CLUSTER BASED DISTRIBUTED DIAGNOSIS IN MANET

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Abstract— **Mobile ad hoc networking allows portable mobile devices to establish communication path without having any centralized infrastructure. As there is no centralized infrastructure and the mobile devices are moving randomly, this gives rise to various kinds of problems such as routing and detecting faulty mobile nodes in the network. In this paper, the problem of fault diagnosis in mobile ad hoc networks (MANETs) is considered. In fact, fault-diagnosis becomes an important building block to establish dependability in MANET. An important problem in MANET is the distributed system-level diagnosis problem whose purpose is to have each fault-free mobile node to determine the state of all the mobile nodes in the system, so for that we have consider a MANET composed of N nodes that can be faulty or fault-free. This paper uses a hierarchical clustering approach proposed by authors Duarte and Nanya for diagnosing nodes in mobile ad hoc networks (MANETs). The proposed diagnosis algorithm is linearly scalable under the assumption that the mobiles may be: (i) crash faulty due to out of range or physical damage and (ii) value faulty due to sending erroneous messages while operating in the field. The generic parameters such as diagnostic latency and message complexity are used for evaluating the proposed diagnosis algorithm. The diagnosis latency and message complexity of the proposed algorithm was found to be** $O(N.\log_2 N.C_{i,s}.T_{out} + T_{xcg})$ **and** $O(N.C_{i,s})$ **respectively. The result shows that diagnosis latency and message complexity is reduced as compared to non-clustering distributed diagnosis algorithm Forward Heartbeat.**

Keywords-component; Diagnostic latency, Hierarchical clustering, Mobile adhoc networks, PMC fault model, System level diagnosis

I. INTRODUCTION

A MANET is an autonomous collection of mobile nodes without any centralized infrastructure such as base station [2], [3], [4]. Manets are very useful when infrastructure is not available, impractical or expensive because it can be rapidly deployable, without prior planning or any existing infrastructure. Mostly mobile ad hoc networks are used in military communication by soldiers, planes, tanks etc. Each node is equipped with wireless receivers and transmitter. Mobile host in a Manet may be highly mobile or stationary and may vary widely in terms of their characteristics, uses and capabilities. They may differ in terms of their communication transmission ranges, processing, storage and power capabilities, and exhibiting varying degree of reliability [5]. Since nodes are mobile, the network topology may change rapidly and unpredictable over time. It has to support multi-hop paths for mobile nodes to communicate with each other and can have multiple hops over wireless links; also connection point to the internet may also change. If mobile nodes are within the communication range of each other then source can send message directly to the destination node otherwise it can send through intermediate node.

Nowadays, mobile ad-hoc networks have robust and efficient operation in mobile wireless networks as it include routing functionality into mobile nodes which is more than just mobile hosts and reduces the routing overhead and saves energy for other nodes [12]. An important problem in designing dependable MANETS that are subject to the failure of mobile hosts is the distributed self diagnosis problem. In distributed self diagnosis each working (fault free) mobile host maintain correct information about the status (working or failed) of each mobile host in the entire MANET for some corrective actions.

The existing distributed self diagnosis algorithms have been developed for wired networks assuming a centralized infrastructure which creates a bottleneck and single point of failures. Motivated by the need of a fault diagnosis algorithm for MANET, this paper proposes a distributed self diagnosis algorithm which runs in every mobile node under a realistic fault environment. The main contributions of this paper are (i) we used an explicit fault detector suitable for MANET, (ii) both crash and value faults are considered and (iii) experimental validation using MATLAB.

The paper is organized as follows. The section 1 introduces the concept of distributed fault diagnosis and its impact on wireless ad hoc networks such as MANET. The section 2 discusses an exhaustive works related to the diagnosis of various distributed networks. The section 3 describes the system and fault model, the section 4 describes diagnosis model of our proposed algorithm. The section 5 describes the Hi-ADSD algorithm. The section 6 covers the proposed fault diagnosis algorithm. The section 7 shows the experimental result of diagnosis on MANET obtained through simulation. Finally, section 8 concludes the paper.

II. RELATED WORKS

The concept of system level diagnosis was initiated by authors Preparata, Metz, and Chien in their work is known as PMC model in 1967 [6]. According to them, any system can be decomposed into various units those can run testing tasks to diagnose the faulty units in the system. Since then, there is a great deal of diagnosis algorithms available in the diagnosis literature to diagnose faulty nodes in various systems such as VLSI systems, multiprocessors and distributed systems [7],[14,16]. However these algorithms are not suitable for networking environment such as Internet and Wireless networks. In 1998, E.P.Duarte and T.Nanya, introduced Hi-ADSD algorithm [1] in which it uses SNMP to implement fault diagnosis in LAN connected with Internet. In this, network management system consist of NMS (Network Management Station) also called monitor, that queries a set of agents and gets diagnosis information of them. The main disadvantage was that it was centralized system i.e. if (NMS) got failed then all diagnostic information is lost. Hi-ADSD is both adaptive in the sense that the system nodes can be diagnosed based on the test outcomes obtained so far. Hi-ADSD is hierarchical in the sense that the nodes in the system are arranged in a tree of height three based on SNMP protocol. While root node corresponds to NMS, intermediate nodes correspond to monitors and leave nodes correspond to agents.

In 2004, Arun Subbiah, considered the problem of distributed diagnosis in the presence of dynamic failure and repair [8]. Though the algorithm has been developed for dynamic fault environment, they assume a crash fault model without using clustering. This increases the diagnosis overhead for large class wireless networks such as MANET. All previous diagnosis algorithms for MANETs also do not address any explicit fault detector for diagnosing faulty nodes [9], [11], [13]. Based on the comparison approach, In [9], authors developed a new distributed self diagnosis protocol, called DSDP for MANETS that identifies both hard (crash) and soft (value) faults in a finite amount of time. Their algorithm also suffers from increase in diagnosis overhead for large MANET without using clustering. We show in this paper, the diagnosis overhead is reduced to a great extent in large MANETs using a hierarchical and adaptive clustering technique for diagnosis purposes.

III. SYSTEM & FAULT MODEL

An arbitrary network topology is assumed to model MANET. A synchronous system is assumed where the processing time and message delay is bounded. It is being assumed that nodes defined in this paper are mobile nodes. The set of fault free initiator mobile nodes in the system tests clusters of different sizes asynchronously. It is assumed that the system is grouped into number of clusters of size power of 2 as in the case of Hi-ADSD. This is the only restriction in the system model. Generic parameters are assumed for executing the diagnosis tasks, send initiation time and propagation time of the messages in the MANET. Once a node changes its state (fault free to faulty or faulty to fault free) it cannot further change its state in the same testing round. The work assumes a free space radio model for MANET where all the neighboring nodes whether intended or not, receive a message once transmitted from a source node.

In this paper, we assume that the mobile nodes are subjected to two types of faults such as crash and value faults [10]. Crash faulty mobile nodes are unable to communicate with the rest of the system, due to physical damage, battery depletion or being out of range. Value faulty nodes usually perform incorrect computation and communicate erroneous result or value while processing the data packet. A value faulty node may also corrupt the header of the message. We assume there are no link faults, a fully-connected network and imposes no bounds on the number of crash and value faulty nodes.

IV. DIAGNOSIS MODEL

The diagnosis model specifies the fault detection mechanisms in a MANET. The proposed algorithm assumes commonly used heartbeat based testing mechanism to detect faulty nodes in a cluster [8]. A node x can test another node y if y is a neighbor of x. The algorithm assumes that the diagnosis process is initiated by a set of fault free nodes at the highest layer of clusters known as initiator nodes. There are two types of messages exchanged during the diagnosis execution: (i) fixed size heartbeat message and (ii) variable size diagnostic message. The heartbeat messages are further of two types: (a) initiation heartbeat message (init_hb_msg) and (ii) response heartbeat message (res_hb_msg). The format of the heartbeat message sent by a node u consists of four fields: (u, v, diagnostic value, message code) u and v are the sending and receiving nodes respectively. Diagnostic value is the result of a diagnosis task executed in the node and is used to capture the value fault by comparison testing. Message code is a 2-bit field identifies the type of message. The diagnostic messages exchanged during the execution of the algorithm are of two types such as (i) local diagnostic message (local_diag_msg) and (ii) global diagnostic message (global_diag_msg). Local diagnostic message is used by the initiator nodes and global diagnostic messages are used to achieve the global diagnostic view of the entire MANET. The format of a diagnostic message sent by a node u contains (i, f (i), message code) where f (i) is the set of identifiers nodes currently diagnosed as faulty by node i, and message code is the code to identify the type of message.

To maintain the status of nodes about entire network each cluster head maintains a vector known as Status_Table[i] which stores the status of each node i in the network. In fact, each initiator node is also a cluster head. Since the present work uses the clustering technique presented in the diagnosis algorithm Hi-ADSD, we reproduce the Hi-ADSD in the following section 5 for completeness of this paper.

V. Hi-ADSD ALGORITHM

Hi-ADSD maps nodes to cluster, which are set of nodes and employs a divide and conquer testing strategy to permit nodes to independently achieve consistent diagnosis [1]. In this, nodes are grouped into clusters for the purpose of testing. The number of nodes in a cluster, its size, is always a power of 2 and system itself is a cluster of N nodes.

In figure 2 a hierarchical approach to test cluster is shown. In the first testing interval, each node performs tests on node of a cluster that has one node. In the second testing interval, on nodes of cluster that has two nodes, in the third testing interval, on nodes of cluster that has four nodes and so on, until the cluster of $2^{\log N-1}$ nodes is tested. After that, the cluster of size one is tested again and the process is repeated until all the nodes are tested by every other node in the network. For the system in Fig.2, for all i and s, Ci,s is listed in Table I.

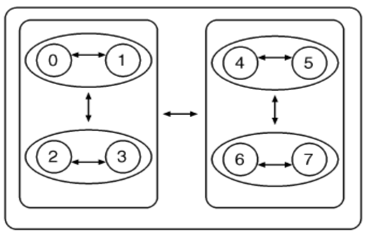

Figure 2. A Hierarchical Approach To Test Cluster

This formula is used for generating cluster of different sizes:

$C_{i,s}$= {n_t= (iMOD2^s+2^{s-1}+j) MOD 2^{S-1+a} + (iDIV2^S)*2^S+ b*2^{s-1}; j=0, 1……..2^{s-1} –1},

Where

a= {1 if mod 2^s<2^{s-1}, 0 Otherwise}

b= {1 if a=1AND (iMOD2^S+2^{s-1}+ j) MOD 2^{S-1+a}+ (iDIV2^S)* $2^{s <}$ i,

0 Otherwise

Where,

$C_{i,\ s:\ -}$ is a list of ordered nodes tested by node i in a cluster of size 2^{s-1}, in a given testing round.

A. An Example

When node i performs test on nodes of $C_{i,s}$ it performs test sequentially until it finds a fault free node or all other nodes are faulty. Suppose a fault free node is found, from this fault free node, node i copies diagnostic information of all nodes in $C_{i,s.}$ Figure.3 is being represented in the form of tree which shows the testing hierarchy for eight nodes, from the viewpoint of node 0. When node 0 tests a cluster of size 2^2 , it first test node 4, if node 4 is fault free, node 0 copies diagnostic information regarding nodes 4,5,6 and 7,if node 4 is faulty ,node 0 test node 5 and so on. Each initiator node i will collect local diagnostic information and store in their status table.

TABLE I. $C_{I,S}$ FOR THE SYSTEM

S	$C_{0,s}$	$C_{1,s}$	$C_{2,s}$	$C_{3,s}$	$C_{4,s}$	$C_{5,s}$	$C_{6,s}$	$C_{7,s}$
1	1	0	3	2	5	4	7	6
2	2, 3	3, 2	0, 1	1, 0	6, 7	7, 6	4, 5	5, 4
3	4, 5, 6, 7	5, 6, 7, 4	6, 7, 4, 5	7, 4, 5, 6	0, 1, 2, 3	1, 2, 3, 0	2, 3, 0, 1	3, 0, 1, 2

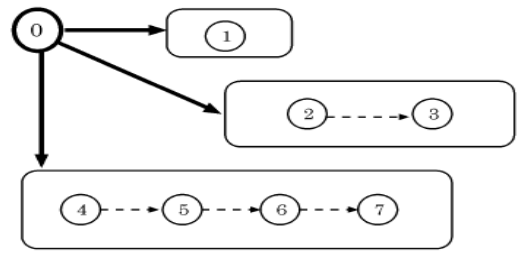

Figure 3. Each node tests all clusters

VI. THE PROPOSED ALGORITHM

We use the following notations in the diagnosis algorithm as given in the TABLE II below:-

TABLE II. NOTATION USED IN DIAGNOSIS ALGORITHM

Symbols	Description
F	number of faulty nodes
Ff	number of fault free nodes
init_hb_msg	initiator heartbeat message
res_hb_msg	response heartbeat message
Status_Table [node-id]:	status of all nodes in the network maintained at every node
$D_{node-id}$	diagnosis value of the node
T_{out}	Maximum waiting time by the initiator nodes to diagnose a crash or value faulty mobile node
T_{xcg}	Time needed to exchange the diagnosis information by all initiators in the network to form global diagnosis message.
n_c	Number of nodes in the cluster

A. Description of Proposed Algorithm

The proposed algorithm is given in Figure 4. In step 1 of the algorithm, a cluster is created. Step 2 assumes all the nodes are fault free at the initial stage of algorithm execution. In step 3, diagnosis process is initiated by the initiator node by sending the request heartbeat message to the testee node. An initiator node maintains a time out value after sending a heartbeat message to the tested node. In step 4, the node which is being tested sends the response heartbeat message and observed diagnostic value and estimated diagnostic value are compared, if they are same then the node is free from value fault otherwise that node is value faulty node. In step 5, if the initiator node does not receive any response heartbeat message within the time out value it assumes the tested node is crash faulty. In step 6, the entire initiator node have tested every other node and collected local diagnostic messages. Finally, step 7 prepares the global diagnostic message using local diagnostic message and finally disseminates the diagnosis information throughout all the nodes to maintain a consistent view by every fault free node of the entire network.

B. Analysis of Proposed Algorithm

In this section we analyze our proposed algorithm for computing its performance measures and compare with an existing diagnosis algorithm without clustering. We describe using various claims to support and characterize the correctness and performance evaluation of our proposed diagnosis algorithm. The claims and corresponding proofs are given as follows.

Claim 1. *A crash faulty mobile node is detected crash faulty within the time out period T_{out}.*

Proof. A mobile node is subjected to crash fault if it is out of range or physically damaged. A fault free initiator node sends the request heartbeat message to all mobile nodes in the cluster. This node will receive response heartbeat message from all the fault free nodes within T_{out}. This is due to our assumption of a synchronous system i.e., communication delay of a message is bounded. Since the time out value for a tested node depends on the diameter of the network and the delay encountered in each of the hops, the response heartbeat message from a faulty node is not received by the initiator node and thus detects a crash fault. This proves the stated claim 1.

Claim 2: *A value faulty mobile node is detected within T_{out}.*

Proof. Let us assume that each wirelessly node in MANET is having its own estimated diagnostic value which is available in the diagnostic value field in the request heartbeat message. Let us assume that the tested mobile node executes a diagnosis task whose result is buffered in the diagnostic value field in the response heartbeat message. This diagnostic value is made available at the testing mobile node within T_{out}. Because, T_{out} is estimated as a function of computation time of diagnosis task, transmission delay of request and reply heartbeat message in MANET. The result of diagnosis task at the tested node is said to be observed value. The observed value obtained from the tested nodes is compared with the estimated value and their difference is computed. If the deviation is greater than certain threshold Θ, we say the tested node is value faulty which is detected within T_{out}. This holds the claim 2.

Step 1: Create a cluster by computing the formula $C_{i,s}$ having N number of nodes.
for all i = 0, 1, 2 …, N-1
s=1, 2 ..., logN
Step2: Let us assume that all the nodes in the network can initiate the diagnosis and they all are fault free at the time of initiation.
Step 3: Start Diagnosis:
Repeat
for s=1 to logN Do
Send i_hb (i, j, D_j, init_hb_msg)
Set_Timeout (T_{out})
Step4: response r_hb (j, i, D'j ,res_hb_msg)
if Dj = D'_j, // then the testee node is fault free.
Status_Table[i] =fault free
ff = ff U [j]
else
// the node that replied an erroneous message are diagnosed as faulty
f=N (initnode_id)-ff
if (f=N (initnode_id)) Then
//if its entire neighbor is faulty then the diagnosis is complete
Terminate=True
End if
Step5: Timeout:
//the nodes that did not reply within time T_{out} are diagnosed as faulty.
f=N (initnode_id)-ff
if (f=N (initnode_id)) Then
//if all its neighbors' are faulty then the diagnosis is complete
Terminate=True
End if
Update the entry in the Status_table[i];
Step 6:Receive_local_diag_msg (i, fi)
//when all initiator receives a local diagnostic message then,
f=f U f_i;
D= D U {i}
D= N (init_node_id)-f
Step 7: Now, all initiator node will exchange local diagnostic message with each other and send it to every other nodes in the network.

Figure 4.The Proposed Diagnosis Algorithm

Claim 3. *For any mobile node i,* and a *given cluster s, and at any given instant of time t_i, it takes, at most, $\log_2 N$ testing rounds for mobile node i to test Ci, s.*

Proof. This follows from the definition of the algorithm, i.e., at a given testing round node i test a cluster, and looks for a fault-free mobile node in that cluster. In one testing round, each fault-free mobile node tests at least another fault-free node, if there is one. There may be at most $\log_2$ N clusters for mobile node i to test. In $\log_2 N$ consecutive rounds, at each round, a different cluster is tested. Thus, if node i execute exactly one successful test per testing round, it will take $\log_2 N$

testing rounds for it to test all clusters. Therefore, in the worst possible case, for time t_i immediately after a given cluster is tested, it will take up to $\log_2 N$ testing rounds for that cluster to be tested again. This proves claim 3.

To prove claim 4, we define the diagnostic latency as the time elapsed between the initiation of the diagnosis process and all fault free mobile nodes diagnose every fault event.

Claim 4. *The diagnostic latency of the proposed diagnosis algorithm is* $O(N.\log_2 N.C_{i,s}.T_{out.} + T_{xcg})$.

Proof. In proposed diagnosis algorithm, an initiation heartbeat message goes from each initiator node simultaneously to a node of a cluster of size $C_{i,\ s}$ of one and waits for a time out period of T_{out}. If the node in this cluster is fault free, the initiator node will receive a response heartbeat message from this fault free node and collects the diagnosis information about the entire network from this node. If the node in the cluster is faulty, the initiator node either will not receive a response heartbeat message (crash fault) or it may receive an erroneous message (value fault). Irrespective of crash or value fault, the initiator will detect this fault maximum within T_{out}. The initiator then sends another initiation heartbeat message to another node in the cluster of size 2 and repeats same process. In the worst case, an initiator node has to send an initiation heartbeat message to all the nodes of all the clusters of size $C_{i,\ s}$ consisting of only faulty nodes. Thus, the total time elapsed to test every node in every cluster for a network size of N by an initiator node is $(\log_2 N.\ C_{i,\ s})\ T_{out}$.

Every initiator prepares a local diagnostic message based on the diagnosis information about all clusters it has diagnosed. Every initiator node broadcasts the local diagnostic message to every other initiator node as specified in step 7 of the proposed diagnosis algorithm. In the step 7, every initiator node prepares a global diagnostic message and exchange further these message to provide a global and consistent diagnostic view for the entire MANET. Though numbers of message exchanges are high, the algorithm can take the advantage of broadcast communication of MANET. The maximum time to execute step 7 is assumed to be T_{xcg}. Since there are N initiator nodes, the total diagnostic latency is $O(N\log_2 NC_{i,\ s}T_{out} + T_{xcg})$. This proves claim 4.

Claim 5. *The diagnostic latency of the proposed diagnosis algorithm is less than that of Forward Heartbeat.*

Proof. The diagnostic latency of our algorithm depends on number of messages such as initiation heartbeat message, response heartbeat message, local diagnostic message and global diagnostic message and the message size. Mobile nodes running algorithm heartbeat complete get messages with diagnostic information concerning all nodes in all testing rounds; in contrast our proposed algorithm diagnostic messages only contains information about the nodes in each cluster being tested. Since the number of messages and message size is directly proportional to diagnostic latency, the diagnosis latency of our proposed diagnosis algorithm is less in comparison with algorithm ForwardHeartbeat. This proves claim 5. The proposed diagnosis algorithm has been compared with an existing diagnosis algorithm ForwardHeartbeat proposed in paper [8], using the diagnostic latency and message complexity as the parameter for evaluating the performance. The ForwardHeartbeat is applicable to a not completely connected network such as MANET. Our proposed diagnosis algorithm achieves correctness in an arbitrarily connected mobile ad hoc network taking mobility of the node into consideration. The experimental results are shown in section 7 in this paper.

VII. EXPERIMENTAL RESULTS

A. Simulation Model

A simulator is designed in MATLAB language where we present experimental results of diagnosis on large network using Hi-ADSD, obtain through simulation. The experiments were conducted for the network of varying sizes of 8, 16, 32, 64,128 nodes. Tests were scheduled for each node at each 30 ± б units of time, where σ is a random number between 0 and 3. During each test, the status of nodes are checked and if the node is fault free, diagnosis information regarding the cluster is copied to testing node. If the tested node is faulty, the testing nodes proceed testing as in the algorithm. Network is clustered using the algorithm described above. The parameters from diagnosis literature are assumed for executing the diagnosis tasks, send initiation time and propagation time of the messages in the MANET. The values of these parameters are given in the following TABLE III.

TABLE III. Values Of Different Parameters Used In The Simulation

Sl. No	Parameter	Value (units)
1	Diagnosis task execution time	0.01 to 0.05
2	Send initiation time	0.002
3	Request heartbeat/ Response heartbeat delay	0.008 to 0.08
4	Local diagnostic message /Global diagnosticmessage delay	0.012 to 0.12

The parameters to evaluate the diagnosis algorithm are given in the following section.

B. Simulation Parameters

There are three different parameters are used in the literature. These parameters are usually used to evaluate the proposed fault diagnosis algorithm.

Diagnostic Latency: It is the time elapsed by the initiator node to determine the status of the node in the network.

Message Complexity: It is the number of messages exchanged among nodes in the network to determine the status of nodes.

Hop Count Ratio: It is the ratio of the euclidian distance between the source and destination node to the number of nodes in between the source and destination node.

C. Results

1) Diagnostic Latency Vs. Network size

Figure 5 compares the diagnostic latency for the proposed algorithm using clustering and compares the diagnostic latency without clustering technique. As the network size increases, the diagnostic latency for both clustering and non-clustering increases. However, there is a significant reduction in diagnostic latency by using clustering as compare to the diagnostic latency without clustering as used in ForwardHeartbeat. This shows that the proposed algorithm is suitable for large MANETs deployed in hostile and harash environments.

It can be observed that the diagnostic latency depends on number of messages exchanged and the network parameters such as transmission and propagation delay and directly proportional to the number of messages exchanged in the network to achieve diagnosis. Nodes running in algorithm ForwardHeartbeat get messages with diagnostic information concerning all nodes in all testing round; in contrast our proposed algorithm diagnostic messages only contain information about the nodes in each cluster being tested. So, diagnosis latency of our proposed algorithm is less in comparison with algorithm Forwardheartbeat.

2) Message Complexity Vs. Network Size

Figure 6 shows the number of messages exchanged during the execution of proposed fault diagnosis algorithm. Message complexity i.e. total number of messages exchanged increases linearly with the number of nodes and found to be $O(N.C_{i,s})$. Whereas the message complexity of ForwardHeartbeat is O(N.E) where N is the network size and E is the number of edges and is very high as compared to proposed diagnosis algorithm. This shows the proposed diagnosis algorithm is linearly scalable.

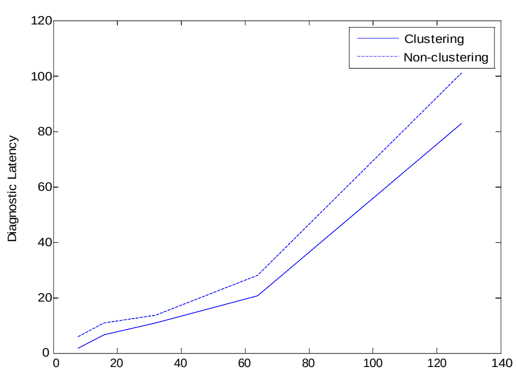

Figure.5 Comparison of the amount of diagnostic units required in both clustering and non-clustering fault diagnosis algorithm

3) Hop-count Vs. Network Size

Figure 7 shows the number of hop counts for the proposed diagnosis algorithm to complete fault diagnosis for network of different sizes. Hop count on an average is being calculated as the ratio of the euclidian distance between the source and destination node in the simulation and the number of nodes in between the source and destination node.

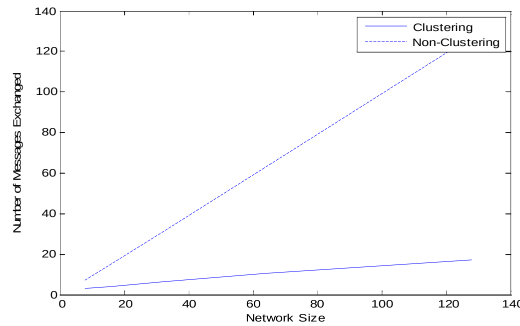

Figure.6 Message complexity graph

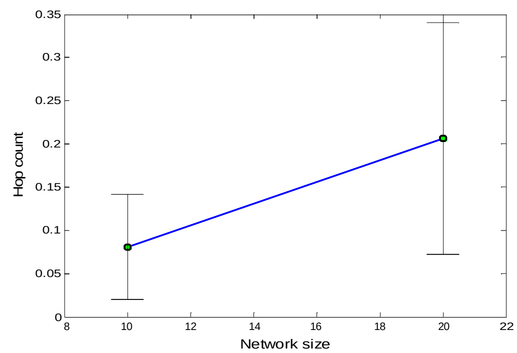

Figure 7 Number of hop counts required to diagnose nodes

VIII. CONCLUSION & FUTURE WORK

In this paper, we proposed a hierarchically adaptive distributed diagnosis algorithm for diagnosing crash and value faulty nodes in MANET based on Hi-ADSD. Hi-ADSD maps nodes to cluster and uses a divide-and-conquer testing strategy to achieve diagnosis. The proposed algorithm has been simulated using MATLAB and has been evaluated analytically using the standard performance measures such as diagnostic latency and message complexity. The result shows that the proposed algorithm is linearly scalable in terms of diagnostic latency and message complexity.

Our future work includes fault diagnosis in MANET using other clustering techniques. Investigation of roving diagnosis where some of the cluster may run the application while other cluster in the system may execute the diagnosis algorithm simultaneously.

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