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A Survey of Checkpointing Algorithms in Mobile Ad Hoc Network

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A SURVEY OF CHECKPOINTING ALGORITHMS IN MOBILE AD HOC NETWORK

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A Survey of Checkpointing Algorithms in Mobile Ad Hoc Network

Ms. Pooja Sharma [α] & Dr. Ajay Khunteta [σ]

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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 [33]. In a traditional distributed system all hosts are stationary. Recent advances in portable computers with wireless communication interfaces and satellite services have made it possible for mobile users to perform distributed applications and to access information anywhere and at anytime. This new computing environment where some hosts are mobile computers connected by wireless communication networks and some are stationary computers connected by a fixed network is called a distributed mobile computing environment. Thus, a distributed mobile system can be considered as a special kind of general distributed systems where some of its hosts are not fixed in their location. A distributed mobile system is characterized by the mobility and poor resource of mobile hosts.

The distributed mobile systems use checkpointing for providing fault tolerance. In this case, when fault or failures of process occur, an application with mobile hosts should rollback to a consistent global checkpoint as close as possible to the end of the computation. Checkpointing is also used in debugging distributed programs and migrating processes in a multiprocessor system. Mobile hosts have several characteristics that make them different from other hosts. During the designing of checkpoint protocols for distributed mobile systems following features must be take care into account otherwise the protocol will incur high overheads or it will not work correctly [33], [35], [32].

1. Wireless networks deliver lower bandwidth than wired networks hence mobile computing designs need to be very concerned about bandwidth consumption.
2. Mobility is inherently vulnerable. The disk storage is potentially unstable for logging or recording of the states. For example, a laptop is accidentally physically dropped or stolen; or the data stored on a mobile host's disk are totally wiped out by some security systems. Thus, the state recording and message logging cannot rely on the mobile host's storage, and the saved local states and message logs cannot be assumed to be immediately available from the mobile hosts when it is required. In such a case an obvious strategy is to treat the MSS to which the mobile host is connected as the stable storage to store local checkpoints. This would require each of the mobile hosts to take their checkpoints and transfer them to their MSSs. Given the bandwidth constraint of wireless channel, carrying out such an operation would be possible only if the amount of data being transferred is not very large. This introduces a new requirement for the checkpointing algorithm wherein the numbers of checkpoints have to be reduced.
3. Mobile hosts are often disconnected from the rest of the system or frequently disconnect by going into low energy mode. A disconnected mobile host can neither send nor receive messages, but can continue an application execution by using its local data and cashed shared data [34].
4. The mobility implies that a mobile host may change its location during distributed computation because of this they have to be searched and located before control messages associated with the checkpointing scheme can be delivered to them. Thus, the location management or search for the targeted mobile host becomes an indispensable task of any distributed protocols/algorithms[38].

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5. Since the mobile computers are portable, they have limited battery power. As a result of this the checkpointing algorithms are required to reduce the number of synchronization messages [32].
6. Generally wireless computers have less resource relative to stationary (wired) computers, this is because wireless computers are required to be smaller, lighter and consume less power than stationary computers. Wireless communication is more difficult to implement than wired communication because of the interaction of the surrounding environment with the message signal. Problems caused by the environment include blocked signal paths, echoes and noise. These factors can increase communication latencies due to error control checks, retransmissions, time-out delays and brief disconnections.

Storage space on a mobile computer is limited by the size and power requirements. Some solutions to storage problems are compression, code sharing, remote access storage, and interpreting script languages instead of executing compiled code [35]. All these new issues and challenges have made those algorithms devised for traditional distributed systems not applicable.

One of fundamental issues in distributed computations: calculating the consistent global states, which underlying many distributed applications. Calculating global states is sometimes called taking Distributed Snapshots. A large class of important problems in distributed systems can be cast as periodically calculating consistent global states and executing some reactions based on the global state that have been taken. Examples of such problems include distributed debugging and monitoring, fault-tolerant and rollback-based recovery, detection of state properties such as a deadlock and termination. This paradigm requires consistently recording the global state of a distributed computing.

One special kind of mobile distributed systems is called Mobile Ad hoc networks (MAHNs), which are wireless multi-hop packet networks without fixed infrastructure; it is a self-organizing and configuring “multi-hop” network. MANET allow mobile host to communicate with each other without any fixed infrastructure. The advantages of ad hoc network are rapid deployment, robustness, flexibility and Inherent support for mobility. The topology of ad hoc network is very dynamic because of host mobility. So it is very useful where we require instance communication in emergency like mobile conferencing and military applications [41]. The main constraints of system includes no centralized control, dynamic network topology, limited bandwidth, low node capability in terms of power, variability of the links, broadcast nature of transmission and packet losses[41]. There have been many algorithms on finding checkpointing of distributed mobile application. However, the constraints imposed by the mobility and poor resource of mobile hosts as outlined above complicate the design of distributed algorithms and applications, and make them inappropriate for MANET.

System Model- In large dynamic MANET it has already shown that a link based proactive routing schemes cannot perform well [*2]. In link based routing protocols communication overheads is $O(n^2)$ [42] as in case of chandy Lamport algorithms. It means that these routing protocols has scalability problem.

One more simple approach for communication is called packet flooding. When both the communicating nodes are in host’s radio coverage, they can communicate directly. Otherwise a route is required to forward messages to the destination in a multi hop manner that cause the packet flooding[20] as shown in figure:-

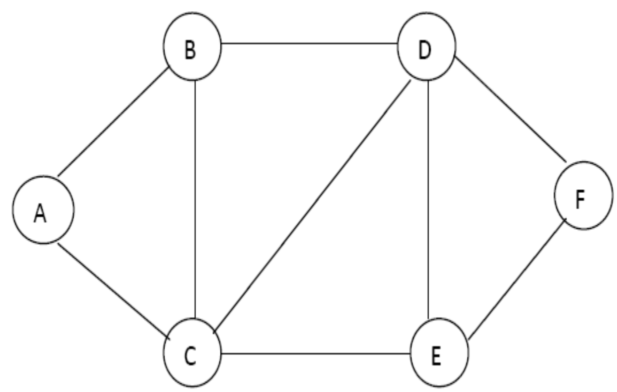

Figure 1: Packet Flooding

In figure 1 suppose node A wants to send the message to node F, because F is not a neighbor node so it will send message to all nodes attached to it (B, C) then B and C will replay the packet to all neighbors and same process will be continued until the message reach to the destination. This scenario is called packet flooding. This increases the size of routing table of each node in the network and make channel busy unnecessary.

A Cluster based or hierarchical architecture is proposed to reduce the flooding packets and to minimize the routing table [8-10]. Clustering approach in an ad hoc network group its nodes into many clusters. In each cluster one node act as a head node (CH) and rest of nodes are divided into ordinary and gateway nodes. The cluster head is responsible for communication within the ordinary nodes in own cluster and gateway node is responsible for in between two adjacent clusters [11]. A cluster is characterized by two types of messages – inter and intra-cluster message. Since Normal nodes only communicate with their cluster head, which in turn, aggregates the collected information and sends it to the MSS. In this scheme, cluster head failures are critical. When it fails, re-election process is invoked within the cluster [10].

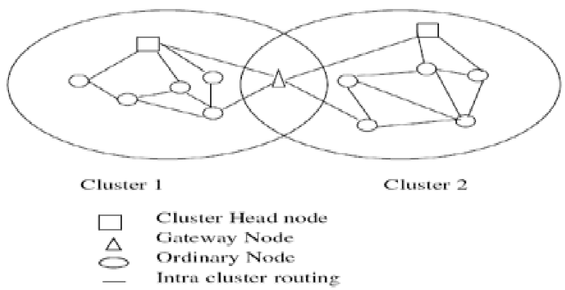

Figure 2 : Clustering Architecture in MANET

cluster based approach provided better performance with large number of mobile nodes[41]. The cluster structure make an MANET appear smaller and stable. It also provides better control on transmission link using a node called cluster head. When a node in MANET changes its cluster only mobile nodes residing in the clusters need to update the informations [41-42]. So local changes not be seen and data processed and stored by each node is greatly reduced[42].

The clustering schemes of MANETs can be classified depending on different areas like requirement of cluster head, the hop distance between node pairs etc. The main schemes are [31]-

- Dominating-Set-based clustering [12] tries to find a DS for a MANET so that the number of mobile nodes that participate in route search or routing table maintenance can be reduced. This is because only mobile nodes in the DS are required to do so.
- Low-maintenance clustering schemes [11] aim at providing stable cluster architecture for upper-layer protocols with little cluster maintenance cost.
- Mobility-aware clustering [13] takes the mobility behavior of mobile nodes into consideration. This is because the mobile nodes' movement is the main cause of changes to the network topology.
- Energy-efficient clustering [14] manages to use the battery energy of mobile nodes more wisely in a MANET. By eliminating unnecessary energy consumption of mobile nodes or by balancing energy consumption among different mobile nodes, the network lifetime can be remarkably prolonged.
- Load-balancing clustering schemes attempt to limit the number of mobile nodes in each cluster to a specified range so that clusters are of similar size. Thus, the network loads can be more evenly distributed in each cluster.
- Combined-metrics based clustering [15] usually consider multiple metrics, such as node degree, cluster size, mobility speed, and battery energy, in cluster configuration, especially in cluster head decisions.

II. Aspects of Checkpointing

Checkpoint-based rollback recovery restore the system state to the most recent consistent set of checkpoints whenever a failure occurs [17]. Checkpoint-based rollback recovery is not suited for applications that require frequent interactions with the outside world, since such interactions require that the observable behavior of the system through failures []. Checkpoint technique can be classified into three categories: uncoordinated check pointing, coordinated check pointing, and communication-induced check pointing.

- Uncoordinated Check pointing: Uncoordinated checkpointing allows any process can initiate checkpointing. The advantage of this scheme is that each process may take a checkpoint in any critical state [18].
- Coordinated Check pointing: Coordinated checkpointing simplifies recovery and with no domino effect, since every process always restarts from its most recent checkpoint. Coordinated checkpointing requires each process to maintain only one permanent checkpoint on stable storage, reducing storage overhead and eliminating the need for garbage collection [19].
- Non-blocking Checkpoint Coordination: In this protocol, the initiator takes a checkpoint and broadcasts a checkpoint request to all processes. Each process takes a checkpoint upon receiving the request and rebroadcasts the request to all processes, before sending any application message. The protocol works assuming the channels are reliable and FIFO. [3].
- Checkpointing with Synchronized Clocks: A process takes a checkpoint and waits for a period that equals the sum of the maximum deviation between clocks and the maximum time to detect a failure in another process in the system. The process can be assured that all checkpoints belonging to the same coordination session have been taken without the need of exchanging any messages [3].
- Minimal Checkpoint Coordination: It is desirable to reduce the number of processes involved in a coordinated checkpointing session. This can be done since only those processes that have communicated with the checkpoint initiator either directly or indirectly since the last checkpoint need to take new checkpoints.
- Communication - induced Check pointing: Communication-induced checkpointing avoids the domino effect while allowing processes to take some of their checkpoints independently [16]. However, process independence is constrained to guarantee the eventual progress of the recovery line, and therefore processes may be forced to take additional checkpoints. The checkpoints that a process takes independently are called local

checkpoints, while those that a process is forced to take are called forced checkpoints.

- Model-based Check pointing: Model-based checkpointing relies on preventing patterns of communications and checkpoints that could result in inconsistent states among the existing checkpoints.
- Index-based Communication Induced Check pointing: Index-based communication – induced check pointing works by assigning monotonically increasing indexes to checkpoints, such that the checkpoints having the same index at different processes form a consistent state [16].

III. Checkpointing Algorithms For Mobile Ad Hoc Network

A checkpointing and rollback recovery scheme for cluster based multi channel ad hoc wireless networks was proposed by chaoguan-Zhenpeng-Xiang algorithm[20]. In this algorithm the checkpointing mechanism for ad hoc network is managed by the cluster head of each cluster. CH used a special packet called beacon packet which contains clock data, sizes of announcement traffic indication message and data window. The functions of CH were performed channel assignment, scheduling intra cluster traffic, and communicating data. Cluster head also maintain several variables, including a checkpoint index, an ordinary node queue, and a variable storing the number of reply messages. When the checkpoint period time is up, cluster head CH firstly delivers timing parameters of the interval with the checkpoint request to all cluster members, upon receipt of the checkpoint request, Those MHs which are not allowed to communicate will take a new checkpoint and MHs which are busy within communication will take the required checkpoint in next beacon interval. In this way the checkpointing process completed within two consecutive beacon intervals and start rollback recovery in one beacon interval. The purposed scheme was fast and have low additional overheads and control messages.

An approach called Checkpointing by flooding method proposed by [21] - In this protocol ad hoc networks works without stable storage and enough communication bandwidth. Here, a checkpoint request message is delivered by flooding. State information of a mobile computer is carried by this message and stored into neighbor mobile computers. A candidate of a lost message is detected and stored by intermediate mobile computer on its transmission route.

Global Snapshot for Host Recovery was proposed by Bhalla, S [22]. This algorithm track independent dependency by tracking total cumulative dependence. It is able to prevent cascading of rollback of dependent states. It also facilitates independent calculation of consistent global snapshot by a mobile process. A most recent global snapshot can be independently generated for host recovery. In case of recovery only one message needs to be sent, to inform about the occurrence of a failure, to each connected station.

In the same concern the problem of Crash Recovery was discussed by Tong- Tony -Chang [23]. In this algorithm they presented an efficient recovery algorithm in wireless mobile ad hoc networks which are organized as a cluster-based structure. All the communication is transmitted from cluster to cluster and each cluster consists of a cluster head node which acts as a local coordinator of transmissions within the cluster. The basic problem in operating system design is there is a need to recover from processor failures. Checkpointing in conjunction with rolling back is a widely used scheme. Processors locally save their history and current states in a stable log from time to time. If there is a processor failure the failed processor can restart from the most recently saved state.

Concurrent Checkpointing and Recovery was proposed by A. K .Singh-P. K. JAGGI [24]. The approach proposes a staggered approach to avoid simultaneous contention for resources. The staggering causes events, which would normally happen at the same time, to start or happen at different times. The proposed protocol does not need FIFO channels and logs minimum number of messages. It supports concurrent checkpoint initiation and successfully handles the overlapping failures in ad hoc networks.

Algorithm By	Features	Approach	Storage location
Chaoguang Men, Zhenpeng Xu, Xiang Li (2008).[20]	1.cluster-based multi-channel management protocol 2.Local consistent checkpoint-two consecutive beacon interval 3.Rollback recovery-one beacon interval	Coordinated	Local Mobile Supporting Stations(MSS) at CH
Ono Masakazu and Higaki Hiroaki in (2005) [21]	1.Mission-critical network applications, 2.checkpoint request message is delivered by flooding 3. communication overhead for taking global checkpoint is reduced	Uncoordinated	Neighbor mobile computer
Tong-Ying Tony Juang Meng-Chang Liu [23]	Efficient rollback algorithm for crash recovery	Independent	Local Mobile Supporting Stations(MSS) at CH
Parmeet Kaur Jaggi and Awadhesh Kumar Singh 2011 [25]	1.Self stabilizing spanning tree upon the network topology to reduce the message overhead 2. Handle the dynamic nature of MANETS.	Coordinated	Local Mobile Supporting Stations(MSS) at CH
RuchiTuli1&Parveen Kumar 2011 [26]	1. Minimum process coordinated checkpointing scheme for Cluster based ad hoc routing protocols. 2. Minimizes the number of control messages needed and also take no useless checkpoints.	Coordinated	Base Station MSS at CH
Kusum Saluja, Praveen Kumar,2011[29]	1.New minimum process checkpointing scheme on cluster based routing protocol 2. Reduce the number of useless checkpoints.	Coordinated	Local Mobile Supporting Stations(MSS) at CH
Ruchi Tuli & Praveen Kumar 2011 [27]	Asynchronous checkpointing and optimistic message logging in clustered based system	Independent	Local Mobile Supporting Stations(MSS) at CH
Kusum Saluja, Praveen Kumar,2011 [28]	Transitive dependencies tracking in minimum process checkpointing protocol in clustered based system	Uncoordinated	Local Mobile Supporting Stations(MSS) at CH
Awadhesh Kumar Singh, Parmeet Kumr Jaggi, 2011 [24]	Staggered approach to avoid simultaneous contention for resources. Successfully handles the overlapping failures	Uncoordinated	Own memory

Table 1: Showing comparison of different checkpointing algorithms for Mobile Ad Hoc Network

Snapshot Recording using a Self Stabilizing Spanning Tree was proposed by Jaggi-Singh [25]. The proposed algorithm is for the recording of a consistent global snapshot of a dynamic cluster based mobile ad hoc network. The CHs are organized into a self stabilizing spanning tree to reduce the number of snapshot related messages as compared to the approach of broadcasting the messages along each outgoing channel as has been done traditionally. The algorithm alleviates the need for FIFO channels without requiring the transfer of complete message histories along the channels. The algorithm can work with multiple initiators and also if the topology of the system changes or a partition is created in the network during the execution of the algorithm itself. This approach of taking checkpointing shows that the algorithm requires significantly lower number of control messages even if we increase the number of clusters in the system.

The Minimum Process Coordinated Checkpointing Scheme proposed by Tuli-Kumar [26]. In this algorithm a cluster head send routing and collected data information to base station, which periodically save the state of cluster head. If a cluster head fails or some fault is detected, then base station detects the cluster head failure and some new node in the cluster is assigned the responsibility of the cluster head. After the receiving of checkpoint request a MH first takes a tentative checkpoint and later on when it receives commit request from the initiator, it converts its tentative checkpoint into permanent checkpoint. In this algorithm all the MH are not required to take checkpoint simultaneously. Only participating nodes are required to take checkpoint because initiator MH sends the request of checkpoint only those nodes which are involve in the communication with him.

Asynchronous Checkpointing and Optimistic Message Logging was proposed by Tuli-Kumar [27]. In this algorithm authors focused on optimistic based message logging for communications in a clustered ad hoc network, In order to cope with the storage problem, the task of logging is assigned to the CH instead of MHs, since each message heading to a MH is routed through the CH. Also, in order to reduce the overhead imposed on mobile hosts, cluster heads take charge of logging and dependency tracking, and mobile hosts maintain only a small amount of information for mobility tracking. In the algorithm each MH in the cluster takes checkpoint independently.

IV. Conclusion

We has reviewed some fundamental concepts of clustering in MANET. It is also observed that cluster structure facilitates the spatial reuse of resources to increase the system capacity. A cluster can better coordinate its transmission events with the help of Cluster Head. Clustering methods allow fast connection and also better routing and topology management of Mobile Ad Hoc Networks. It is also observed that MANET has many important issues to handle like structure stability, message overheads, energy consumption of mobile nodes and traffic load with the cluster, so the algorithms are developed for less overhead, reducing no. of checkpoints by using different approaches We also compared different approaches to rollback recovery and checkpointing with respect to a set of properties in Mobile Ad Hoc Network. Table 1 gives some salient features of various checkpointing algorithms.

V. Future Scope

The clustering is a best suited approach for ad hoc network but the cost of clustering is again a key issue. In cluster the nodes may be arranged in graph, tree, array or in hypercube. In distributed mobile system it is already observed that hypercube arrangement of nodes has better time complexity compared to others as proposed by [30]. Similarly in the ad hoc network hypercube may be a better approach for node arrangement for checkpoint process.

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