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Checkpointing in Mobile Ad Hoc Networks (MANETs)-A Survey

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Abstract— Checkpointing is a popular fault-tolerance technique in mobile computing. It is a way to record the current status of information, which may be required while recovery after failures. Thus, in case of failure, computation may be restarted from the saved checkpoint instead from the beginning. Checkpointing-based rollback recovery is used in various domains like applied sciences, database management, computer networks and many more. Mobile Adhoc Networks (MANETs) consists of a number of mobile hosts (MHs) connected with each other via wireless links. Here, the challenge is limited power supply and storage capacity. Therefore, checkpointing is a major confront in such dynamic environment. This survey paper presents a comprehensive survey of checkpointing algorithms along with an analysis of their performance characteristics. .

Keywords— Checkpont, Distributed Systems, MANET, Rollback Recovery.

I. INTRODUCTION

A distributed system consists of several processes that execute on geographically dispersed computers and collaborate via message-passing with each other to achieve a common goal [14]. Distributed systems nowadays are ubiquitous and facilitate most of the applications like World Wide Web (www), transaction processing systems, client-server systems, and many others. However, the huge computing potential of such system is often hindered due to its vulnerability to failures. Therefore, in the existing literature, many techniques have been proposed to increase reliability and accessibility of distributed systems. These techniques include group communication, transaction processing with tradeoffs. Traditional distributed system includes stationary hosts, however recent advancements in wireless communications has upgraded the same to be mobile. Thus, a MANET can be seen as a special field in distributed systems where hosts are mobile. Nevertheless, these mobile hosts have tradeoffs like limited power supply, least availability of resources and many more.

In the design of distributed algorithms, a major concern is to calculate consistent global states, also termed as distributed snapshot. The problem which relies on consistent global state is detection of deadlock and termination as well as rollback based recovery. Rollback recovery assumes the distributed system as a cluster of application processes that communicate with each other through a network. These processes achieve fault-tolerance by using a stable storage device that survives all failures by using the saved information to restart the execution from the latest state, thereby, reducing the amount of lost information. The recovery information includes the latest saved information of states called *checkpoints*. Various characteristics are associated with the mobile hosts which differentiates them from stationary nodes. While designing any checkpointing protocol for distributed systems, following features must be considered in order to reduce overheads [13], [15], [16]:

- As bandwidth of wireless network is comparatively lower than wired networks. Therefore, *bandwidth* is a major concern.
- The *disk storage* is potentially unstable for logging of messages and recording of states as mobility is inherently vulnerable. For example, when a desktop system or laptop is stolen, the data is wiped out by some intruding systems or any other virus. Hence, message logging and state recording could not rely on mobile host's disk storage. Also, due to its vulnerability to failures, it may not be immediately accessible when urgently required. In such cases, the available option is to treat MSS as the available source of stable storage in order to store checkpoints to which a mobile host is connected. This would require each mobile host to report to their respective MSS whenever they take checkpoints. As the bandwidth is limited, the *checkpointing overhead* increases if the amount of data to be saved is very large. Therefore, the technique is preferred when number of checkpoints to be taken is less.
- *Battery source* is the major concern in mobile environment as there is no permanent source of battery. Also, a low battery may lead to disconnection of mobile hosts from the rest of environment whenever they are in low-energy mode. A mobile host in disconnected mode can stop sending and receiving messages. However, the MHs continue the execution of application using its local data and cashed stored data [15].
- *Topological change* is worthwhile issue in mobile environment. This change refers to the change of existing cluster by a mobile host without any prior information to its MSS. As the mobile host changes its location, it

becomes very difficult to search and locate their new location in order to deliver the computation messages. This requires the mobile host to notify their new location to their respective MSS and other mobile hosts [17].

- Number of *synchronization messages* needs to be reduced because of limited battery supply.
- Available *resources* for wireless devices are lesser as compared to wired devices. This is because the wireless device needs to be smaller, lighter and workable with lesser battery power. Also, wireless communication is comparatively tougher to implement as compared to wired because of interference of surrounding environment with the travelling signals. These problems may include noise, interference echo, signal blockage and many more.
- *Storage space* is a major issue in mobile environment as there is limited size and power available. Compression, code sharing, remote access storage and interpreting script languages instead of executing compiled code [16] are some of the solutions to storage problem

II. RELATED WORK

Arup Acharya and Badrinath, 1994 [1] proposed a checkpoint and rollback recovery for distributed applications on mobile computers. Acharya presented a checkpointing scheme for mobile hosts that uses the stable storage of MSS's to handle the storage issue of MHs. Here each MH has to take checkpoint before migrating to new cluster, before disconnecting from that cluster and in addition when required by two phase rule used in this paper. The two phase rule described in this paper dictates when a MH needs to take checkpoint its local state, which is saved in a message log. Therefore, using this rule it is ensured that there is no dependency between two checkpoints. To solve the problem of search costs, frequent disconnections and stable storage. CKPT and LOC arrays are used. These arrays are piggybacked with each application message to invoke checkpoint procedure and estimate the location of these checkpoints respectively.

Taesoon park and H.Y. Yeom, 2000 [2] proposed an asynchronous recovery scheme based on optimistic message logging for mobile computing systems. The proposed technique was based on optimistic message logging where tasks of message logging and dependency tracking is completely performed by MSS instead of MH to cope with storage problem. Information is carried upon the messages passing between MSS to reduce the dependency whereas, the messages between the MH residing in the same MSS are traced from the message sequence. Due to little overhead and asynchrony, mobile hosts need not to involve in any coordination and the system can easily recover from failures. Asynchronous recovery doesn't involve MHs in any kind of coordination thereby, making them to take their checkpoints independently. Furthermore, the system can handle multiple and concurrent failures.

Guohong Cao and mukesh Singhal, 2001 [3] proposed a new checkpointing approach called mutable checkpoints. Coordinated checkpointing is an efficient fault-tolerance technique since it avoids domino effect and minimizes stable storage requirement. However, it experiences many overheads. Therefore, to minimize these overheads a new scheme called *mutable checkpoints* has been introduced, which is neither tentative nor permanent and can be saved anytime and anywhere *i.e.,* local disk or MSS. Thus, taking a mutable checkpoint avoids wastage of stable storage by not forcing the transferring of large amount of data over the network and thus reducing the overheads and number of checkpoints to be taken. Thus, this new scheme of mutable checkpoints is advantageous over uncoordinated checkpointing as well as reducing the overheads incurred in coordinated checkpointing.

Tong- Tony –Chang, 2000, [4] discussed a new solution to crash recovery. It presented an efficient recovery algorithm for wireless mobile ad hoc networks which are organized as a cluster-based structure. Communication is amongst the clusters only, where each cluster has one cluster head which is acting as a local coordinator of all the communications of its own cluster. However the basic problem to be handled is process failure. Therefore the author has used rollback recovery in conjunction with checkpointing. Each Processor locally saves its history and current state in a stable log from time to time. Processor will start from its most current saved state in case of any failure.

Masakazu Ono and Hiroaki Higaki, 2007 [5] proposed a new approach called Checkpointing by flooding method. In this approach the mobile hosts communicate without any stable storage and enough bandwidth. A request for checkpoint is being sent through flooding. Every neighbor mobile host of a node stores the state information of a node. Any node suffered from lost message is detected and stored by its intermediate nodes.

Chaoguang Men et al. , 2008 [6] proposed a checkpoint and Rollback recovery for cluster based mobile ad-hoc wireless networks. Here the cluster head of each cluster is engaged in checkpointing. CH maintains several variables including checkpoint index, node queue and a variable counting the number of reply messages, moreover CH also performs channel assignment, communicating data and scheduling intra-cluster traffic. A special packet called beacon packet is used which carries sizes of data window, traffic indication message and clock data. Checkpointing process is done in two beacon intervals. Any cluster head when receive checkpoint request first deliver all the perimeters to mobile host in its cluster. The mobile hosts which are currently not communicating will take checkpoint and those which are busy will take checkpoint in next beacon interval. Therefore this scheme was comparatively fast and with lower overheads.

Sapna E. George, Ing-Ray Chen, Ying Jin, 2006 [7] proposed a new failure recovery model for mobile computing systems. The author presented a methodology of movement based checkpointing and logging for recovery in mobile computing system. In this movement based checkpointing, Checkpoint is taken if and only if a mobile host has changed its cluster a threshold number of times where, threshold is function of log arrival rate , failure rate, mobility rate. To calculate this threshold, a performance model has been developed based on stochastic petri nets. Moreover this paper assumed exponential distribution of the system parameters. This approach combined independent checkpointing and message logging enabling asynchronous recovery of a node and optimizes recovery cost, recovery time and storage issues.

Bhalla, S, 2006 [8] proposed a global snapshot for host recovery by calculating cumulative dependency. The author has examined a customized cumulative dependency tracking approach for recovery of processes. Moreover this paper examine the global snapshot generation. However, this algorithm indirectly calculates the independent dependencies. Hence, it is able to prevent cascade rollback. It is also able to calculate consistent global snapshot. Recovery of node can be done from latest snapshot. In case of node recovery only a single message is needed to be sent to all the connected stations about any kind of failure. The proposed approach minimizes the number of messages generated during recovery, delay in recovery time.

Qiangfeng Jiyang et al, 2008 [9] proposed an optimistic checkpointing and message logging approach for consistent global checkpoint collection in distributed systems. The author presented an efficient *communication-induced* checkpointing algorithm that enables all the checkpoints to be a part of consistent global checkpoint. It allows processes to take tentative checkpoints optimistically and store them at stable storage whenever there is no contention for stable storage. All the messages sent and received after a tentative checkpoint has been taken are stored in memory until it is finalized in stable storage. Processes take enough time to take checkpoint before processing received message hence it minimizes network contention.

A. K .Singh-P. K. JAGGI, 2011 [10] proposed concurrent checkpointing and recovery. The author presented a coordinated checkpointing scheme in which self stabilizing spanning tree are used upon the network topology to reduce the message overhead and also handle dynamic properties of MANETs. To avoid simultaneous contention of resources it proposed a staggered checkpointing approach. The staggering causes events, which would normally happen at the same time, to start or happen at different times. This protocol does not need FIFO channels and logs minimum number of messages. It supports concurrent checkpoint initiation and successfully handles the overlapping failures in mobile ad hoc networks.

Jaggi-Singh, 2011 [11] presented a Snapshot recording using a Self Stabilizing Tree. The author proposed an algorithm for recording consistent global snapshot of dynamic mobile ad hoc networks. All the cluster heads organize themselves into a self stabilizing spanning tree to reduce snapshot related message as spanning tree always results in shortest possible path. This approach resulted in decreasing the number of control messages significantly even if the number of clusters is increased. Moreover this scheme can work efficiently even with multiple initiators and dynamic topology.

Tuli-kumar, 2011 [12] proposed the minimum process coordinated checkpointing scheme. In this paper, the author has presented a non blocking and minimum process checkpointing scheme for clustering protocols. This algorithm gratify the need of ad-hoc environment In this scheme a base station saves the information about the cluster heads when the cluster heads send routing and other collected information to it. Here minimum number of processes needs to take checkpoint. Whenever any base station detects that a cluster head is failed, some new mobile host is being assigned the task of cluster head. Therefore it reduces the energy consumption and recovery latency when a cluster head fails.

Suparna Biswas et. al, 2012 [27] proposed a mobility based checkpointing and trust based rollback recovery for fault-tolerance in MANETs. A count variable is maintained to identify number of clusters a mobile traverse during one checkpoint interval. A threshold value is defined and MH saves checkpoint state if that variable crosses that threshold value. In case of any failure, time to search and collect last checkpoint and log is added to recovery time.The proposed approach resulted in low recovery cost and high recovery probability of failed mobile hosts.

Doug Hakkarinen and Zizhong Chen, 2013 [28] proposed a multilevel diskless checkpointing in which the author provided a model to derive expected time to complete a program using two level diskless checkpointing. Moreover this paper presented a method to search for optimal number of checkpoints and also number of levels that provide a valid starting point when exhaustive search is expensive. Results proved that N-level diskless checkpointing is highly capable system for high performance computing programs as compared to previous systems. Therefore this method improves expected execution time even in case of large number of processes and increased failure rates.

Suparna Biswas and Priyanka Dey, 2013 [29] proposed a secure checkpointing recovery using trusted nodes in MANETs. Author proposed a hybrid model of secure checkpointing in which proposed trust model is combined with encryption technique. However, results show that encryption may not be required if checkpointing data is being forwarded through trusted nodes. Hence, energy consumption of nodes and bandwidth consumption of links gets reduced at large scale and therefore increases applicability of this model in MANET environment with least resources.

Table 1. Comparitive analysis of various checkpointing algorithms.

S. No.	Algorithm Proposed By	Features	Approach	Storage location
1.	Arup Acharya, B. R. Badrinath [1]	The approach solve three issues: 1. search costs 2. frequent disconnections 3. lack of stable storage at a MH.	In uncoordinated checkpointing scheme multiple MHs can arrive at a global consistent checkpoint without coordination messages.	Stable storage of Mobile Support Stations(MSS)

2.	Taesoon Park, Heon Y. Yeom [2]	1. The tasks of loggin and dependency tracking are fully performed by MSSs 2. MHs are only carrying the minimum information.	Asynchronous recovery scheme based on optimistic message logging for the mobile computing systems.	Stored at a number of MSS to recover easily.
3.	Guohong Cao and Mukesh Singhal[3]	By using mutable checkpoints: 1. number of irrelevant checkpoints is reduced 2. overhead of taking mutable checkpoints is negligible	A new scheme of mutable checkpoints is used	The main memory or local memory of MH.
4.	Tong-Ying Tony Juang Meng-Chang Liu [4]	1. Independent checkpointing is used 2. Communication amongst cluster heads only.	Efficient rollback algorithm for crash recovery.	Loacal MSS at cluster head
5.	Ono Masakazu and Higaki Hiroaki [5]	1. Mission-critical network applications, 2. Flooding is used to deliver checkpoint request message. 3. Communication overhead is reduced	Message flooding technique is used to reduce control messages and checkpoint request messages.	Neighbor mobile computer
6.	Chaoguang Men, Zhenpeng Xu, Xiang Li[6]	1. Cluster-based multi-channel management protocol. 2. Local consistent checkpoint-two consecutive beacon interval. 3. Rollback recovery-one beacon interval	A special Beacon message is uded to create two intervals to distinguish in which interval a mobile host should take checkpoint.	Local Mobile Supporting Stations(MSS) at CH
7.	Sapna E. George , Ing-Ray , Chen Ying Jin [7]	1. A mobile host takes a checkpoint only after it crosses a threshold value. 2. Threshold is dependent on log arrival rate, mobility rate,failure rate.	Checkpoint is taken on the basis of a particular number of movements of a mobile node.	
8.	Bhalla S.[8]	1. Track independent tracks by calculating cumulative dependency. 2. Prevents rollback cascading	Global Snapshot for Host Recovery and calculation of consistent states.	Local MSS of MH.
9.	Qiangfeng Jiang, Yi Luo, D. Manivannan [9]	1. Every process stores the tentative checkpoint in memory first and then flushes it to stable storage. 2. There is no contention for stable storage .	Communication-induced Checkpointing(CIC) algorithm that makes every checkpoint belong to a consistent global checkpoint	Stable storage of MSS is used
10.	Awadhesh Kumar Singh, Parmeet Kaur Jaggi, [10]	1. It supports concurrent checkpoint initiation 2. successfuly handles the overlapping failures in ad hoc networks	Staggered approach to avoid simultaneous contention for resources. Successfully handles the overlapping failures	Own memory
11.	Parmeet Kaur Jaggi and Awadhesh Kumar Singh [11]	1. Self stabilizing spanning tree upon the network topology to reduce the message overhead 2. Handle the dynamic	Spanning tree formation of nodes is there to minimize the number of messages	Local Mobile Supporting Stations(MSS) atCH

		nature of MANETS.		
12.	RuchiTuli1and ParveenKumar [12]	1. Minimum process coordinated checkpointing scheme for Cluster based ad-hoc routing protocols. 2. Minimum number of control messages needed and does not take useless checkpoints.	In this algorithm a cluster head sends routing and collected data information to base station, which periodically saves the state of cluster head.	Base Station MSS at CH.
13.	Suparna Biswas et. al [27]	1. Mobility based checkpointing based on threshold value. 2. Checkpoint traverses only through trusted mobile hosts. 3. Only trusted mobile hosts can be selected as cluster heads.	In this algorithm a count variable is maintained to identify number of clusters a mobile traverse during one checkpoint interval. A threshold value is defined and MH saves checkpoint state if that variable crosses that threshold value	Mobile Hosts
14.	Doug Hakkarinen and Zizhong Chen [28]	1. Multilevel diskless checkpointing is used. 2. 2-level and 3-level outperforms the one failure checkpointing scheme.	This method improves expected execution time even in case of large number of processes and increased failure rates.	Own memory
15.	Suparna Biswas and Priyankla Dey [29]	1. A secure checkpointing technique. 2. Encryption is used for security 3. Propsed algorithm is consistent and ensures that there are no orphan messages	Energy consumption of nodes and bandwidth consumption of links gets reduced at large scale and therefore increases applicability of this model in MANET environment with least resources.	

III. CONCLUSION

In the paper, we analyze different approaches of rollback recovery and compare their characteristics in terms of storage space and other features. It has been observed that clustering of nodes helps in proper reuse of space by facilitating the reuse of resources. Further, number of mobile hosts residing in the cluster can communicate efficiently with the other mobile hosts by coordinating with their cluster head. Hence, clustering methods allow fast connection as well as better routing and topology management of Mobile Ad-Hoc Networks. Furthermore, we propose a multi-checkpointing protocol which reduces overall overhead incurred while checkpointing. An example execution has been given to prove the static correctness of the protocol. The future scope of the paper is to perform and present the validation of the proposed work.

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