



SURVEY ON FAULT DIAGNOSIS IN MANETs

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Abstract- Recent technological advancements have led to the popularity of mobile devices, which can dynamically form wireless networks. Unfortunately, mobile devices are vulnerable to failure because of various factors, including physical damage due to deployment in harsh environmental conditions, limited energy and malicious attacks. Node faults may be frequent in a mobile ad-hoc network. With the advent of modern computer networks, fault diagnosis has been a focus of research activity and has become a critical need to guarantee robust service for various applications. Many techniques have been suggested to solve this problem but they still cannot satisfy the special needs for MANETs. In this paper we consider the fault diagnosis problem in MANETs, i.e. the problem of identifying faulty host by fault-free ones. This paper reviews the history of fault diagnosis in networks. This survey integrates the vast amount of research efforts that have been produced in this field, from the earliest theoretical models to new promising applications.

Keywords: Mobile ad hoc networks, fault detection, diagnostic latency, System level diagnosis, adaptive diagnosis, distributed diagnosis

I. INTRODUCTION

MANET is an autonomous system of mobile nodes connected by wireless links [1]. Wireless links provide lower bandwidth and higher error rates compared with fixed networks. MANETs can however be deployed quickly and without large infrastructure investments in order to complete assigned tasks e.g., military operations, emergency situations, sensory environments, etc. The nodes may be resource constrained, have limited battery power, and because of mobility must continuously monitor and react to changes in their transmission neighborhood. Mobile devices are vulnerable to failure: they are deployed in harsh environmental conditions, are subject to accidental or malicious damage by humans, and have a limited energy source that will be depleted with time and usage. Detecting node failure is the cornerstone of developing fault-tolerant applications; it is essential to detect failure of a node holding a desired resource in order to allow processing to progress.

At a given point of time t , the topology of the MANET can be described as a directed graph $G_t = (V_t, E_t)$ where V_t is the set of nodes and E_t is the set of links at time t . For any two nodes $u, v \in V_t$, (u, v) is in E_t , if the transmitter of u can reach v . The nodes u and v are said to be one hop neighbors. The topology of a MANET may change due to a node crashing but it could also be that node has moved such that it has different neighbors or it has moved out of range. A node that has crashed versus a node that has moved out of range has the same impact on the topology. The node is not in V_t . This makes it difficult to make the distinction. This distinction is needed for some environments e.g., tactical networks. A node that often moves out of range may view suspiciously and thus there may be reluctance to assign tasks to that node.

The remainder of the paper is organized as follows. Section 2 describes related work done so far in this field. Section 3 describes system level diagnosis. Finally the paper concludes with a summary.

II. RELATED WORK

As the popularity of ad-hoc networks grows and the computational power of mobile units increases, the need for dependability becomes an issue. 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 must maintain correct information about the status (working or failed) of each mobile host in its neighborhood. Moreover, for some MANETs' applications each mobile host should be able to diagnose the state of all mobiles in the network. In fact, a faulty mobile host that is not in the neighborhood of a mobile host, say u , might sooner become one of u 's neighbors, since the mobile hosts are moving with varying speeds. Besides the diagnosis itself, another important related problem is the diagnosability that is, determining the largest number t of faulty units that do not make it impossible to diagnose the system. This is a relevant quantitative measure of the reliability of a given system. However, The first model proposed for system-level diagnosis was the PMC model in 1967 [2], this model is named after author's initials: Preparata, Metze and Chien. The assumption of model is that a fault-free unit performs tests and generates results reliably. The PMC model gave necessary conditions for t -diagnosability, means at most t number of faulty nodes can be

diagnosed by the system. In addition to, Later Hakimi *et al.* [3] and Amin in 1974 characterized the PMC model. Each node is tested by at least t nodes, and $N > 2t + 1$, no two units test each other, and they gave necessary and sufficient conditions for a system to be t -diagnosable.

Another early model for system-level diagnosis is the BGM model [4], also named after authors' initials: Barsi, Grandoni and Maestrini in 1976. This model is similar to the PMC model. Its basic assumptions are: each test is executed by a single unit; each unit has executed by a single unit; each unit has the capability of testing any other unit; no unit tests itself. It is based on asymmetric invalidation rule; faulty units always generate wrong result. Similar models are proposed by Malek in 1980 [5], and by Chwa and Hakimi in 1981 [6]. These models assume a central observer which collects and examines the result about diagnosis. The MM model [5] assumes that comparisons are executed by the units themselves, and only results are sent to the central observer if both the units are fault free.

One more model proposed by Maeng and Malek in 1981 [7], it is a variation of MM model, assumes that node performs comparisons for its neighbors, no need of central observer for comparison and only comparison results are sent to the central observer if both the units are fault free. This model is called MM* model.

Sengupta and Dahbura simplify the MM model in 1992 [8]. In this model the comparator is compared by one of units. They also characterized diagnosable systems under the MM model. Probabilistic comparison-based models were first introduced by Dahbura *et al.* [1987], and this method was applied to multiprocessor diagnosis. Probabilistic models assume a fault probability, that is, the probability that a unit produces an incorrect output. Blough *et al.* [9] introduced the Broadcast Comparison based model in 1999. This model was generated for a fully distributed system, performed the comparison based approach to diagnosis the system. This model was based on reliable broadcast. In this model a task is assigned to the different pair of nodes, which perform the task and send their outputs to all nodes in the system. All fault-free nodes compare all results and diagnose the system. Other comparison based models introduced by Albini *et al.* [10, 11] in 2001 and 2005 that was fully distributed system but not a reliable broadcast. Here fault-free nodes perform test and categorize the system nodes in sets. Whereas, Radhakrishnan *et al.* [12] presented the distributed algorithm that adapts to the topology by utilizing spanning trees in the regions where the topology is stable and restoring to an intelligent flooding like approach in highly dynamic network. It is based on hold and forward or shuttling mechanism.

In 2004, Subbiah *et al.* [13], introduced a dynamic failure problem. To address this problem bounded correctness defined, which is made up of three properties: *bounded diagnostic latency*, which ensures that information about state changes of nodes in the system reaches working nodes with a bounded delay; *bounded start-up time*, which guarantees that working nodes determine valid states for every other node in the system within bounded time after their recovery, and *accuracy*, which ensures that no spurious events are recorded by working nodes. A node sends heartbeat message to a subset of other nodes and then rely those messages. The assumption of this approach is, heartbeats are the basic mechanism for a node to notify other nodes that it is working. Moreover, Rangrajan *et al.* [14] presented a distributed algorithm for detecting and diagnosing faulty processor in an arbitrary network. A fault free node responds correctly within a specified timeout to test and forward diagnosis information correctly. A faulty node gives undesirable response.

III. SYSTEM-LEVEL DIAGNOSIS

As faults are inevitable in every computer system, it is important to be able to determine which units of the system are working and which are faulty. The first model proposed for automatic system-level diagnosis was the PMC model [Preparata *et al.* 1967], named after the author's initials: Preparata, Metze, and Chien. The PMC model assumes a system S that consists of a set of N independent units, $u_0, u_1, \dots, u_{N-1}$. Alternatively unit u_i is also referred to as *unit i* or *node i* , or even *processor i* . Each unit u_i is assumed to be in one of two states, *faulty* or *fault free*. Diagnosis is based on the ability of units to test the status of other units [Masson *et al.* 1996; Jalote 1994][16,20]. A unit is tested as a whole, it is not possible to test part of a unit, and the state of a unit does not change during diagnosis. In the PMC model a test involves the controlled application of stimuli and the observation of the corresponding responses from the tested unit. Preparata *et al.* [1967] define a test as a "diagnostic program" tailored for each system. The PMC model assumes that a fault-free unit executes tests and reports test results reliably, that is, a fault-free tester can always correctly determine whether the tested unit is faulty or fault free. While fault-free units are assumed to be able to execute tests correctly, no assumptions are made about tests executed by faulty units, that is, they may produce incorrect test outcomes [Preparata *et al.* 1967; Hakimi and Amin 1974].

The set of tests is called the *connection assignment*, and the set of all test outcomes is called the *syndrome* of the system. The syndrome is processed by an external entity which diagnoses the system, that is, determines the state of all system units. The model employs a directed graph in order to represent the connection assignment. The vertices of this graph are the system units, and there is an edge directed from unit i to unit j if unit i tests unit j . Each edge is labeled by the test outcome, $ai, j = \{0, 1\}$. If unit i tests unit j as faulty, then $ai, j = 1$, on the other hand if unit i tests unit j as fault free, then $ai, j = 0$. These results hold only if the tester is fault free, otherwise the test outcomes are unreliable. Depending on the number of faulty units and on the testing assignment, it is impossible to correctly diagnose the system. A system is

defined as *one-step t-diagnosable* if all faulty units within the system can be identified when the number of faulty units is not greater than t . Furthermore, a system is defined as *sequentially t-diagnosable* if at least one faulty unit can be identified and be repaired or replaced, so that the testing can be continued using the repaired unit to eventually diagnose all faulty units in the system. In t -diagnosable systems the problem of determining the maximum value for t is called the diagnosability problem. Preparata et al. gave necessary conditions for t diagnosability of their model [Preparata et al. 1967]. Later Hakimi and Amin [1974] characterized the PMC model, and proved that if no two units test each other, each unit is tested by at least t others, and $N \geq 2t+1$, these are not only necessary but also sufficient conditions for a system to be t -diagnosable.

Another early model for system-level diagnosis is the BGM model, also named after its authors' initials: Barsi, Grandoni, and Maestrini [1976]. This model is similar to the PMC model, employs the same testing graph, but assumes different test outcomes. Its basic assumptions are: each test is executed by a single unit; each unit has the capability of testing any other unit; no unit tests itself; and, for any pair of units u_i , u_j , unit u_i performs at most one test on unit u_j . The diagnostic model is defined as follows:

- if u_i is fault free, the test outcome is 0 if u_j is fault free; the test outcome is 1 if u_j is faulty;
- if u_i is faulty and u_j is fault free, both test outcomes are possible; and
- if u_i and u_j are faulty, the test outcome is necessarily 1.

The adaptive distributed system-level diagnosis algorithm, *Adaptive-DSD*, was proposed by Bianchini and Buskens [15] [1991, 1992]. Adaptive-DSD is, at the same time, distributed and adaptive. Adaptive-DSD is executed at each node of the system at predefined *testing intervals*. Each node is tested only once per testing interval. A *testing round* is defined as the period of time in which all nodes of the system have executed their assigned tests at least once. All fault-free nodes achieve consistent diagnosis in at most N testing rounds. Up to $N-1$ nodes may be faulty so that fault-free nodes are still able to diagnose the system. Each time the algorithm is executed on a fault-free node, it performs tests on other nodes until another fault-free node is found, or the tester runs out of nodes to test. The testing graph is thus a ring connecting fault-free nodes. When the tester executes a successful test, that is, the tested node is fault free, the tester obtains diagnostic information from the tested node. Let the *diagnosis latency* be the number of testing rounds required by all fault-free nodes to complete the diagnosis of the system. Adaptive-DSD has a worst-case latency of N testing rounds. Adaptive-DSD was implemented and practical results were presented showing the effectiveness of the algorithm when used to monitor a real Ethernet network. Hierarchical diagnosis was proposed in order to reduce the latency of adaptive distributed diagnosis [Duarte Jr. and Nanya 1995; 1998; Duarte Jr. et al. 2000][18,19]. In hierarchical diagnosis, nodes are grouped in progressively larger virtual clusters so when a fault-free node is tested, the tester obtains information about all nodes in that cluster.

The Hierarchical Adaptive Distributed System-level Diagnosis (*Hi-ADSD*) algorithm system of N nodes. Another hierarchical diagnosis algorithm, Hi-ADSD with timestamps [Duarte Jr. and Nanya 1998][19] has a diagnosis latency of at most $\log_2 2N$ testing rounds for [Duarte Jr. et al. 2000][17], employs clusters with size $N/2$ resulting in an average latency shown to be lower than Hi-ADSD's. Subbiah and Blough [2004] define a theoretical framework called *bounded correctness* in which it is possible to prove the correctness of distributed diagnosis in the presence of dynamic faults and repairs. They present both an algorithm for fully connected systems and another for general topology networks and prove their bounded correctness.

IV. COMPARISON-BASED DIAGNOSIS APPLIED

TO AD HOC NETWORKS

Comparison-based diagnosis has been applied for mobile ad hoc networks by Chessa and Santi in [21] [2001] and Elhadef et al. in [2006, 2007][22,24]. Protocols for both models are able to identify *hard* (permanent) and *soft* (temporary) faults. A node suffers a hard fault when it ceases completely to communicate with other nodes. On the other hand, a node affected by a soft fault continues to operate and communicate, but with altered behavior. The description of both models follows.

A. Chessa and Santi's Diagnostic Model

First time they introduced the distributed diagnosis comparison model based on one-to-many comparison in ad hoc network. They diagnosed Permanent (hard and soft faults) and occurrence of fault was static. The model assumed that network topology doesn't change during diagnosis session and it is $\frac{3}{4}$ -diagnosable MANET. It used the asymmetric comparison based invalidations. In this model, every node receives different task from neighbors and every node responses for the different task. This model has used flooding approach to disseminate the diagnosis information.

B. Elhadef et al. Diagnostic Model

In Elhadeef et al. [2007, 2006][24,22] the authors present comparison-based diagnosis protocols for mobile ad hoc networks. Two protocols are presented: the Adaptive Distributed Self-Diagnosis Protocol (Adaptive-DSDP) for fixed topology networks, and the Mobile Distributed Self-Diagnosis Protocol (Mobile-DSDP) for time-varying topology networks. The key idea of both protocols is that a node, when replying to a test request, should also provide the test task along with its output for that test. Thus any receiver would be able to diagnose its state by simply comparing this output to similar outputs for the same test, or even by comparing the received result to its own output after performing the same test.

Besides the fact that nodes forward tasks with test responses, the fixed-topology diagnosis model on which Adaptive-DSDP is based also differs from Chessa and Santi's model [2001] in their dissemination strategies. In Chessa and Santi's [2001] model, once a node collects all its neighbours' responses, it forwards its local view to all other nodes in the MANET using a flooding-based dissemination phase. On the other hand, Adaptive-DSDP uses a spanning tree and a gossip-style dissemination strategy [Elhadeef et al. 2007]. Elhadeef et al. present in [2006][23] another distributed comparison-based self-diagnosis protocol for wireless ad hoc networks based on Chessa and Santi's [2001] model.

The proposed protocol is called Dynamic-DSDP which also identifies hard and soft faults. They compare the Dynamic-DSDP protocol with Chessa and Santi's [2001] Static-DSDP protocol.

V. CONCLUSIONS

In this survey we have discussed about different methods and algorithm to diagnose the fault in the system. This work presented a comprehensive and integrated view of comparison-based diagnosis results including models, algorithms, diagnosability bounds, and applications. These results have been published for a period that spans the past three decades. A uniform notation for describing all these results was employed. In comparison-based system-level diagnosis tasks are assigned to and executed by pairs of units. The task outputs are returned and then compared. Depending on the comparison outcomes, units are classified as faulty or fault free. This survey described how the several models for comparison-based diagnosis differ, that is, in terms of assumptions, on how tasks are assigned, how outcomes are returned, where task outputs are compared, and how results are interpreted. Models either assume that only the task execution is distributed, or, alternatively, that also comparisons and the diagnosis itself are distributed among the system units. Some models work under probabilistic assumptions.

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