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Probabilistic Virtual Head Selection based Proactive Routing Mechanism in Military MANET

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Abstract: Routing in a military MANET requires a complex strategy to provide highly reliable communication amongst the nodes. Modern Tactical Communication Networks (MTCN) requires integration of existing legacy networks (like semi-ad hoc) and fully IP based mobile ad hoc networks (IPV6 and Mobile IPV6 compatible or scalable features). Routing in MANET based MTCN requires a complex strategy to provide highly reliable communication amongst the nodes. Developing a routing algorithm for such a dynamic environment is cumbersome exercise. In this study, we propose a novel Probabilistic Virtual Head based proactive routing mechanism (ProVH) where the selection of high power nodes in a given geographical area is based on a probabilistic method by analyzing pre-historical and current statistical movement of all nodes. ProVH considers the factors such as node's mobility, power, memory and storage for dynamic selection of virtual heads in a distributed MTCN. Simulation and experimental analysis shows that ProVH routing protocol improves the routing metrics in a large scale MANET deployed environment. ProVH proves to be highly proactive and efficient in setting up high reliability for critical infra-structure in terms of varied mobility patterns. The results were analyzed and compared with known proactive protocols like OLSR, ZRP in terms of throughput, delay, packet delivery ratio, routing overhead and network balancing. Our protocol ProVH outperforms in a critical and resource constraint tactical mobile ad hoc networks enhancing quality of service and experience.

Key words: MANET, tactical communication networks, probabilistic virtual head selection, proactive routing, benders decomposition, linear programming

INTRODUCTION

Mobile ad hoc network is a collection of independent mobile nodes that can communicate to each other via. radio waves. These networks are fully distributed and can work at any place without the help of any fixed infrastructure such as access points or base stations. The infrastructure-less technology also known as the ad hoc network connects the wireless nodes without the requirement of any access points. When such kind of wireless nodes are moving then they become mobile ad hoc networks also known as MANETs (Jeng and Jan, 2011; Kumar and Mishra, 2012). MANETs provide robust and efficient operation in mobile environments. The mobile nodes that are in radio range of each other can directly communicate whereas, others need the aid of intermediate nodes to route their packets. Each of the nodes has a wireless interface to communicate with each other. In ad hoc networks all the mobile nodes are dynamically connected in an arbitrary manner. Nodes in such network maintain their own routes to other nodes in the network (examples, like rescue operations in defence service). There is no background network for the central control of the network operations, the control of the network is distributed among the nodes. The nodes involved in a MANET (Ghaderi *et al*., 2009) should cooperate with each other and communicate among themselves and each node acts as a relay as needed to implement specific functions such as routing and security (Deng *et al*., 2002; Goyal *et al*., 2011). Each nodes act as light-weight (less CPU capability, low power storage and small memory size) independent terminal which could function as both a host and a router. Network topology dynamically changes at unpredictable time as each mobile node are free to move arbitrarily with different speeds. Though ad hoc network is self-configuring, scalable, independent from central network administration, robust and less expensive when compared to wired network, its challenge lies in its mobility, dynamic topology, limited bandwidth, packet loss due to transmission errors, etc., Mobile Ad hoc (MANET) routing protocol's (Hinds *et al*., 2013; Muralishankar and Raj, 2014) has been an important research field. The focus of these routing studies concerns the investigation of the

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effects of changing routing protocol parameters on their performances in different environments. The performance metrics determine which protocol is suitable for a specific application for each environment case. Routing algorithm for MANETs usually assumes that nodes are cooperative and non-malicious. Tactical communication systems consists of semi-ad hoc and fully-ad hoc network (Breed, 2007) elements like hand held radios, ManPackRadios, low mobility vehicles, high mobility vehicles, Tankers, Power supply units, ammunition dispatchers, etc. It is highly heterogeneous in terms of varying usage of computation and communication. Modern tactical communication networks requires integration of existing legacy networks (like semi-ad hoc) and fully IP based mobile ad hoc networks (IPV6 and mobile IPV6 compatible or scalable features). Developing a routing algorithm for such a dynamic environment is cumbersome exercise. Few routing protocols like AODV (Mohseni *et al*., 2010), OLSR, DSR, Loose-virtual-clustering-based Routing for power heterogeneous MANETs (Taneja and Kush, 2010; Zhao *et al*., 2013; Bakht *et al*., 2011) were deviced for tactical networks but do not support a power heterogeneous environment. These existing routing protocols are often destructive in non-delay tolerance, overloading factors (Liu *et al*., 2011), least network balancing and poor performance in QoE (Quality of Experience). Most often reactive approach develops multipath between source and destination in order to avoid link failure and robustness. Proactive protocols can save a lot of overhead during route discovery. In proactive link-state protocols such as OLSR, nodes maintain a view of the network topology by communicating with their neighbors. With a complete view, the protocols can find routes in networks. But partial views are used to reduce the cost.

In this study, we propose a novel routing protocol called ProVH (Probabilistic Virtual Head) which makes use of a proactive power heterogeneous routing mechanism where the selection of such high power nodes in a given geographical area is based on a probabilistic method of analyzing pre-historical and current statistical movement of all nodes. ProVH considers the factors such as node's mobility, power, memory and storage for dynamic selection of virtual heads in a distributed MTCN. Using ProVH, non-uniform virtual clusters are formed for local routing among MANETs. A backbone link is established among virtual cluster heads in the network for global routing. This methodology efficient reduces the routing overhead during route discovery thereby reducing latency and bandwidth utilization. Novel aspect of the proposed approach lies in spreading traffic load uniformly among the VCH statically distributed across tactical battlefield area. We have implemented the proposed protocol using OMNET++ network simulator integrated with MATLAB and analyzed its behaviors. Simulation and experimental results shows that protocol has higher efficiency in to destination w.r.t reduction in packet loss rate, packet replication and lower latency thereby increasing the overall network life time. Simulation results show that reach higher network balance compared to other existing protocols and outperforms it in terms of desired delivery rate average loss rate, packet replication and lower latency thereby increasing the overall network life time.

MATERIALS AND METHODS

System description: We consider an autonomous ad hoc working on its own. It has no gateway or connection to the external world. The network is formed starting from one node and then the other nodes add up one by one. The Mobile Ad hoc Network (MANET) is connected with mobile nodes like Tanker, ManPackRadio (MPR) and a military jeep. Every node has varied transmission power and exhibit bidirectional communication to each other during the initial stage of the network deployment. Network structure of the proposed ProVH model is shown in Fig. 1. The proposed ProVH routing mechanism consists of two phases:

- Topology formation phase
- Route discovery phase

Topology formation phase: Formation phase as depicted in Fig. 2 categorized into the following:

- Election of virtual cluster head
- Loose virtual cluster construction
- Backbone link establishment

Election of virtual cluster head: Among the set of mobile nodes, coordinate head referred as virtual cluster head is selected. Factors considered for virtual cluster head selection is average transmission power, low optimal storage capacity and computation memory. The node that satisfies these criteria is elected as Virtual Cluster Head (VCH).

Loose virtual cluster construction: Once the virtual cluster head is selected, non-uniform virtual cluster formation is triggered. Loose virtual cluster is constructed based following conditions have only optimal number of nodes (m) within each cluster, i.e.:

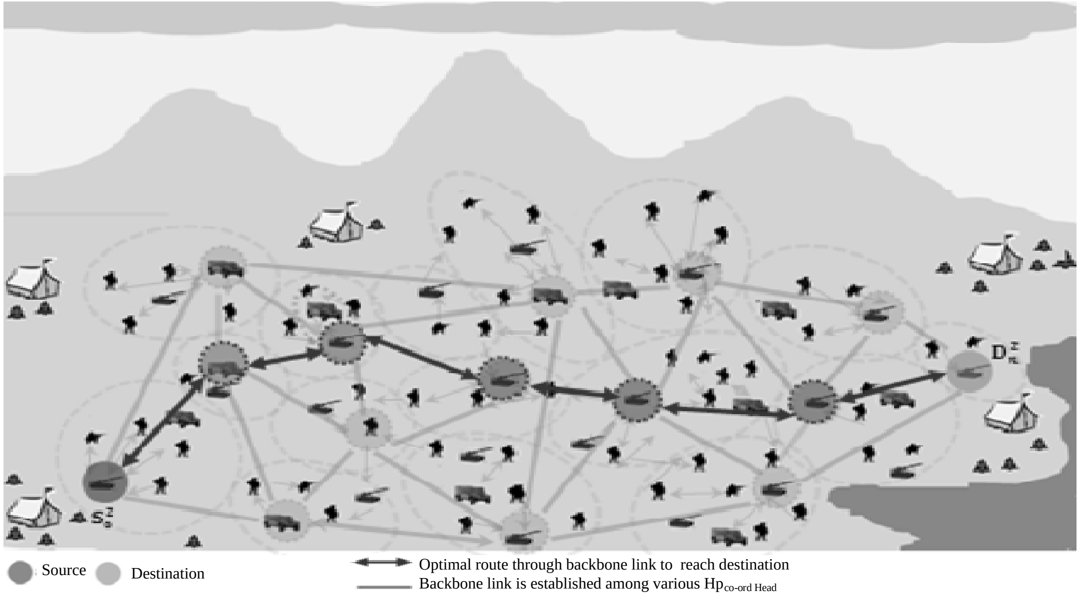

Fig. 1: Network structure of the proposed ProVH

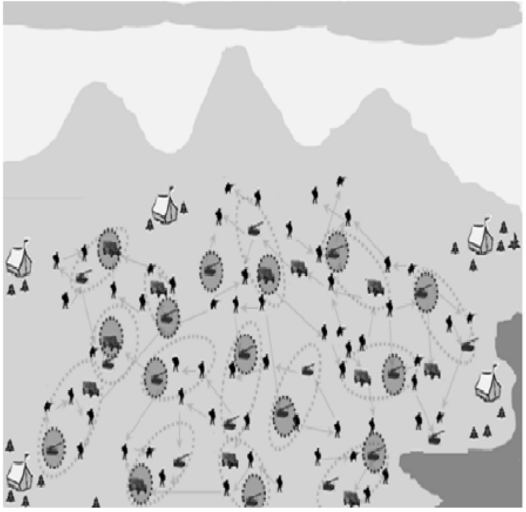

Fig. 2: Topology formation phase in ProVH Model

$$m \geq m_{max} \text{ and } m \leq m_{min}$$

Where:

m = Indicates the number of nodes
m_{max} = Maximum number of nodes in a cluster
m_{min} = Minimum number of nodes in a cluster that limits to optimal range of nodes within each cluster

This m_{max} and m_{min} may increase or decrease depending on the bcoverage area for effective cluster formation. Prevent interference caused between nodes, i.e., overlapping between the inter-clusters should be avoided to prevent anonymous nodes that may fall out of the transmission range of VCH. Initially, VCH broadcast the request to its surrounding nodes. The node which receives the request sends its response (address) to VCH. VCH receives the response and stores the data in its LAT (Local Aware Table). It then commands the responded nodes within its virtual cluster to shift from unidirectional to bidirectional link. Furthermore, all the nodes that are within the virtual cluster only communicates to its VCH using the bidirectional link. After a stipulated timeslots or when any dynamic, the virtual cluster formation is re-triggerd to form non-uniform virtual clusters depending on the transmission range of VCH.

Backbone link establishment: Every VCH within the network establishes a backbone link with all other VCHs in the network.

Route discovery phase: When a source node wants to find a route, the source node initiatesn a route discovery process. Discovery is invoked to find the path from source to destination. A route is established only when it is required by a source node for transmitting data packets to the destination. Route discovery phase using ProVH routing mechanism as depicted in Fig. 3, involves two types of routing:

- Local routing
- Global routing

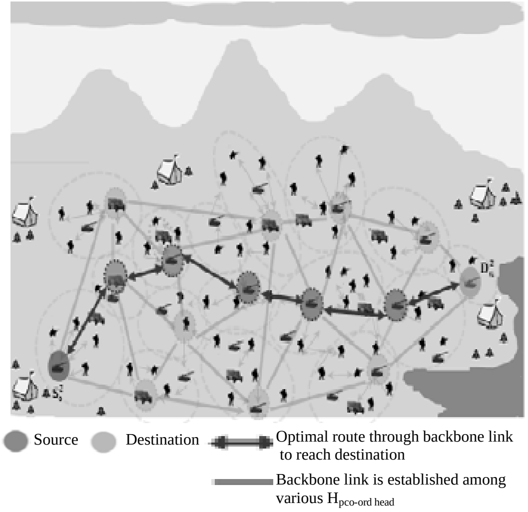

Fig. 3: Route discovery phase in ProVH Model

Both routing mechanism work allow nodes to discover and maintain source routes to destinations.

Local routing: In this the routes are created as and when required instead of maintaining up-to-date routes at every node. Table (LAT) maintains routing information to every other node within the virtual cluster and Global Aware Table (GAT) maintains information to every other VCH network. All VCH maintain an update and GAT for a consistent and up of the network. The routing procedure is based on the information in these tables. Builds routes using a route request and route reply mechanism. When a source node desiresn a route to a destination it broadcasts a Route Request (RREQ) packet to its VCH receiving this packet update their information for the source node. If VCH receive which is already processed, it RREQ and does not forward, it contains the most recent sequence number, source node's IP address, sequence number and broadcast ID. VCH verifies its LAT and if the VCH that receives RREQ is either a destination or if it has the route to destination (destination node resides in the local then the VCH sends a route reply, i.e., in this case, it unicasts a RREP source. As the RREP propagates back to the source it sets up forward pointers to the destination through its local VCH.

Global routing: If the VCH RREQ from the source node is either destination or if it does not have destination node upon verifying its LAT then broadcasts the RREQ to its nearby in the network using Global Awarem Table (GAT). Other VCH that receives then RREQ, verifies it's LAT and if it finds then destination within its virtual cluster then the VCH sends a route reply, i.e., RREP VCH which contain the destination addressm (i.e., destination node) will responds back to the source VCH. Now, the source VCH establishes global routing through t backbone link using optimized routing protocol with row-generation algorithm. Thus, an optimal route through the backbone link is identified. RREQ is forwarded till either the destination is reached or another VCH is found with a route to the destination node. Each VCH appends own identifier when forwarding RREQ. After destination node received the first RREQ it sends RREP by reversing the route. It uses source routing where all information is maintained at determining routes, it is necessary to accumulate the address of each device between the source and destination during route discovery. The learned paths are used to route packets. To accomplish source routing, the routed packets contain the address of each device the packet will traverse. Propagates back to the source forward pointers to the destination. After receiving the RREP the source node may begin to forward data packets to the destination.

ProVH-probabilistic virtual head selection protocol: The primary objective is to select a most optimal node within each virtual cluster as a head or leader node and then find an efficient route using the LAT and GAT in order to reach the destination. The aim of our algorithm is to use a solution approach called Bender's decomposition to select an efficient route to reach the destination. By applying Bender's decomposition, the problem of identifying efficient proactive path for successful data transmission to the destination is established where the original problem is divided into master problem and sub problem. The master problem deals with Virtual Cluster Head (VCH) selection (using set of parameters such nodes with low mobility with uniform trajectory, high computing capability, high storage capacity and has high transmission power). From the master problem, solutions to the sub problem is constructed with same set of initial constraints where the average mean for the constraints is calculated and compared against sub problem cut to finally choose an efficient routing path to forward data to the destination. The phases involved in the algorithm includes:

- Topology formation (virtual cluster head selection process as the master problem)
- Route discovery process (proactive path selection as the sub-problem)

Algorithm 1; topology formation-virtual cluster head selection process as the master problem:

Identification of problem: Identifying the given Problem (P), the problem of estimating best suitable head node for successful virtual cluster formation

Input: The high power nodes with mobility speed, higher transmission power, the computing memory and storage capacity of the each node in given as input to process

Initialisation step: From the given Problem (P), construct the Master Problem (MP) with initial constraints for virtual head selection such as Mobility (M^i_n), Transmission Power (Tp^i_n), computing power (A^i_n) and storage capacity (B^i_n)

```
Initialize
for set of 'n' nodes
Applying master problem bound cut ($\beta_i$) to set of 'n' nodes,
if (Node's mobility $M^i_n \le$ master problem bound cut $\beta_i$) and (Node's transmission power $Tp^i_n \ge$ master problem bound cut $\beta$) and (Node's computing memory $A^i_n \ge$ master problem bound cut $\beta$) and (Node's storage capacity $B^i_n \ge$ master problem bound cut ($\beta_i$)) then
Assign feasible = TRUE
else if (Node's Mobility $M^i_n \ge$ master problem bound cut $\beta_i$) and (Node's transmission power $Tp^i_n \le$ master problem bound cut $\beta_i$) (Node's computing memory $A^i_n \le$ master problem bound cut $\beta$) and (Node's storage capacity $B^i_n \le$ master problem bound cut ($\beta_i$)) then Assign feasible = FALSE
else
Assign feasible = FALSE
end
end//end of the for loop
Output: The set of 'k' nodes after applying Master problem bound cut
```

Algorithm 2; Route discovery process-proactive route selection as the sub problem

Input: The set of nodes (k) after applying master problem bound cut (β_i) which is given as an input to the Sub Problem (SP)

```
1:  Consider the subset of nodes (k) derived after applying master-problem bound cut ($\beta_i$) which is given as an input to the Sub Problem (SP)
2:  Calculate average Mobility ($M_{av}$), average Transmission power ($Tp_{av}$), Average memory ($A_{av}$) and average storage capacity ($B_{av}$) for 'k' nodes
3:  Derive sub-problem bound cut ($\alpha_i$) value
        •  For mobility ($\alpha^k_m$) that does not exceed the average Mobility ($M_{av}$)
        •  For Transmission Power ($\alpha^k_{tp}$) that has upper limit compared to average Transmission power ($Tp_{av}$)
        •  For memory ($\alpha^k_{mem}$) that has upper limit compared to average Mobility ($M_{av}$)
        •  For storage capacity ($\alpha^k_{sc}$) that has upper limit compared to average storage capacity ($B_{av}$)
4:  Initiate data communication from $S_{VCH}$ (VCH that has the node with data to be transmitted)
5:  Source virtual cluster head ($S_{VCH}$) advertises to collect status of neighbouring node's mobility ($M^k_{neig}$), transmission power ($Tp^k_{neig}$), storage capacity ($Sc^k_{neig}$) and memory ($Mem^k_{neig}$))
6:  $S_{VCH}$ receives response from the neighbor Virtual Cluster Heads VCH ($N_{VCH}$)
7:  $S_{VCH}$ gets the count ($N_{count}$) of $N_{VCH}$
    $Best_{count} = 0$; $i = 1$
    if $N_{count}$> then
    Repeat for each neighbor cluster head ($N_{VCH}$)
    /* Checks whether neighbor VCH has the destination node*/
     if $N_{iVCH}$ has the $D_s$ then
            Establish route path between $S_{VCH}$ to $N_{VCH}$; Exit;
    else if ($N_{VCH}$ nodes mobility $M^k_{neig} \le$ sub-problem bound cut $\alpha^k_m$) and ($N_{VCH}$ nodes transmission Power $Tp^k_{neig} \ge$ Sub-problem bound cut $\alpha^k_{tp}$ ) || ($N_{VCH}$ nodes Storage Capacity $Sc^k_{neig} \ge$ Sub-problem bound cut a $\alpha^k_{sc}$) and ($N_{VCH}$ nodes memory $Mem^k_{neig} \ge$ the Sub-problem bound cut $\alpha^k_{mem}$)
    /*Store the list of neighbor VCHs separately in a list and increment the counter*/
    Store $N_{VCH}$ data
    Set $Best_{count} = Best_{count}+1$
    end
    $I = i+1$
    Until $i \le N_{count}$
    /*continue for all neighbor N i.e., all VCHs are processed*/
    End
8:  Get the count ($Best_{count}$) of neighbor count
    $N_{VCH}$) in order to select best virtual cluster head to
    transmit the data
    /*Efficient Route detection*/
    $final_{count} = 0$ ; $j = 1$; If>1 then
     Adjust the sub-problem bound cut value ($\alpha_{adjk}$) of the VCH according to their value
     else if ($N_{jVCH}$ nodes mobility $M^k_{neig} \le$ adjusted sub-problem bound cut $\alpha_{adjk}$) &&
($N_{jVCH}$ nodes transmission power $Tp^k_{neig} \ge$ adjusted sub-problem bound cut $\alpha_{adjk}$) ||
($N_{jVCH}$ nodes storage capacity $Sc^k_{neig} \ge$ Adjusted sub-problem bound cut $\alpha_{adjk}$) &&
($N_{jVCH}$ nodes memory $M^k_{neig} \ge$ adjusted sub-problem bound cut $\alpha_{adjk}$)
/*Store the virtual cluster head (VCH)*/
Store optimal virtual cluster head ($O_{VCH}$ )
            $final_{count} = final_{count}+1$
end
    if $final_{count}>1$ then
            Re-adjust the sub-problem bound cut value ($\alpha_{adjr}$) of the VCH according to their value
    Repeat the process
              $j = j+1$
               Until j $final_{count}$ /*Continue until one optimal VCH is selected*/
            end
9:  Repeat from step (5) to step (8) until destination ($D_s$) is identified.
10: Thus, route has been established and data is transmitted
Output: Efficient proactive path selected after the iteration process in order to reach the destination
```

Mathematical analysis: Benders decomposition solution approach is a cut or row-generation technique for specially structured mixed linear programming problems. When the Virtual Cluster Head (VCH) sends a multicast request to all the VCHs that exists within its network topology, all other VCHs receives this request from the source VCH and checks whether destination VCH's address exists within its local aware table. If the destination address is found in Table 1, then the VCH that has the destination in its cluster responds back to source VCH. The response is received by the source VCH. Then, the source VCH establishes global route through backbone link. Bender's Decomposition approach is applied to the above scenario where the cproblem of identifying efficient proactive path for successful data transmission to the destination is required. The original problem is splitted into master problem and sub problem. The master problem deals with Virtual Cluster Head (VCH) selection with initial set of parameters. Further, from the master problem, solution to the sub problem is constructed with same set of initial constraints and average mean is calculated and compared against sub problem cut to finally choose an efficient path to forward data to the destination.

Master problem: Solving Master Problem (MP) for virtual head selection using initial constraints which includes low

Table 1: Input parameters for selecting vh

	Selection parameters			
No. of nodes (I)	Mobility (M^i_n)	Transmission power (Tp^i_n)	Computing power (A^i_n)	Storage capacity (B^i_n)
1	M^1_n	Tp^1_n	A^1_n	B^1_n
2	M^2_n	Tp^2_n	A^2_n	B^2_n
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
n	M^n_n	Tp^n_n	A^n_n	B^n_n

mobility (uniform trajectory), i.e., M^i_n high Transmission power (Tp^i_n), high computation power $(A_n)^i$ and higher storage capacity (B^i_n) among all nodes. The input factors which is considered for electing a High Power Node (HPN) as a virtual head is given in tabular column, shown in Table 1.

In a MANET, it is assumed that the nodes are free to move randomly while being able to communicate with each other, often over multi-hop links without the help of fixed network infrastructure. Due to the mobility of nodes, the network topology changes unpredictably. The virtual head is electedv among all high power nodes which exhibit lower mobility (i.e., uniform trajectory) in their neighbourhood. The virtual head should have higher transmission power than the other nodes in the network. Virtual head selection is based on high computing power which quickly computes the data from the source to destination and the node that has higher storage capacity. Solving the Master Problem (MP) using Bender's decomposition approach for virtual cluster head selection process is shown:

$$\text{Subject to: } \text{Min}\sum_{i=1}^{n} M^i_n + \sum_{i=1}^{n} Tp^i_n + \sum_{i=1}^{n} A^{i}_{n} + \sum_{i=1}^{n} B^i_n$$

$$Gi_x + K_i y_i \geq b_i \; \forall i_x \in M_x y_i \geq 0 \forall_i$$

Where:

Gi_x = Set of nodes under mobility criteria

$k_i y_i$ = The node to be elected that is optimal mobility nodes

b_i = The number of virtual cluster head nodes

M_x = Low Mobility and uniform trajectory condition

'i' = The number of nodes in the network subject to

$$Hi_x + L_i y_i \geq b_i \; \forall i_x \in Tp_x y_i \geq 0 \forall_i \tag{2}$$

Where:

Hi_x = Set of nodes under higher transmission power criteria

$L_i y_i$ = The node to be elected that is higher transmission power

b_i = The number of virtual cluster head nodes

Tp_x = Higher Transmission power condition

i = The number of nodes in the network

$$\text{Subject to: } Pi_x + Q_i y_i \geq b_i \; \forall i_x \in A_x y_i \geq 0 \forall_i \tag{3}$$

Where:

Pi_x = Set of nodes under higher computing memory criteria

$Q_i y_i$ = The node to be elected that is optimal memory nodes

b_i = The number of virtual cluster head nodes

A_x = higher computation power of node

i = The number of nodes in the network

$$\text{Subject to: } Ri_x + S_i y_i \geq Ri_x + S_i y_i \geq b_i \; \forall i_x \in B_x y_i \geq 0 \forall_i \tag{4}$$

Where:

Ri_x = Set of nodes under higher storage capacity criteria

$S_i y_i$ = The node to be elected that is higher storage capacity

b_i = The number of virtual cluster head nodes

B_x = Denotes storage of node

i = The number of nodes in the network

We partition the above problem, combining the low mobility and high transmission power in one subset (u_{imt}) and other memory and storage in another subset (u^i_{ms}) as follows:

$$\min_{X \in M_X} \min_{x \in Tpx} \sum_{1=1}^{n} (\max M_{ij} : \{K_i y_i \geq b_i - Gi_x \geq 0\}) + \sum_{1=1}^{n} (\max Tp_{ij} : \{L_i y_i \geq b_i - Hi_x \geq 0\}) \tag{5}$$

$$\min_{X \in A_X} \min_{X \in B_X} \sum_{1=1}^{n} (\max A_{ij} : \{Q_i y_i \geq b_i - Pi_x \geq 0\}) + \sum_{1=1}^{n} (\max B_{ij} : \{S_i y_i \geq b_i - Ri_x \geq 0\}) \tag{6}$$

The subset (u_1, u_2, ..., u^k_{mt}) indicates the number of nodes satisfying both mobility and transmission power. Similarly, the subset (u^1_1, u^1_2, ..., u^k_{mt}) indicates the number of nodes satisfying both memory and storage capacity of the node. We can rewrite the problem as our Master Problem (MP) and derive a bound cut (β_i):

$$u^k_{mt}(b_i - Gi_x) \tag{7}$$

Similarly, comparing the node's transmission power (TP^i_n), memory (A^i_n) and storage (B^i_n) with master problem bound cut (i.e., bound limit):

$$\text{Subject to: } \beta_i \geq u^k_{mt}(bi - Hi_x) \forall_i \forall_k \tag{8}$$

1 contains the list of selected virtual cluster heads after applying bound cut. The subset containing (u^1_1, u^1_2, …, u^k_{ms}) is compared with bound cut as follows:

$$\beta_i \geq u^k_{ms}(b_i\text{-}pi_x)\forall_i\forall_k \tag{9}$$

$$\text{Subject to: } \beta_i \geq u^k_{ms}(b_i\text{-}Ri_x)\forall i\,\forall k \tag{10}$$

If the optimal solution of the master problem satisfies all the constraints, then $z_i \in \{0, 1\}$, = 1, 2, ..., n is the obtained solution. The problem models a situation consisting of a where 'i' be the number of nodes and 'j' is the initial constraints of virtual cluster head selection (A matrix) taken for our scenario. The row (m) information consists of high power nodes based on the selection criteria and this row data keeps changing based on the above criteria's. The value 1 indicates true condition (i.e., head node satisfying the parameters). The column (n) indicates the number of parameters for Virtual cluster head election, for which the value $a_{11} = 0$ which represents the higher mobility, $a_{12} = 0$ also indicates the less transmission power, $a_{23} = 0$ shows node which has low computation power and finally the $a_{24} = 0$ possesses low storage capacity of the node. Therefore, taking all these conditions into considerations, the Virtual Head Node (VCH_3) that has low mobility (i.e., less trajected path), high transmission power, huge memory and maximum storage capacity is chosen as the cluster head for that virtual cluster which is a row as shown in Fig. 4.

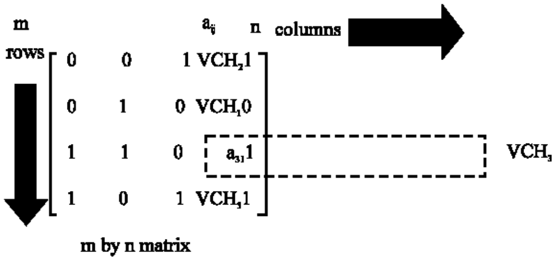

Fig. 4: Matrix using benders decomposition for VCH selection

Solving the sub-problem Quality of Experience (QOE) based on proactive path selection: The Benders strategy is to fix the integral variables, solve the dual of the sub-problem and from that dual solution generate constraints to add to the master problem, until the re-written master problem is sufficiently constrained to yield an optimal solution. In our scenario, the notation 'i' indicates the list of cluster heads after the application of bound cut. From the list head nodes, the average mean is taken for each node with their parameters they possesses. By this, the neighbor virtual cluster head can establish routing in order to transmit the data to the destination:

$$\text{Max} \sum\nolimits_{i=1}^{k} M_{av} + \sum\nolimits_{i=1}^{k} Tp_{av} + \sum\nolimits_{i=1}^{k} A_{av} + \sum\nolimits_{i=1}^{k} B_{av} \tag{11}$$

where, 'k' is denotes the list of heads selected (solution from master problem) based on the criteria. Calculating the average mobility of each node by summation of all nodes in the list (M_{ij}) gives the value (M_{av}). Similarly, average for power of every node in the list (Tp_{ij}) gives (Tp_{av}), computing memory of each node (A_{ij}) gives (A_{av}) and storage capacity of each node (B_{ij}) denotes the value (B_{av}) as shown in the. The optimality cuts are generated only after feasible cuts (i.e., virtual cluster heads election) was found. The idea of optimality cut is to gradually take towards the optimal solution by applying sub problem bound limit (α) and finding best proactive path to establish the transmission. Consider the average comparison for the first iteration (j = 1) for the current virtual head node:

$$M_{av} \leq \alpha_i\, \forall_i\, \forall_k \tag{12}$$

Subject to the constraints $M_{av} \leq 0$, since, the $z_i \in \{0, 1\}$ where 0 indicates the low mobility $Tp_{av}+A_{av}+B_{av}<\alpha_i$ where $Tp_{av}>1$ $A_{av}>1$,$B_{av}>1$. Since, the $z_i \in \{0, 1\}$. Similarly, $Tp_{av} \leq \alpha_i$ $\forall i\, \forall k$ for the higher memory $A_{av} \leq \alpha_i$ $\forall i\, \forall k$ and for storage capacity $B_{av} \leq \alpha_i\, \forall_i\, \forall_k$.

Similarly, the iteration (j = j+1) continues the destination head node is found. Flow model of Benders decomposition process for optimal route selection process is shown in Fig. 5.

RESULTS AND DISCUSSION

Simulation and experimental analysis: We have implemented the proposed protocol using OMNET++ network simulator integrated with MATLAB and analyzed its behaviors. In our experiments, mobile nodes were randomly deployed in a 1000×1000 m area. Wireless mobile nodes were set to move across the simulated area with a varying speed. To diversify mobile nodes, we randomly set mobile nodes with high power and large transmission range (tanker or military jeep) and with low power and small transmission range (ManPackRadio). The data rate of low power and high power nodes are set to 1 and 2 MB, respectively. Low power mobile nodes Transmission range (T_L) is below 300 m. High power mobile nodes transmission range (T_H) is set larger than T_H

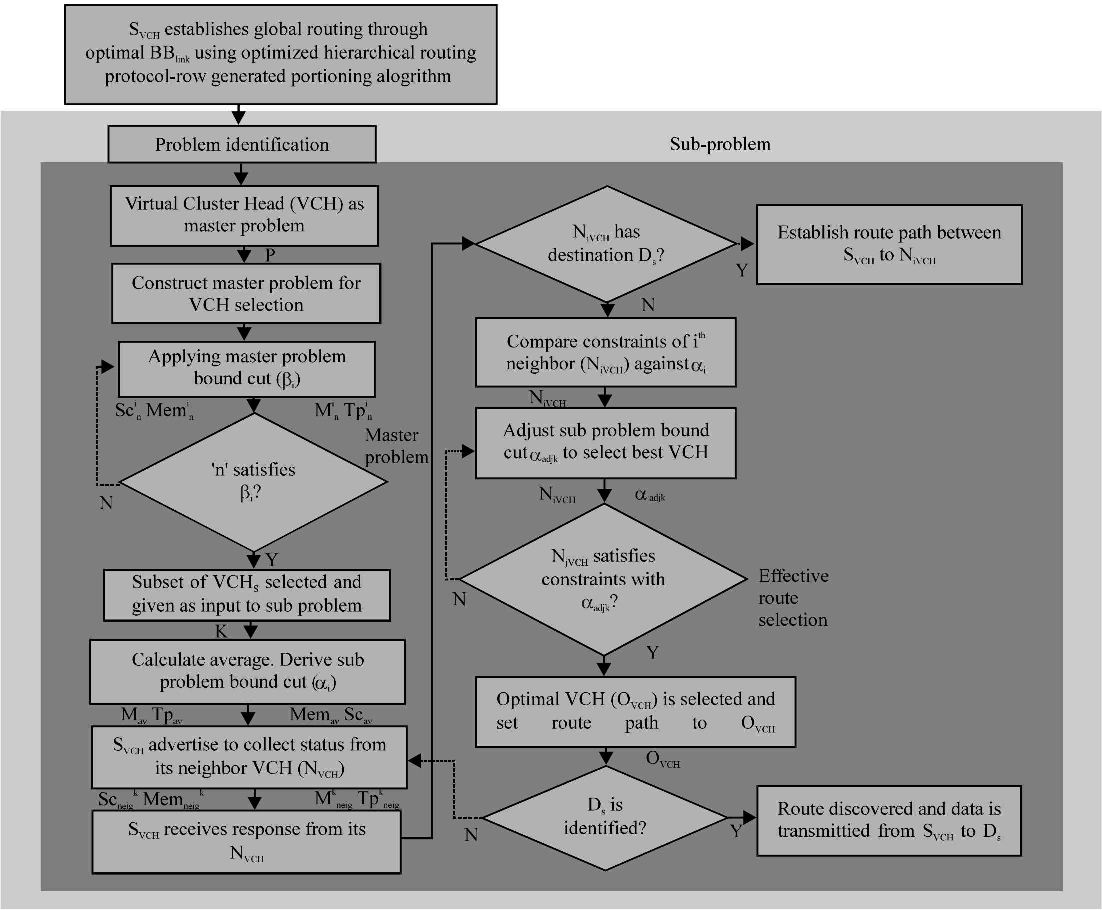

Fig. 5: Flow model of benders decomposition process for optimal route selection

i.e., 300 m till 1000 m. To reflect the real-world environment, Effective transmission Ranges (ERs) of all nodes are 10% deviated from the theoretical transmission range. In our simulations, we use the Constant Bit Rate (CBR) traffic. The source and the destination are randomly selected during the simulation. The mobility model is based on a random waypoint with the maximum node speed V and a pause time of 0 sec. To implement message sending and receiving, a virtual concept of time slots was used. In each time slot, we randomly chose a node to generate a new message and let it send the message to the destination node. Nodes send packets of 512 B at a rate of ten packets per second. VCH node used a buffer to cache packets from other nodes. Assume all packets in the buffer could be transmitted to the next VCH node within one time slot. The simulation time was set to 500 time slots. The 20 different deployments of mobile ad hoc networks were generated during the experiment. The desired delivery rates was set to be 99% (very high) and 85% (medium). The number of nodes was varied from 200-500 and averaged the simulation results. V is set to 0 m/sec which means all nodes remain static during the simulation. Two sets of simulations are conducted, varying N from 0-60 with R = 600 m and Increasing R from 200-1400 m with 20 B-nodes. We used the following metrics to evaluate the performance of ProVH:

- Throughput
- Packet delivery ratio
- End-to-end delay
- Normalized overhead and
- Energy consumption per received packet

Figure 6 displays the ProVH network scenario captured during simulation.

Transmission range of high power nodes: The performance of ProVH, LRPH, AODV and DSR is evaluated when high power nodes Transmission range (T_H) is in 300-1000 m. For the experimental setup, 250 low power nodes with 20 high power nodes were considered. T_L is 200 m and the number of CBR is 20. The maximum node speed V is set to 10 m/sec. All sources send

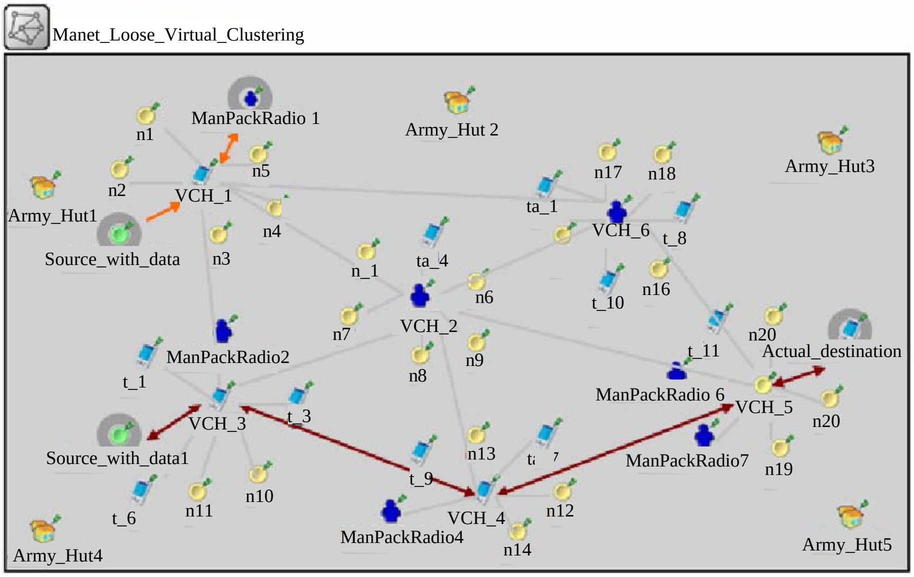

Fig. 6: OMNET++ network model using ProVH protocol

packets of 512v B at the rate of five packets per second. Figure 7a shows the throughput of four proto colsversus T_H. As expected, as the transmission range of high power nodes increases, the throughput of the four protocols decreases due to interference among the nodes. For example, when the transmission range of high power nodes is 1000 m, the throughput of ProVH can be improved by approximately 10, 25 and 55% in comparison with LRPH, AODV and DSR, respectively i.e., ProVH constantly achieves much better throughput than LRPH, AODV and DSR. The reason being high power nodes in ProVH avoids data packet forwarding during the time interval when the number of high power nodes with high transmission range increases thus the interference of high power nodes is largely reduced. The throughput of DSR is the lowest because it treats all nodes equally. Figure 7b shows the packet delivery ratio of the four protocols versus T_H. From the observations, the PDR of ProVH, LRPH, AODV and DSR decreases as T_H increases because the transmission of high power nodes incurs a large number of conflicts during transmission. Additionally, PDR for ProVH is the highest in comparison with the other three protocols. Recall that in ProVH, high power nodes avoides to forward data packets during such time slots, which reduces the negative impact of high power nodes on data transmission.

Although, the impact of high power nodes in AODV is reduced, sparse high power nodes cannot guarantee that each VCH contains a high power node at a particular instant of time.

In addition, the routing discovery in AODV is poor for sparse high power nodes. Figure 7c shows the end-to-end delay of the four protocols versus T_H. We have several observations. First, the end-to-end delay of ProVH, LRPH and AODV decreases as T_H increases. If T_H is larger, then the LAT in ProVH and LRPH will maintain more local topology information. It increases the chance of obtaining the path directly from the local route cache. Even, if the path cannot be derived from the local route cache, the route can be quickly discovered within several hops through high power nodes. Nevertheless, the delay of AODV is higher than ProVH and LRPH for the poor routing discovery under unidirectional links and sparse high power nodes. Second, the delay of DSR increases as high power nodes increases and is much higher than that of ProVH and LRPH. It can be reasoned that unidirectional links in networks increase as increases.

Figure 7d shows the normalized overhead of ProVH, LRPH and AODV versus T_H. We have a few observations. First, the normalized overhead of ProVH, LRPH and AODV decreases as T_H increases. When high power nodes is large, the VCH becomes stable and the cost of maintaining virtual cluster isv reduced. Hence, the overhead in ProVH decreases as T_H increases. The normalized overhead of AODV decreases because of the increase in the density of high power nodes. Second, because of the higher PDR of ProVH, the normalized overhead of LHPR is slightly higher than that of ProVH. The normalized overhead of DSR is much higher than that of other three protocols for the highc over-head along with the low PDR. In the best case, the normalized overhead is more than 1000 which is not shown in Fig. 7.

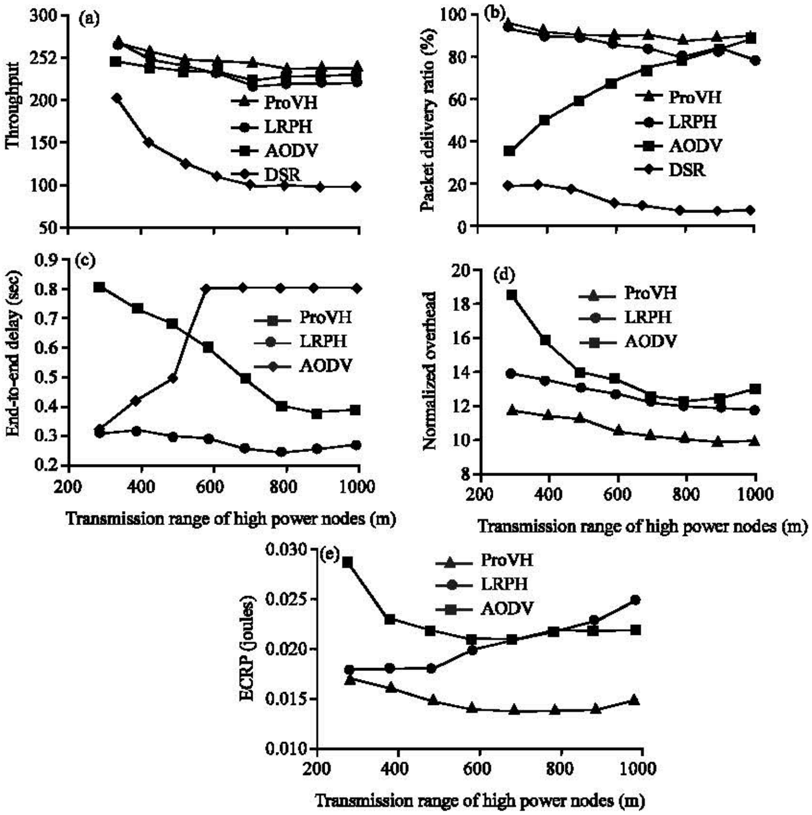

Fig. 7: a) Throughput versus TH; b) PDR versus T_H; c) End-to-end delay versus T_H; d) Overhead versus T_H and e) ECRP versus T_H

Figure 7e shows the ECRP of the four protocols versus T_H. We have a few observations. First, the ECRP of ProVH decreases as T_H increases. As shown in the earlier simulation results, the normalized overhead decreases as T_H increases. Although, the transmission through high power nodes consumes more energy as T_H increases, the mechanism for avoiding high power node forwarding enables that the energy consumption is minimally affected by the increase in . Second, the ECRP of the other three protocols increase because more energy is required for a larger T_H. In particular, the average ECRP of DSR is above 1 J. Hence, we do not show the ECRP of DSR in Fig. 7e. Nevertheless, there was one exception that the ECRP of AODV decreases at the beginning phase of the T_H increase due to a sharp decrease in the normalized overhead of AODV. Finally, ProVH has the lowest ECRP in comparison with the other three protocols.

Effect of mobility: The performance of ProVH, LRPH, AODV and DSR was evaluated under different mobility by varying the node's speed from 0-20 m/sec. Transmission range of low power node was set to 200 m and high power node was set to 600 m, respectively. All sources transmit packets of 512 B at the rate of five packets per second.

Figure 8a shows the throughput of four protocols under different node mobility. Upon observation, the throughput of four protocols decreases as the node speed increases. A higher mobility causes more broken links and transmission failures. Second, the throughput of ProVH is higher than that of the others because ProVH avoids forwarding data packets when interference caused among high power nodes is higher. Third, the throughput of DSR is the smallest because the interference of high power nodes and the unidirectional links are not considered in DSR.

Figure 8b shows the PDR of four protocols under different node mobility values. We have a few observations. First, ProVH achieves the highest PDR in comparison with the other three protocols. Even, in the worst case (e.g., V_{max} = 20), the PDR of ProVH is constantly over 85%. Second, the PDR of AODV is lower than that of ProVH and LRPH because of sparse high power nodes and unidirectional links.

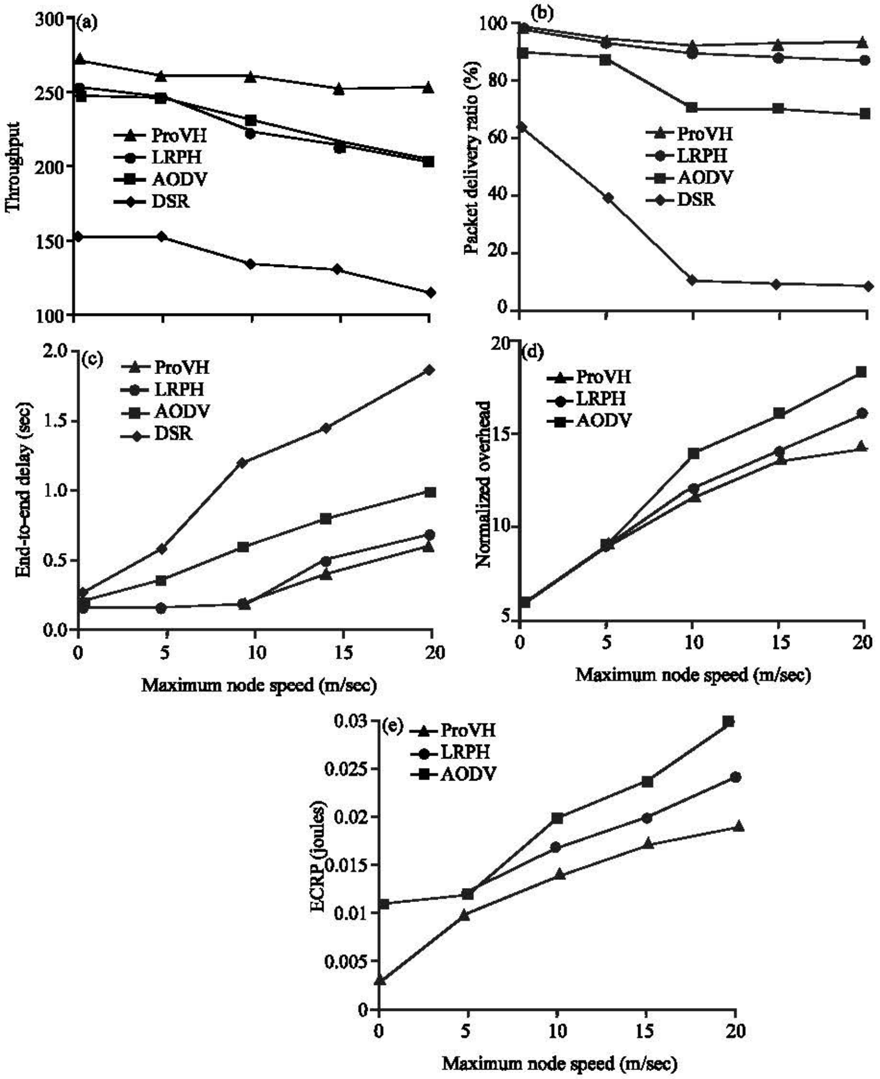

Fig. 8: a) Throughput versus high power node's speed; b) PDR versus high power node's speed; c) End-to-end delay versus high power node's speed; d) Overhead versus high power node's speed and e) ECRP versus high power node's speed

Figure 8c shows the end-to-end delay of four protocols under different node mobility. We have several observations. First, the end-to-end delays of four protocols increase as the node speed increases, leading to more packet retransmission and rerouting. Second, the end-to-end delay of ProVH and LRPH is approximately equal to and much smaller than that of the others because the virtual cluster and unidirectional links are considered in ProVH and LRPH. The end-to-end delay of AODV is higher than that of ProVH and LRPH and DSR achieves the highest delay, as expected.

Figure 8d shows the normalized overhead of four protocols under different nodemobility. We have a few observations. First, as expected, the normalized overhead of four protocols increases as the node speed increases. This can be explained by the fact that higher node mobility will cause more overhead for network maintenance (e.g., vrouting, clustering and others). Second, the normalized overhead of ProVH is smaller than that of LRPH because of the higher PDR of ProVH. Third, the normalized overhead of AODV is higher than that of ProVH and LRPH. The normalized overhead of DSR is the highest in comparison with other three protocols for the same reason as before.

Figure 8e shows the ECRP of four protocols under different node mobility. We have a few observations. First, The ECRP of four protocols increases as the node speed grows because more energy should be used for retransmission and rerouting. Second, ProVH shows the lowest ECRP in comparison with that of other three protocols. The ECRP of LRPH is higher than that of ProVH but lower than that of AODV. The energy consumption cof DSR is much higher than that of AODV, LRPH and PRoVH for the same reasons as mentioned before.

CONCLUSION

Our experimental results and its analysis showed that, the heterogeneity factors affecting the deployed MANET were dealt with real factors causing the change management. Future tactical mobile ad hoc networks would certainly demand a good network balancing and faster routing metric updates, so as to provide a ubiquitous connectivity. The unequal proportionate method of computing the mean and variance of received parameters at VCH helps the ProVH to outperform in computing best effort forward path selection and reducing the error rate compared to existing protocols. One important factor to discuss was the lifetime of the MANET of different capability level which was an assumption factor in most related research works. So, designing and developing a hybrid routing protocol in a forward path strategy considering the processing capability, memory management and signal processing in a MANET will be our next attempt.

NOMENCLATURE

M^i_n = Low Mobility with uniform trajectory of node
Tp^i_n = Transmission power of ith node
A^i_n = Computing power (memory) of ith node
B^i_n = Storage capacity of of ith node
Gi_x = Set of nodes under mobility criteria
Hi_x = Set of nodes under higher transmission power criteria
Pi_x = Set of nodes under high computing memory criteria
K_iy_i = Node to be selected as optimal mobility nodes
Q_iy_i = Node to be selected asc optimal memory nodes
S_iy_i = Node to be selected as optimal storage capacity nodes
M_x = Own Mobility and uniform trajectory condtion
Tp_x = Higher Transmission power condition
A_x = Higher computation memory condition
B_x = Higher storage capacity condition
i = No. Of nodes in the cnetwork condition
j = No. of iterations involved at the sub problem
u^k_{ms} = Subset containing number of nodes satisfying both memory and storage capacity
u^k_{mt} = Subset containing number of nodes satisfying both mobility and transmission power
β^i = Master problem bound cut
K = The list of heads selected (solution from master problem)
Z_i = Feasiblesolution obtained after master problem which results in 1-true condition and 0-false condition
M_{av} = Average Mobility of selected nodes (from the master problem)
Tp_{av} = Average Transmission power of selected nodes (from the master problem)
A_{av} = Average memory of selected nodes (from the master problem)
B_{av} = Average cstorage capacity of selected nodes (from the master problem)
α_i = Sub problem bound cut
α^k_m = Sub problem cut (α_i) value for mobility of 'k' nodes
α^k_{tp} = Sub problem cut (α_i) value for transmission power of 'k' nodes
α^k_{sc} = Sub problem cut (α_i) value for storage capacity of 'k' nodes
α^k_{mem} = Sub problem cut (α_i) value for memory of 'k' nodes
S_{VCH} = Source Virtual Cluster Head (which has the data to transmit)
D_s = Destination to which data to be reached
M^k_{neig} = Neighbor node's Mobility value
Tp^k_{neig} = Neighbor node's Transmission power value
Sc^k_{neig} = Neighbor node's secondary Storage value
Mem^k_{neig} = Neighbor node's Memory value
$Best_{count}$ = Indicates the number of selected neighbour nodes (condition satisfied nodes) for adjusting sub problem bound cut
N_{count} = Indicates the number of neighbour Virtual Cluster Head (VCHs) nodes used for calculating sub problem bound cut

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