UNIVERSITI PUTRA MALAYSIA

PERMISSION-BASED FAULT TOLERANT MUTUAL EXCLUSION ALGORITHM FOR MOBILE AD HOC NETWORKS

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By

FARANEH ZARAFSHAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

May 2015

This thesis is dedicated to

My husband Abbas

For teaching me not to be disappointed and taking steps with me in hard moments of life

My dear parents

For their endless support and love

and

New member of my family, my son: Radwin

For all the hopes and happiness he brought to us

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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This study focuses on resolving the problem of mutual exclusion in mobile ad hoc networks. A Mobile Ad Hoc Network (MANET) is a wireless network without fixed infrastructure. Nodes are mobile and topology of MANET changes very frequently and unpredictably. Due to these limitations, conventional mutual exclusion algorithms presented for distributed systems (DS) are not applicable for MANETs unless they attach to a mechanism for dynamic changes in their topology.

Algorithms for mutual exclusion in DS are categorized into two main classes including token-based and permission-based algorithms. Token-based algorithms depend on circulation of a specific message known as token. The owner of the token has priority for entering the critical section. Token may lose during communications, because of link failure or failure of token host. However, the processes for token-loss detection and token regeneration are very complicated and time-consuming. Token-based algorithms are generally non-fault-tolerant (although some mechanisms are utilized to increase their level of fault-tolerance) because of common problem of single token as a single point of failure. On the contrary, permission-based algorithms utilize the permission of multiple nodes to guarantee mutual exclusion. It yields to high traffic when number of nodes is high. Moreover, the number of message transmissions and energy consumption increase in MANET by increasing the number of mobile nodes accompanied in every decision making cycle.

The purpose of this study is to introduce a method of managing the critical section, named as Ancestral, having higher fault-tolerance than token-based and fewer message transmissions and traffic rather that permission-based algorithms. This method makes a tradeoff between token-based and permission-based. It does not utilize any token, that is similar to permission-based, and the latest node having the critical section influences the entrance of the next node to the critical section, that is similar to token-based algorithms. The algorithm based on ancestral is named as DAD algorithms and increases the availability of fully connected network between 2.86 to 59.83% and

decreases the number of message transmissions from 4j-2 to 3j messages (j as number of nodes in partition).

This method is then utilized as the basis of dynamic ancestral mutual exclusion algorithm for MANET which is named as MDA. This algorithm is presented and evaluated for different scenarios of mobility of nodes, failure, load and number of nodes. The results of study show that MDA algorithm guarantees mutual exclusion, dead lock freedom and starvation freedom. It improves the availability of CS to minimum 154.94% and 113.36% for low load and high load of CS requests respectively compared to other permission-based algorithm. Furthermore, it improves response time up to 90.69% for high load and 75.21% for low load of CS requests. It degrades the number of messages from n to 2 messages in the best case and from 3n/2 to n in the worst case. MDA algorithm is resilient to transient partitioning of network that is normally occurs due to failure of nodes or links.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA SALING PENGASINGAN BERASASKAN PERMINTAAN TOLERANSI RALAT UNTUK RANGKAIAN AD HOC MUDAH ALIH

Oleh

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Tesis ini memfokuskan kepada menyelesaikan masalah saling pengasingan dalam rangkaian talian sementara mudah alih. Rangkaian Talian Sementara Mudah Alih (MANET) adalah sebuah rangkaian wayarles tanpa infrastruktur yang tetap. Nod-nod adalah mudah alih. Topologi MANET sangat kerap berubah dan tidak menentu. Disebabkan batasan-batasan ini, algoritma saling pengasingan yang biasanya dikemukakan untuk sistem teragih (DS) tidak boleh digunakan untuk MANETs melainkan mereka disambungkan kepada satu mekanisme untuk perubahan dinamik di dalam topologi mereka.

Algoritma untuk saling pengasingan dalam DS dikategorikan kepada dua kelas utama yang merangkumi algoritma berasaskan-token dan berasaskan-kebenaran. Algoritma berasaskan-token bergantung kepada peredaran sebuah mesej khusus yang dikenali sebagai token. Pemilik token itu mempunyai keutamaan untuk memasuki bahagian yang kritikal. Token boleh hilang sewaktu komunikasi, disebabkan kegagalan sambungan atau kegagalan hos token. Walau bagaimanapun, proses-proses untuk pengesanan token-yang-hilang dan penjanaan semula token adalah sangat rumit dan memakan masa. Algoritma berasaskan-token biasanya bukan tahan-rosak (walaupun beberapa mekanisma telah digunakan untuk meningkatkan tahap tahan-kerosakan mereka) disebabkan oleh masalah biasa token tunggal sebagai kegagalan titik tunggal. Sebaliknya, algoritma berasaskan-kebenaran menggunakan kebenaran beberapa nod untuk menjamin saling pengasingan. Oleh itu, tiada kegagalan token dan tiada kegagalan titik tunggal. Walau bagaimanapun, ia menyumbang kepada trafik yang tinggi apabila bilangan nod bertambah. Tambahan pula, bilangan penghantaran mesej dan penggunaan tenaga dalam MANET meningkat dengan bertambahnya bilangan nod mudah alih yang mengiringi setiap kitaran membuat keputusan.

Tujuan tesis ini adalah untuk memperkenalkan satu kaedah baru dalam menguruskan bahagian kritikal, yang dinamakan sebagai Warisan, yang mempunyai tahan-kerosakan yang lebih tinggi daripada berasaskan-token dan mempunyai penghantaran mesej dan trafik yang lebih rendah berbanding algoritma berasaskan-kebenaran.

Kaedah ini memberi keseimbangan antara berasaskan-token dan berasaskan-kebenaran. Ia tidak menggunakan apa-apa token, iaitu serupa dengan berasaskan-kebenaran, dan nod terbaru yang mempunyai bahagian yang kritikal mempengaruhi kemasukan nod seterusnya ke bahagian kritikal, iaitu serupa dengan algoritma berasaskan-token. Algoritma yang berasaskan warisan dinamakan sebagai algoritma DAD dan meningkatkan ketersediaan rangkaian bersambung penuh antara 2.86 sehingga 59.83% dan mengurangkan bilangan penghantaran mesej dari 4j-2 sehingga 3j mesej (j sebagai bilangan nod-nod didalam pemetakan).

Kaedah baru kemudiannya digunakan sebagai asas kepada algoritma saling pengasingan warisan dinamik untuk MANET. Algoritma ini dibentangkan dan dinilai untuk senario-senario yang berbeza dari segi mobiliti nod, kegagalan, beban dan bilangan nod. Keputusan kajian menunjukkan bahawa algoritma MDA menjamin saling pengasingan, kebebasan kunci mati dan kebebasan kebuluran. Ia juga memperbaiki ketersediaan CS kepada minimum 154.94% dan 113.36% masing-masing untuk permintaan-permintaan CS bebanan rendah dan bebanan tinggi berbanding dengan algoritma berasaskan-kebenaran yang lain. Tambahan pula, ia memperbaiki masa tindak balas sehingga 90.69% untuk bebanan tinggi dan 75.21% untuk permintaan-permintaan CS bebanan rendah. Ia mengurangkan bilangan mesej dari n kepada 2 mesej dalam kes yang terbaik dan dari 3n/2 kepada n dalam kes yang paling teruk. Algoritma MDA mempunyai ketahanan tinggi kepada pemetakan sementara rangkaian-rangkaian yang biasanya berlaku disebabkan oleh kegagalan nod atau sambungan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Signature: ________________________ Date: __________________

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LIST OF ABBREVIATIONS

Anc	Ancestor
AODV	Adhoc On-demand Distance Vector
BFA	Backbone Formation Algorithm
CS	Critical Section
CSMA	Carrier Sense Multiple Access
DAD	Distributed Ancestral Dynamic
DME	Distributed Mutual Exclusion
DN	Distinguished Nodes
DP	Distinguished Partition
DS	Distributed System
DSDV	Destination-Sequenced Distance Vector Routing
DSR	Dynamic Source Routing
ES	Entry Section
FIFO	First In First Out
FTP	File Transfer Protocol
GloMoSim	Global Mobile Information System Simulator
MANET	Mobile Ad hoc NETwork
MCA	Merging Clustering Algorithm
MDA	MANET Dynamic Ancestral Algorithm
MH	Mobile Host
MSS	Mobile Support Station
MutEx	Mutual Exclusion
NC	Node Copies
NCS	Non-Critical Section
NS2	Network Simulator 2
PARSEC	Parallel Runtime Scheduling and Execution Controller
PR	Permission
RA	Ricart-Agrawala
RCV	Relative Consensus Voting
RL	Reverse Link
RSVP	Resource Reservation Protocol
TCP	Transmission Control Protocol
TORA	Temperory-Ordered Routing Algorithm
TTL	Time To Live
UDP	User Datagram Protocol
VN	Version Number
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1.1 Background

A Mobile Ad Hoc Network (MANET) is a collection of autonomous wireless mobile nodes established on a non-fixed infrastructure (Fife & Gruenwald, 2003). MANET is a kind of distributed system (DS) (Challenger et al., 2013) where links are wireless and each mobile node can communicate with its single or multi-hop neighbors though message passing. Message passing is the sole means for implementing and timestamp (Lamport, 1978a; Ricart & Agrawala, 1981) is basic strategy for prioritizing the requests for critical sections in DS and its extensions, e.g. mobile ad hoc networks. Due to absence of a central coordinator, each mobile node acts as a router.

Due to mobility of nodes and frequent changes in topology of network, mobile nodes and wireless links are vulnerable to fail. Failure of nodes or links yields to transient or permanent failure of MutEx algorithms. Fault-tolerant MutEx algorithms utilize different methods to deal with failure of nodes and links, while some algorithms try to detect and repair faulty nodes, other group are equipped with techniques, e.g., redundancy, to tolerate faults. Redundancy has been widely utilized to improve fault-tolerance of hardware or software systems in four main form of redundancy of software version, hardware modules, time and data. Replication of data improves the fault-tolerance of database systems. MANET and other kinds of DS use the replication of one or more data resources in the following ways: to increase the system's availability, to service requests for the same information in parallel (Gifford, 1979) to decrease the system's response time and communication costs by providing the nearest copy of the resource to the location of demand, and to have load sharing by distributing the computational load of responding to queries among a number of nodes rather than centralized in a single node (Thomas, 1979). Besides these advantages, there is a huge challenge in the maintenance of the replicated resources in such a way that at the most, the one node can access the shared resource(s) at a given time t. This problem is well known as Mutual Exclusion (MutEx), and is still an active research area since more than three decades ago when the first distributed MutEx (DME) algorithm presentations established by (Le Lann, 1977) and (Lamport, 1978b). In order to facilitate efficient data access and update, databases are deployed on MANETs (Padmanabhan et al., 2008). Data replication is widely used in MANET database (Opeoluwa & Opeyemi, 2010) which improves the availability of data (Lipskoch & Theel, 2014).

Many reasons make the conventional MutEx algorithms inefficient and even infeasible in MANET. Due to mobility of nodes, the geographic position and topology of MANET change very frequently. Although, knowing the topology of network leads to improvements in MutEx algorithms in terms of the number of messages transmitted, energy saving, time complexity of algorithms and the order of visiting the nodes, it is very expensive for MANETs (Malpani et al., 2005). Due to mobility and wireless communication of nodes, crash of software or hardware, node movement to out of radius range, power and battery constraints, and no fixed client/server or coordinator, DME algorithms cannot be simply implemented on

MANET. Because of mobility and very frequent changes in the topology, the method of formation or removal of wireless links is unpredictable. Mobile nodes are also limited by the energy and processing power compared to fixed nodes. A higher mobility rate and more radio transmission increase the power consumption of mobile nodes, which leads to a lack of battery and the failure of nodes. furthermore, due to a higher probability of node or link failures (Moallemi et al., 2007) and a high ratio of faults in wireless connections, MANETs are relatively high in failure rate compared to wired linked networks. Mobile Support Station (MSS) in conventional DS can act on behalf of the mobile hosts (MH) once failure occurs; however, there are no infrastructure and MSS in MANETs (Wu et al., 2005).

Conventional algorithms for MutEx in DS are categorized into two main classes including token-based and permission-based algorithms. This classification is presented for MANET as well. Token-based algorithms depend on circulation of a specific message known as token. The owner of the token has priority for entering the Critical Section (CS). They required logical structure (tree or ring), and useless circulation of token when there is no request for CS. Token may be lost during communications, because of link failure or failure of token host. Unfortunately, the process of recovering a new token after token loss is very complicated and time consuming in MANETs in comparison with conventional DS. Because of common problem of single token as a single point of failure, token-based algorithms are generally non-fault-tolerant (although some mechanisms are utilized to increase their level of fault-tolerance). Almost all MANET MutEx algorithms are token-based (except (Masum et al., 2010; Wu et al., 2008)). Token-based algorithms (Attiya et al., 2010; Baldoni et al., 2002; Jiang, 2003; Moallemi, et al., 2007; Tamhane & Kumar, 2011; Yang, 2005) have some beneficial features for MANETs including fewer number of messages transmitted and less information to be stored about other mobile nodes.

Permission-based algorithms utilize the permission of multiple nodes to guarantee MutEx. Basic form of permission-based MutEx algorithm permits a CS request to enter the CS when permission of at least the majority of nodes is received by requesting node. Permission-based algorithms have some unique features including there is no need to maintain logical topology to pass the token, neither to propagate any message if no host requests to enter critical section (Wu, et al., 2008). However, it leads to high number of message transmissions and increments energy consumption in MANET by increasing the number of mobile nodes.

1.2 Problem Statement

MutEx is a well-known problem in maintenance of replicated data in DS, in which at a given time t at most one node is eligible to update common data (Iakab, 2012). MutEx becomes more complicated in MANETs, because topology and position of mobile nodes changes very frequently (Erciyes & Dagdeviren, 2012), wireless links are more vulnerable to fail, there is no central coordinator, and every node is responsible for routing the messages (Gupta et al., 2012).

This study deals with the following research problems:

a) Consecutive failure of mobile nodes or links causes loss of a large number of small packets and a high traffic on routing protocols (Gill et al., 2011) which direct the messages from upper layer of network (here application layer) to destination nodes through communication channels. Obviously, the traffic on routing layer is caused by many factors; however, the factor related to this study is the number of messages generated by MutEx algorithm. It is important to decrease the number of message transmissions per CS entry as introduced in literature. In order to measure the number of messages per CS entry, the number of message transmissions is counted by a node since it has issued the request for the CS until it receives the CS permission (or token).

b) For every unanswered request for CS, reattempts are performed by requesting nodes (Parameswaran & Hota, 2010). Every packet has a limited Time To Live (TTL) and also a limited and predefined time-out is considered for every request for CS (Mallikarjuna et al., 2012). Due to time-outs in the nodes, failure of nodes or links leads to unanswered (or unsuccessful) CS request. Obviously, with higher successful CS entries, lower reattempts are performed and processes by nodes. Service availability (Gill et al., 2011) (henceforth, name as availability) is simply defined as the probability that an update request can be serviced at any time, t. The ratio of successful CS entries over network lifetime simply reflects the probability that an update request can be serviced successfully by DS or simply the availability of MutEx. One solution for high reattempts is to degradation in the number of unsuccessful CS entries, i.e., improving the rate of successful CS entries or simply improving the availability of CS.

c) Response time is the time interval for a node to issue its request, until it enters the CS (Sharma et al., 2014; Wu, et al., 2008). Permission-based algorithm generally wait until they receive permission from a predefined set or number of nodes. In case of failure of one or more nodes, the node is halted until the fautly node is repaired. This event increases the response time to CS request or response time per CS entry. Therfore, it is important to find an approach to decrease response time per CS entry.

d) Partitioning is a kind of failure that may occur in the network due to failure of some mobile hosts or links (Shi & Chen, 2014). When a network is partitioned, it is divided to two or more isolated groups of nodes that can communicate inside the groups but they cannot communicate with other nodes in other groups. Hence, each partition does not have any view from the other partition. Partitioning is harmful for MutEx if two nodes in two partitions decide to enter the CS simultaneously (Wu et al., 2008). In order to face with partitioning, MutEx algorithm should have a strategy to prevent the entrance of isolated partitions to critical section at the same time. This problem has been studied in DS and is a major issue that should especially be considered in MANET (Shi & Chen, 2014). Due to failure of mobile nodes or wireless links, disconnection of nodes, movement of nodes to out of radius range, or battery deployment of nodes, MANET is more likely to be partitioned to isolated groups of nodes. Thus, a MANET MutEx algorithm, as well as conventional DS MutEx, should be able to tolerate faults and transient partitioning of network.

1.3 Research Questions

This research embarks on following questions:

a) Can be found any solution for MutEx, other than permission and token, to resolve problem of high traffic in permission-based algorithms and problem of token as a single point of failure?

b) How new solution improves permission-based MutEx?

c) How the problem of token as a single point of failure is resolved?

d) How is the scalability of new solution when number of nodes becomes large?

e) Do MANET and DS tolerate failure of nodes or links?

f) How long a MANET and DS can resist against failure of nodes or links?

g) How is its fault-tolerant for different scenarios of failure occurrence?

h) How is the performance of new solution in terms of availability, time complexity and message complexity?

1.4 Research Objectives

The main purpose of this research is to introduce a method of managing the CS having fault-tolerant and partition-tolerant features with fewer message transmissions and response time than other permission-based algorithms. The research objectives are as follows:

a) To design a permission-based technique to enhance the fault tolerance of token-based and resolve the high number of message transmissions of previous permission-based algorithms.

b) To develop a fault-tolerant and permission-based algorithm to resolve the problem of MutEx in conventional DS, which prolongs the service to CS request and improves the availability of CS.

c) To develop a fault-tolerant and permission-based algorithm for resolving the problem of MutEx in MANET with higher availability of CS, lower response time for a CS request to be served and fewer numbers of messages imposed to network.

1.5 Contribution

The topic of MutEx algorithms for MANET is an ongoing topic. In this study, a review on dynamic MutEx algorithms is presented for MANETs along with a classification on the techniques involved in decision making. It is hoped that this discussion can increase the understanding on this subject and help the designers of systems and engineers to implement efficient protocols for MANETs. This study reviews MutEx algorithms in different way with (Benchaiba et al., 2004).

Ancestral method as used in this research resolves the issues related to token-based and permission-based algorithms. This technique has been first introduced in this study. Two algorithms based on ancestral technique are introduced and evaluated in this study. The first algorithm (DAD algorithm) resolves the problem of MutEx in DS. It also improves the availability of CS and prolongs the life time of service. Second Ancestral MutEx algorithm (MDA algorithm) is presented for MANET and evaluated for different levels of mobility of nodes, fault-injection and number of nodes. It guarantees MutEx, dead lock freedom and starvation freedom and can be used in every situation where mobile devices are connected each other in form of MANET and helps them to stay up when multiple failure of mobile nodes or links occurs. It resolves the problem of network partitioning which frequently occurs in DS and MANET.

Ancestral technique is different with combination of token and permission based technique which has been introduced as hybrid technique. It does not utilize any token, that is similar to permission-based, and the latest node having the CS influences the entrance of the next node to the CS, that is similar to token-based algorithms. As the technique needs permission of other node, i.e., it can be counted as permission-based. Fault tolerance or even partition tolerance feature of ancestral method, keeps MANET up in systems such as disaster management systems (Gupta, et al, 2012) (for discovering alive human or their body) or traffic control system (Luo et al., 2014) (for avoiding heavy traffic on roads or tunnels).

By decreasing the response time per CS entry and increasing the availability of CS, MDA algorithm is more efficient than similar methods. It needs fewer messages to be transmitted between mobile devices in order to access CS. This feature influences the energy efficiency of MANET because higher energy will be preserved and saved during wireless communication of mobile devices. MDA algorithm can be utilized where the mobile nodes need to share resources or codes of the data in all of these applications. MutEx is required to guarantee the consistency of the shared objects in automated battlefields, forestry, environmental analysis, disaster managements and traffic control applications.

MDA algorithm does not need to know every connected node and works according to local knowledge of a node from its neighbors. Therefore, MDA is more realistic. MDA algorithm benefits the main assumption of previous permission-based algorithms on MANET environment; however, they are basically different.

1.6 Scope of the Project

The project focuses on fault-tolerant MutEx algorithms for DS and MANET. Among different categories of fault-tolerant MutEx algorithms, permission-based algorithms are concentrated for resolving the problem of MutEx in conventional DS and MANET as a kind of DS (Challenger et al., 2013). Nowadays, mobile systems are used everywhere. A decade ago, almost all database systems were established in fixed location in different geographic positions. Fixed database systems are not efficient anymore regarding the widespread using of mobile devices, cellular phones, and Laptops. Furthermore, WiFi and WiMax provide internet connection almost everywhere. Therefore, using mobile Ad Hoc database systems is feasible in many situations. A direct application of presented algorithm in this study is in mobile Ad Hoc database systems.

A mobile Ad Hoc database may be used with or without a conventional database system. In Figure 1-1, a system with both conventional and Ad Hoc database system is illustrated. In order to facilitate efficient data access and update, databases are deployed on MANETs (Azeem & Khan, 2012; Padmanabhan, et al., 2008). An ideal database system must provide the most up-to-date data to every request for inquiry which is only possible when replicated data is up-to-date. MutEx guarantees that at a given time t only one node updates shared data, while data consistency guarantees that every node in network updates its copy from shared data to the latest version. This study is limited to MutEx algorithm and assumptions related to data consistency are not taken into account. Mobility of nodes makes MANET sustainable to multiple connection or disconnection of nodes, in addition to failure of nodes. MANET as concentrated in this study is fault-prone and its topology changes frequently.

The DS and the MANET as concentrated in this study initially form one partition P; however, some nodes may be timely disconnected from the partition due to failures. Every single node N_k sees the partition from its point of view as partition P_k, so that initially $P_k=P$. In the case of partitioning, some partitions may have outdated data (because they do not receive updates from the DP), and reading from such partitions may result in outdated information. Nodes do not need to know the information of other partitions and only act based on their partition information. However, concurrent read operations are allowed if the node belongs to a DP. Therefore, for each query, reading permission from one node is enough (Barbara & Garcia-Molina, 1986). This study concentrated on writing on replicated data or update.

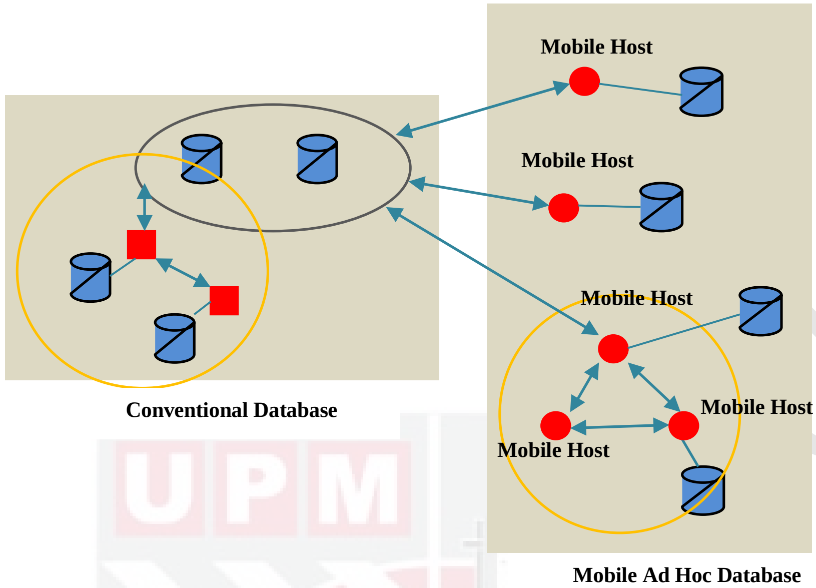

Figure 1-1: Relation between conventional distributed database and ad hoc database in a mobile database system (Opeoluwa & Opeyemi, 2010)

1.7 Research Outline

Chapter 1 introduces the problem of MutEx in DS (and database system) and its relation to mobile data base system as used in mobile ad hoc environments. Two main classes of MutEx algorithms for DS and MANET as a generalization of conventional DS are explained and their benefits and problems are highlighted. The research objectives are stated and the problem statement in current situation and contribution are also given.

Chapter 2 is dedicated to literature review on fault-tolerant MutEx algorithms and begins with introduction to MutEx algorithms. DME algorithms related to MANET algorithms are discussed. The benefits and weaknesses of each algorithm are also highlighted. Finally, MutEx DS and MANET algorithms are summarized and compared.

Chapter 3 describes the system model, performance metrics and methodology used for designation of DAD and MDA algorithms. It also presents the description of basic distributed algorithm and the MANET MutEx algorithms. The experimental setup that is used for development and evaluation of the algorithms is also presented in this chapter.

Chapter 4 discusses the result of distributed algorithms in conventional DS and in MANET. The MutEx, deadlock freedom and starvation freedom of algorithms are proved. Different scenarios of fault injection, different speed of mobility of nodes and load of requests are considered for the purpose of simulation.

Chapter 5 concludes the study by summarizing the result and conclusion, stating the contributions and identifying future research direction.

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