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Alternative Node Based Energy Depletion and Expected Residual Lifetime Balancing Method for Mobile Ad Hoc Networks

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---ABSTRACT---
A mobile ad hoc network is an infrastructure less network, where nodes are free to move independently in any direction. The nodes have limited battery power; hence we require efficient balancing techniques (energy depletion or expected residual lifetime, whichever is applicable under specific circumstances) to reduce overload on the nodes, wherever possible, to enhance their lifetime and network performance. This kind of balance among network nodes increase the average lifetime of nodes and reduce the phenomenon of network partitioning due to excessive exhaustion of nodes. In this paper, we propose an alternative-node based balancing method (ANB) that channels the forwarding load of a node to some other less exhausted alternative node provided that alternative node is capable of handling the extra load. This greatly reduces the number of link breakages and also the number of route-requests flooded in the network to repair the broken links. This, in turn, improves the data packet delivery ratio of the underlying routing protocol as well as average node lifetime.

Keywords - Ad hoc network, Alternative Node, Energy Depletion, Link Breakage, Expected Residual Lifetime Balancing.

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I. INTRODUCTION

An ad hoc network is a group of wireless mobile devices or nodes that communicate with each other in a collaborative way over multi-hop wireless links without any stationary infrastructure or centralized management. These networks are deployed mainly in battlefields and disaster situations such as earthquake, floods etc. Many routing protocols have been proposed for ad hoc networks. They can be mainly 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 route 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 through out 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 relaying 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

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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 in the ANB versions of the above-mentioned routing protocols compared to their ordinary versions. As a result, network throughput or data packet delivery ratio enhances with decrease in energy consumption in nodes.

Our present article proposes a alternative-node based balancing method (ANB) technique for in ad hoc networks where the forwarding load of a node is transferred partly to an alternative one in a very specific manner so that the average longevity of the nodes increase. This reduces the phenomena like link breakage and network partitioning. Automatically it reduces the cost of message and average energy consumption in network nodes. This, in turn, decreases the number of packet collision in the network and improves the network throughput or data packet delivery ratio. Our proposed technique can be applied with any reactive routing protocol to enhance the performance of the protocol.

II. THE SCHEME OF ANB

The entire concept of ANB is dependent upon the notion of alternative nodes. It is defined below.

Definition : Alternative Node

A node n_j is termed as an alternative to another node n_i where $n_i \neq n_j$ (i.e. a node cannot be the alternative of its own), if n_j has the same set of uplink and downlink neighbours of n_i at the same time, except the nodes themselves. For example, let $U_i(t)$ and $D_i(t)$ denote the set of uplink and downlink neighbours of n_i at time t. So, n_i and n_j will be alternatives provided the following conditions are satisfied:

i) $U_i(t) – \{ n_j \} = U_j(t) – \{ n_i \}$

ii) $D_i(t) – \{ n_j \} = D_j(t) – \{ n_i \}$

Please note that the alternative nodes need not necessarily be the neighbours (uplink or downlink) of one another.

2.1 How to find out alternatives

In ANB, each node transmits HELLO message within its radio-range at regular intervals which is received by its downlink neighbours. In response, the downlink neighbours transmit the ACK or acknowledgement message to sender of the HELLO message. The components of HELLO message transmitted by a node n_i at time t, are given by,

i) Node identification number n_i

ii) Current timestamp t

iii) Identification number of uplink neighbours i.e. $U_i(t)$

iv) Identification number of downlink neighbours i.e. $D_i(t)$

v) Radio range rad(i)

vi) Geographical location i.e. $(x_i(t), y_i(t))$ where $x_i(t)$ is the latitude of n_i at time t and $y_i(t)$ is the longitude of the same node at the same time

vii) Forwarding load p_i so far, in terms of number of packets forwarded per second (for these packets n_i is not the source)

viii) Amount of energy α_i required to forward each packet

ix) Total battery power E_i

x) Residual battery power P_i at the current time

xi) Time t_i of starting operation in the network

xii) Number of packets pt_i transmitted as source so far by n_i

xiii) Total size M_i of message queue

xiv) Number of messages W_i waiting in the message queue at that time

On the other hands, the components of ACK message transmitted by a downlink neighbour n_p of n_i at time t, are given by

i) Sender identification number n_p

ii) Receiver identification number n_i

iii) Identification numbers of the alternatives of n_i

iii) Current timestamp t

As soon as a node n_p receives two HELLO messages from two nodes n_i and n_j then n_p compares between the uplink and downlink neighbour sets mentioned in those HELLO messages. If they satisfy the criteria of alternative nodes, then n_p embeds the identification number n_i in the ACK that it sends to n_j and the identification number n_j in the ACK that it sends to n_i. More than one such alternative can be found in such way. Among all the downlink neighbours of the alternative nodes, the one with least identification number performs all the balancing computations and informs the alternative nodes about their actual forwarding load for balanced environment for each alternative node in a message ALT. The components of ALT sent by n_p are as follows:

i) Sender identification number n_p

ii) Receiver identification number n_i

iii) (Identification number of alternative n_j, balancing method , balanced forwarding load of n_i, balanced forwarding load n_j, M_j, W_j) for each alternative n_j of n_i; The balancing method is both residual lifetime balancing and energy depletion balancing.

Note: The alternative relation is non-reflexive, symmetric and transitive. Its proof is given in the appendix section.

2.2 Balance of Energy Depletion and Residual Lifetime

At any point of time, let n_j be an alternative of n_i. Balancing (energy depletion or residual lifetime) is performed as per the following cases. Without any loss of

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generality these conditions are based on the assumption that n_j started operating after n_i i.e. $t_i < t_j$):

Case -1

When n_j started operation, the residual energy of n_i at that time was higher than the total battery power of n_j and at present the residual battery power of n_i is less than the present residual battery power of n_j although the number of packets transmitted by n_i as source is lesser than the number of packets transmitted by n_j as source. These are mathematically expressed as follows:

i) $(E_i – p_i \alpha_i (t_j – t_i) - pt_i \alpha_i) > E_j$

ii) $R_i < R_j$

iii) $pt_i < pt_j$

The situation indicates that n_i has forwarded much more packets than n_j. In this case, we go for residual energy balancing provided the average node lifetime doesn't deteriorate (this is discussed in detail in section 2.3).

Case -2

If the conditions mentioned in case 1 are not true or somehow residual lifetime cannot be balanced then we try for energy depletion balancing.

2.3 Pair-wise Balance of Residual Lifetime

After balance of expected residual lifetime some of the forwarding load of n_i is channelled through n_j because at present the forwarding load p_i of n_i is greater than the forwarding load p_j of n_j. For this channelling, n_i need to communicate with some of its uplink neighbours and need to inform them that they will forward the packets to n_j now instead of n_i. Let, the upper limit of time duration for this kind of communication from n_i with uplink neighbours is given by τ_{max}. Also assume that R'_i and R'_j denote the residual energy of n_i and n_j after time duration τ_{max} where R_i and R_j are initial energy of the nodes n_i and n_j.

Then,

$$R'_i = R_i - p_i\alpha_i\tau_{max} \quad (1)$$

$$R'_j = R_j – p_j \alpha_j \tau_{max} \quad (2)$$

Let p'_i and p'_j denote forwarding load of n_i and n_j after residual lifetime balancing.

$$\text{So, } (p'_i + p'_j) = (p_i + p_j) \quad (3)$$

After lifetime balancing, the new energy depletion rate of n_i is $p'_i \alpha_i$ per second. Then the expected remaining lifetime of n_i after lifetime balancing is $(R'_i / (p'_i \alpha_i))$. The same of n_j is $(R'_j / (p'_j \alpha_j))$. These two are equal since residual lifetime has been balanced. So,

$$R'_i / (p'_i \alpha_i) = R'_j / (p'_j \alpha_j) \quad (4)$$

$$\text{i.e. } p'_i = p'_j (R'_i \alpha_j) /(R'_j \alpha_i) \quad (5)$$

Replacing p'_i by $\{p'_j (R'_i \alpha_j) /(R'_j \alpha_i)\}$ in (3) we get,

$$p'_j (1 + (R'_i \alpha_j) /(R'_j \alpha_i)) = (p_i + p_j) \quad (6)$$

$$\text{So, . } p'_j = \{(p_i + p_j) (R'_j \alpha_i)\} / \{(R'_i \alpha_j + R'_j \alpha_i)\} \quad (7)$$

If p'_j is a fraction, we take, $p'_j = \lceil p'_j \rceil$. Putting this in (3) we get,

$$p'_i = (p_i + p_j - p'_j) \quad (8)$$

2.4 Effect of Balancing Residual Lifetime on Average Node Lifetime

Initial residual lifetime IL_i of node n_i and the same IL_j of n_j are as follows:

$$IL_i = R'_i / (p_i \alpha_i) \quad (9)$$

$$IL_j = R'_j / (p_j \alpha_j) \quad (10)$$

After balancing, the balanced residual lifetime BL_i of node n_i and the same BL_j of n_j are given by,

$$IL_i = R'_i / (p'_i \alpha_i) \quad (11)$$

$$IL_j = R'_j / (p'_j \alpha_j) \quad (12)$$

Without any loss of generality, please assume that $p_i > p'_i$. Then, automatically $p_j < p'_j$ because $(p'_i + p'_j) = (p_i + p_j)$. It means that n_i gains in terms of residual lifetime whereas n_j losses it.

$$\text{Let } (p_i - p'_i) = (p'_j - p_j) = c \quad (13)$$

Lifetime gain G_i of n_i is formulated as,

$$G_i = R'_i / (p'_i \alpha_i) - R'_i / (p_i \alpha_i) \quad (14)$$

Therefore, $G_i = (R'_i / \alpha_i) (1/ p'_i – 1/p_i)$

i.e. $G_i = (R'_i / \alpha_i) \{1/ p'_i – 1/(p'_i +c)\}$

$$\text{i.e. } G_i = (R'_i / (p'_i \alpha_i)) (c/(p'_i +c)) \quad (15)$$

Lifetime loss L_j of n_j is formulated as,

$$L_j = R'_j / (p_j \alpha_j) - R'_j / (p'_j \alpha_j) \quad (16)$$

Therefore, $L_j = (R'_j / \alpha_j) (1/ p_j – 1/p'_j)$

i.e. $L_j = (R'_j / \alpha_j) \{1/(p'_j - c) - 1/ p'_j \}$

$$\text{i.e. } L_j = (R'_j / (p'_j \alpha_j)) (c/(p'_j - c)) \quad (17)$$

Since after residual lifetime balancing $R'_i / (p'_i \alpha_i) = R'_j / (p'_j \alpha_j)$, so for $G_i > L_j$ to be true, the required condition is,

$c/(p'_i +c) > c/(p'_j - c)$

i.e. $1/p_i > 1/p_j$ (from (13))

i.e. $p_i < p_j$

If $p_i=p_j$ then the average node lifetime remains unaffected and if $p_i>p_j$ then the average node lifetime decreases. During balancing, the average node lifetime should not suffer.

2.5 Pair-wise Balance of Energy Depletion

After balancing, let p'_i and p'_j denote forwarding load of n_i and n_j.

So, $(p'_i + p'_j) = (p_i + p_j)$

Energy depletion rates of n_i and n_j are given by $(p'_i \alpha_i)$ and $(p'_j \alpha_j)$ respectively. For balanced energy depletion, these two must be made equal. So,

$$p'_i \alpha_i = p'_j \alpha_j \quad (18)$$

$$\text{So, } p'_i = p'_j \alpha_j / \alpha_i \quad (19)$$

Putting this in (3) we get,

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$p'_j = (p_i + p_j)\,\alpha_i \,/\, (\alpha_i + \alpha_j)$ (20)

If p'_j is a fraction, we take, $p'_j = \lceil p'_j \rceil$. Putting this in (3) we get,

$p'_i = (p_i + p_j - p'_j)$

The utility of energy depletion rate balancing is that it arrests further deterioration of difference of residual energy of n_i and n_j.

The proof is given in the appendix section.

2.6 Effect of Balancing Energy Depletion on Average Node Lifetime

In this case also, the expressions for G_i and L_j remain same as in section 2.3. Since after energy depletion balancing, $(p'_i\ \alpha_i) = (p'_j\ \alpha_j)$, so for $G_i > L_j$ to be true, the required condition is,

$c\,R'_i/(p'_i + c) > c\,R'_j/(p'_j - c)$ (21)

i.e. $(R'_i/p_i) > (R'_j/p_j)$ (from (13))

If $(R'_i/p_i) = (R'_j/p_j)$ then the average node lifetime remains unaffected and if . $(R'_i/p_i) < (R'_j/p_j)$ then the average node lifetime decreases. During balancing, the average node lifetime should not suffer.

III. How alternative nodes help in routing

Let n_j be an alternative of n_i. Without any loss of generality we can assume that n_i channels some of its load through n_j i.e. $p'_i < p_i$ and $p'_j > p_j$. Balancing will be possible if the message queue of n_j can handle the extra load i.e. $(M_j - W_j - (p'_j - p_j)) \geq 0$. Accordingly n_i instructs some of its uplink neighbours to canalize their packets through n_j now instead of n_i. If the link from an uplink neighbour to n_i breaks, that neighbour now forwards the packet destined to n_i, to n_j now, instead of initiating a new route discovery session, saving a huge amount of message cost.

Preventing route discovery during link repair saves a huge amount of message cost.

Proof: With the initiation of a new route discovery session, route request packets are broadcast in the network which traverse at least 1 and at most H hops (i.e. (1+H)/2 hops on an average) where H is the maximum allowable hop count in the network. Please assume that, on an average, the number of downlink neighbours of a node is q. So, on an average, the number RR of route request packets generated is given by

$RR = q+q^2+q^3+\ldots+q^{(H+1)/2}$

i.e. $RR = q(q^{(H+1)/2}-1)/(q-1)$ (22)

Preventing the injection of RR amount of route request packets into the network in the context of repairing each broken link, is a huge one. This reduces message collision in ANB embedded protocols increasing the data packet delivery ratio.

Repairing the link through a balanced alternative protects the energy efficiency of the path. Actually, alternative nodes are a ready and effective solution to the link breakage problems. Improvement in average node lifetime in ANB produces more alive nodes at any point of time in the network as far as ANB-embedded protocols are concerned compared to their ordinary versions. The utility of ANB embedded routing protocols is very high in today's dense networks where alternative nodes are easily available.

IV. Simulation Results

Simulation of the mobile network has been carried out using ns-2 [12] 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 2 to 7 showing emphatic improvements in favor of limited area 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. In the simulation runs where speed is varied, number of nodes is kept constant at 300. Similarly, when number of nodes is varied, the speed is kept constant at 25 m/s. Transmission range varied between 20m and 100m. Used network area is 500m $\times$500m. Used traffic type is constant bit rate. Mobility models used in various runs are random waypoint, random walk and Gaussian. Performance of the protocols AODV, ABR and FAIR are compared with their ANB embedded versions ANB-AODV, ANB-ABR and ANB-FAIR respectively. In order to maintain uniformity of the implementation platform, we have used ns-2 simulator for all the above-mentioned communication protocols. The simulation matrices are data packet delivery ratio (total no. of data packets delivered$\times$100/total no. of data packets transmitted), message overhead (total number of message packets transmitted including data and control packets) and alive node ratio (total no. of alive nodes$\times$100/total no. of nodes in the network). Simulation time was 1000 sec. for each run.

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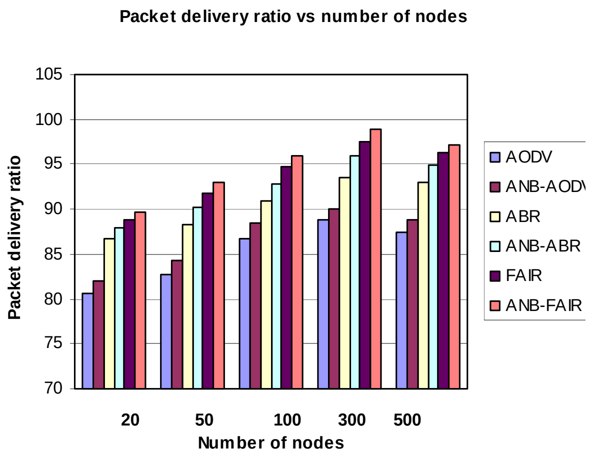

Figure 2: Data packet delivery ratio vs number of nodes

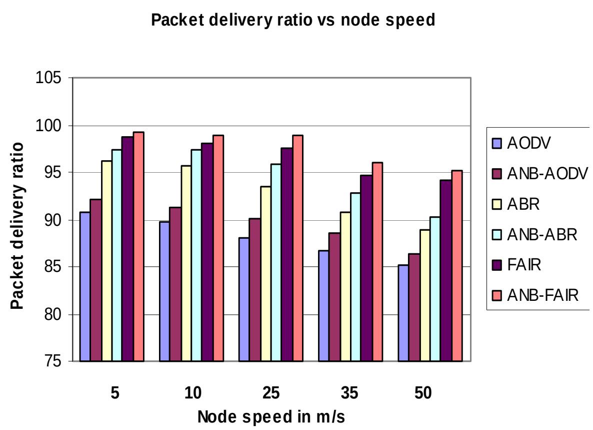

Figure 3: Data packet delivery ratio vs node speed

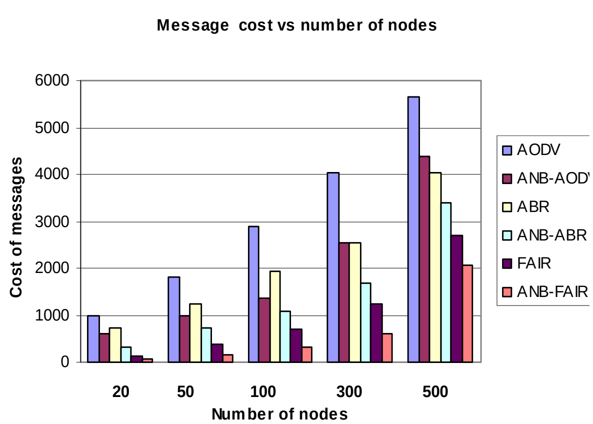

Figure 4: Cost of messages vs number of nodes

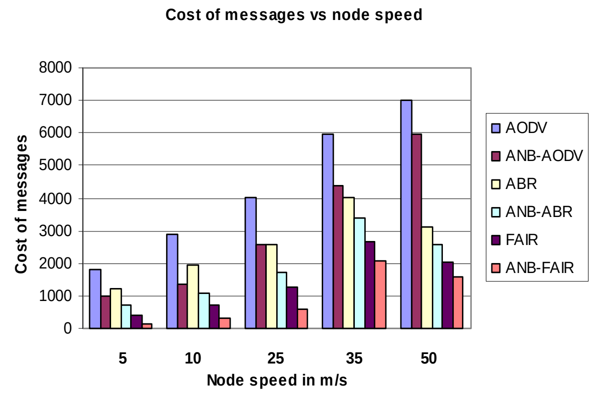

Figure 5: Cost of messages vs node speed

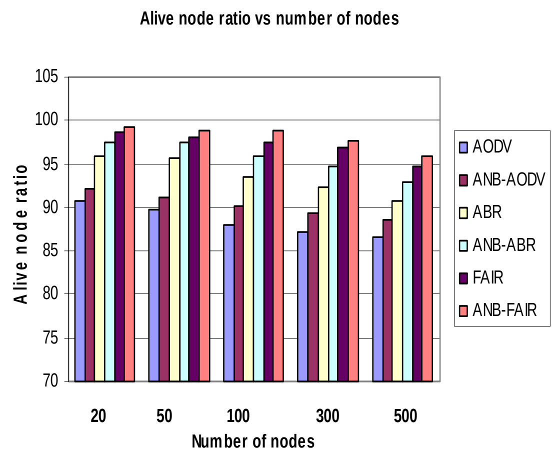

Figure 6: Alive node ratio vs number of nodes

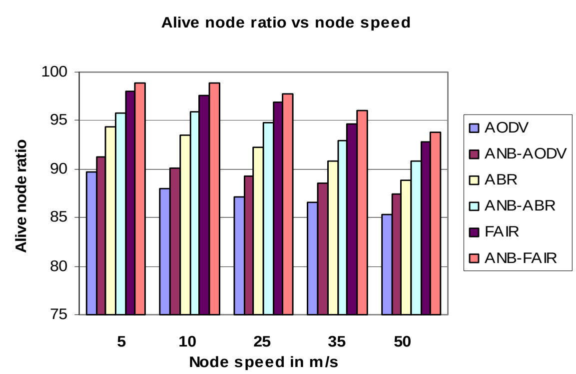

Figure 7: Alive node ratio vs node speed

Figure 2 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. 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 again by colliding. Figure 4 shows that for all the protocols cost of messages increase with increase in number of nodes. This is quite self-explanatory. From figure 6 it may be seen that as the number of nodes increase, the alive node ratio decreases. 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 were initially disconnected. This, along with the phenomenon of more packet collision increases the energy consumption in nodes reducing the alive node ratio. Figures 3, 5 and 7 are concerned with the influence of node speed on these metrics. As the node speed increases, many new links form and older ones break increasing the network congestion and message collision. Colliding messages are unable to reach their respective destinations; hence they need to be retransmitted. This causes injection of some more route-request messages. As a result, packet delivery ratio and alive node ratio decreases with increased cost.

ANB improves the average lifetime of network nodes. Automatically it reduces the occurrence of link breakage due to node exhaustion and tremendously contributes to avoid network partition. This not only improves alive node ratio of ANB-embedded routing protocols compared to their ordinary versions, but also significantly reduces the number of route-request messages that would have been otherwise injected into the network to repair the links broken due to node exhaustion. This reduces the packet collision. As a result, data packet delivery ratio of ANB embedded versions of the above-mentioned protocols also increase compared to the ordinary versions of those. The improvements are evident from figures 2 to 7.

Please note that the improvement produced by ANB-AODV over ordinary AODV is more than those produced by ANB-ABR over ordinary ABR and ANB-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 ANB-AODV over AODV is more than that produced by ANB-ABR over ABR and ANB-FAIR over FAIR.

V. Conclusion

The concept of alternative node based balancing (ANB) presented in this paper greatly reduce message overhead of the network by increasing the average node lifetime. As a result, data packet delivery ratio increases along with alive node ratio with the decreased message cost. Also the phenomenon like network partitioning can also be avoided up to a great extent in ANB-embedded protocols. In today's dense network, the utility of ANB embedded protocols are more applicable because it increases the chance of finding alternative nodes.

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Appendix

Here the following two propositions are proved.

Proposition 1: The alternative relation is non-reflexive, symmetric and transitive.

Proof: As per the definition of alternative node, since a node cannot be its own alternative, so the alternative relation is non-reflexive.

In order to prove the symmetric property, let n_j ($n_j \neq n_i$) be an alternative node of n_i at time t. So,

i) $U_i(t) – \{ n_j \} = U_j(t) – \{ n_i \}$

ii) $D_i(t) – \{ n_j \} = D_j(t) – \{ n_i \}$

Interchanging the L.H.S. of the above equations by their respective R.H.S. we get,

i) $U_j(t) – \{ n_i \}= U_i(t) – \{ n_j \}$

ii) $D_j(t) – \{ n_i \} = D_i(t) – \{ n_j \}$

These are the conditions for n_i to be an alternative of n_j at the same time t. So, the relation is symmetric.

In order to prove the transitivity property, let n_j be an alternative of n_i and n_k be an alternative of n_j at time t. Then,

i) $U_i(t) – \{ n_j \} = U_j(t) – \{ n_i \}$ (23)

ii) $D_i(t) – \{ n_j \} = D_j(t) – \{ n_i \}$ (24)

and

i) $U_j(t) – \{ n_k \} = U_k(t) – \{ n_j \}$ (25)

ii) $D_j(t) – \{ n_k \} = D_k(t) – \{ n_j \}$ (26)

Subtracting $\{n_k\}$ from both sides of (13), we get

$U_i(t) – \{ n_j \} – \{n_k\} = U_j(t) – \{ n_i \}– \{n_k\}$ (27)

Replacing ($U_j(t) – \{ n_k \}$) by ($U_k(t) – \{ n_j \}$) in (17),

$U_i(t) – \{ n_j \} – \{n_k\} = U_k(t) – \{ n_j \}– \{ n_i \}$ (28)

Cancelling $\{ n_j \}$ from both sides of (28) we get,

$U_i(t) – \{ n_k \} = U_k(t) – \{ n_i \}$ (29)

Similarly subtracting $\{n_k\}$ from both sides of (24), we can prove that

$D_i(t) – \{ n_k \} = D_k(t) – \{ n_i \}$ (30)

If (29) and (30) are true, then we can say that n_k is an alternative of n_i.

Proposition 2: The utility of energy depletion rate balancing is that it arrests further deterioration of difference of residual energy of n_i and n_j where n_j is an alternative of n_i.

Proof: Let at time t, the residual energies of n_i and n_j are R_i and R_j respectively. Also assume that after time interval τ, their residual energies will be $R1_i$ and $R1_j$ respectively. Then,

$R1_i = R_i - p_i \alpha_i \tau$ (31)

and

$R1_j = R_j – p_j \alpha_j \tau$ (32)

So, $R1_i - R1_j = R_i - p_i \alpha_i \tau - R_j + p_j \alpha_j \tau$ (33)

Since energy depletion rate is balanced, so $p_i \alpha_i = p_j \alpha_j$

Putting this in (33) we get

$R1_i - R1_j = R_i - R_j$ (34)

The equation (24) indicates that after energy depletion rate balancing, the difference of residual energy of n_i and n_j does not deteriorate.

Authors Biography

Dr. Anuradha Banerjee is an assistant professor in the department of Computer Applications at Kalyani Govt. Engg. College. She completed her B.E. from Bengal Engineering College Sibpur in 2001 and Ph.D. from West Bengal University of Technology in 2013. Her research areas are Ad hoc network, Soft computing and Neural networks. She has 22 publications in different international and journal journals.

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