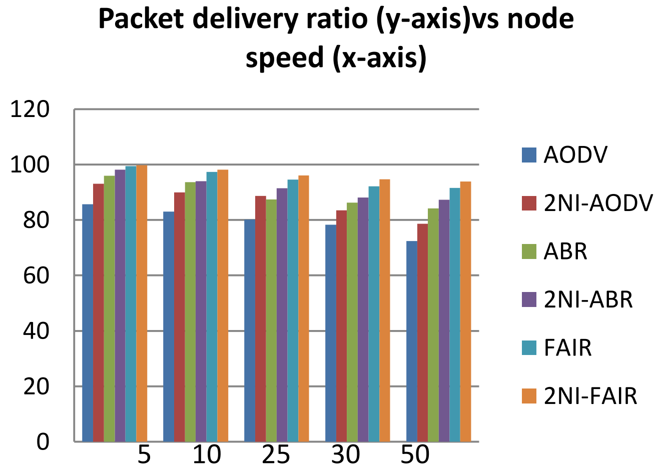

Fig 6: packet delivery ratio vs node speed

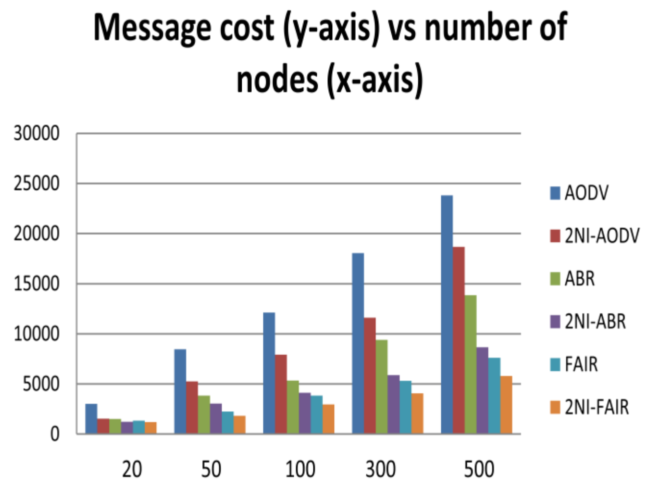

Fig 7: Message cost vs number of nodes

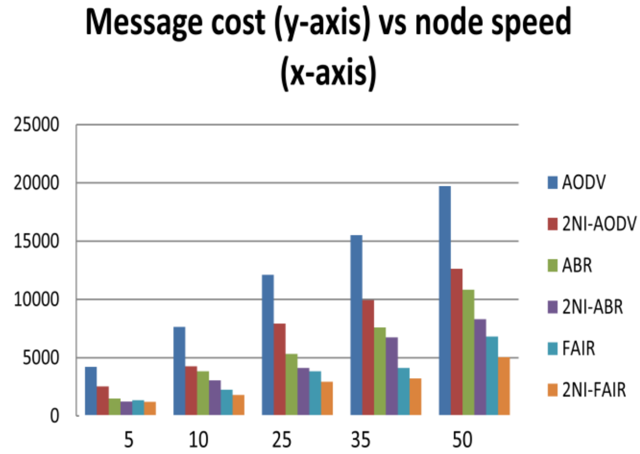

Fig 8: Message cost vs node speed

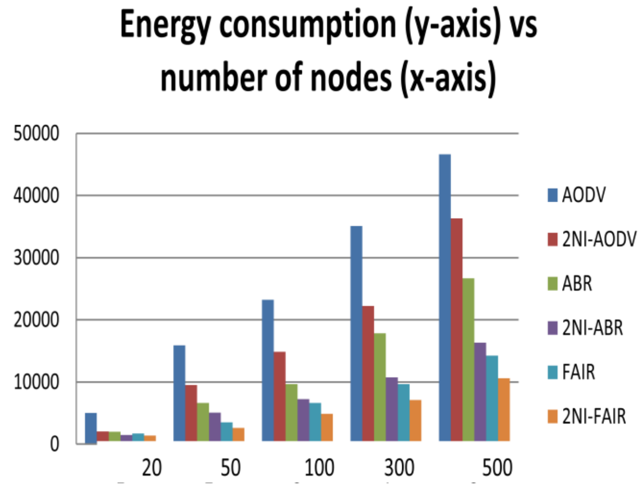

Fig 9: Energy consumption vs number of nodes

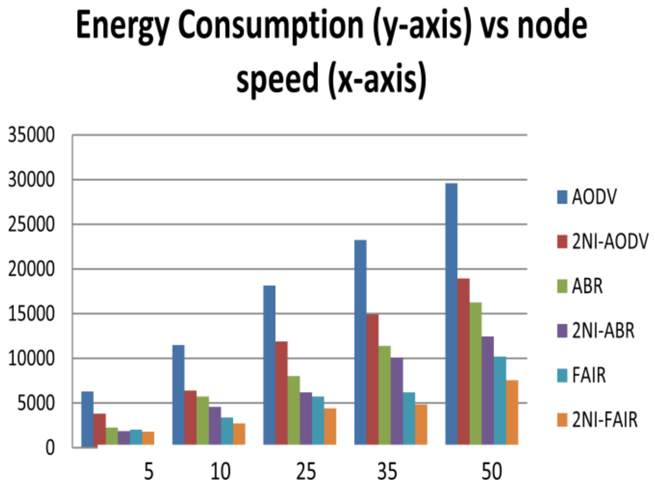

Fig 10: Energy consumption vs node speed

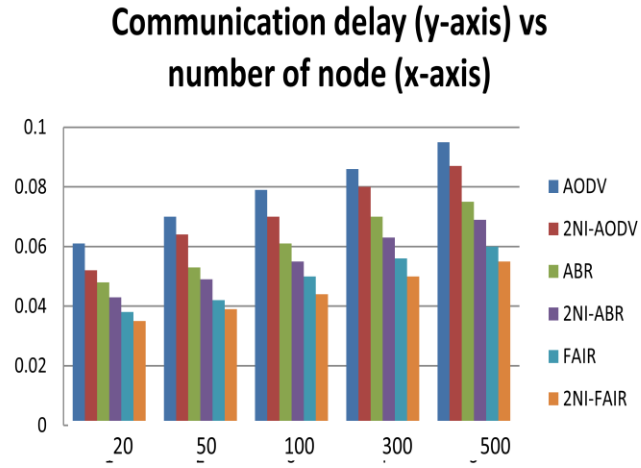

Fig 11: Communication delay vs number of nodes

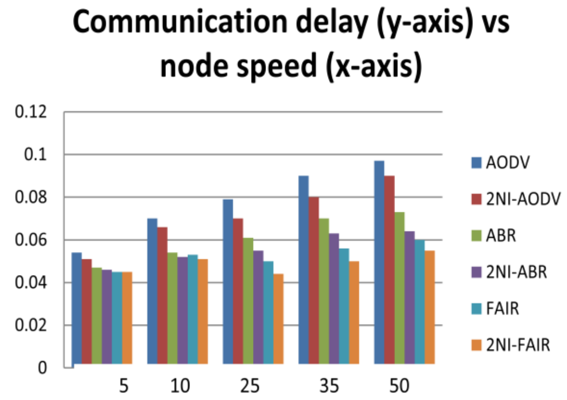

Fig 12: Communication delay vs node speed