Data Divergence with Consistency Based Replication in MANETs

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ABSTRACT: *Mobile ad hoc Networks (MANETs), due to frequent network partition, data availability is lower than that in traditional wired networks. Data divergence provides an attractive solution for this problem. In this paper we propose an approach for maintaining divergence while data diverge from local consistency region to global consistency region in MANETs, in which we will take the data of leaving node. It also maintains replica of data. Here each region has a cluster head that keeps the information of the region. When cluster head diverge from one region to other it keeps the information in itself and copies data to the new formed cluster head. This helps to improve the data availability and overall performance of the network.*

Keywords: Mobile ad hoc network, Local consistency, Global consistency, Divergence, Data replication, Consistency management

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1. Introduction

MANETs is a self-organizing, infrastructure less, dynamic wireless network of autonomous mobile devices (nodes)[1]. The network is called ad-hoc network, because there is no fixed and known structure of the network. The decision of forwarding data among nodes is made dynamically based on the network connectivity. MANETs is a wireless network and have unpredictable mobility. The mobile nodes roam freely and can go anywhere, this cause the network partition in different separated networks which are inaccessible to each other. In MANETs it is very important to prevent the deterioration of data accessibility at the point of network partition [2]. The replica of data items in mobile hosts may be inconsistent solution because of write operation performed by mobile hosts. In this type of situation, the global consistency of the data items is not desirable by many applications. Thus new consistency maintenance based on conditions such as local consistency, divergence, location etc are performed. In MANETs devices are battery powered, inefficiency of communication protocols can shorten the active lifetime of these devices. Today's MANETs are actively used in military applications, rescue services and sensor networks .The replica of the data items become invalid after the mobile host holding the original updates and consistency among replicas is kept in the entire network. Since mobile hosts become disappear from the network and network partitions frequently occur in MANETs. This strict consistency management weakens the data availability [3].

For example, consider a situation where members of a rescue service team that constructs an ad hoc network in the disaster area are divided into several groups each of which is responsible of a certain region and the members in each group share the information on their progress, i.e., the information is replicated at mobile hosts to deal with possible network partitions. In this situation, the consistency among replicas must be strictly kept in the same group and is not required among replicas in different groups since the information sharing in a different group is only for reference.

2. Related Work

Recently consistency management and data replication is becoming more popular and significant topic of research in distributed database systems and MANETs. The authors [1] discussed cache coherency issues and classified several coherency conditions such as time-based, value-based, and version-based ones. In [2], the authors discuss the methods by which replicas are allocated to a fixed number of mobile hosts that act as servers and keep the consistency among the replicas. The consistency is maintained by employing a strategy based on the quorum system that has been proposed for distributed databases. In [3,6,7], the authors discuss probabilistic quorum system. The consistency among replicas is maintained based on the quorum system. The consistency is maintained in the entire network. The authors [4], proposed the concept of d-consistency, which is a cluster-based approach and allows a certain degree of divergence of values of copies in different clusters which provide replication inter cluster integrity constraints. For such integrity constraints, bounded inconsistency means that all copies in the same logical cluster have the same value while among copies at different logical clusters there is bounded divergence, bounded divergence is quantified by a positive integer called degree of divergence. The replication constraint for this bounded divergence is called d-consistent. The degree of divergence among copies can be tuned based on the strength of connection among physical clusters, by keeping the divergence small in instances of high bandwidth availability and allowing for greater deviation in instances of low bandwidth availability. The authors [9], discussed two different consistency levels, local observation consistency and global observation consistency. Global observation consistency is equivalent to GC (Global Consistency).Local observation consistency is equivalent to LC (local consistency). The authors tried to keep consistency based on an optimistic manner, i.e., transactions are tentatively committed and the consistency is checked afterward by using serializability. Such an optimistic approach may not work well in MANETs because it will cause a large number of aborts and rollbacks of transactions due to conflicts of data operations performed in partitioned networks. Zheng et al. [15] is proposed that the network is clustered into several clusters and network partitions often present between clusters, especially clusters without overlap. The basic idea of CDRA (Clustering-based Data Replication Algorithm) is that the requested data object in the clusters is replicated to prevent deterioration of data accessibility at the point of network partitioning. Hao et al. [16] proposed that DHTR employs a cluster-based hierarchical structure, and uses a distributed hash table technique and a distributed replica information directory to improve the efficiency of update propagation. Distributed hash table technology is normally applied in peer-to-peer networking environments to help the user locate the resources quickly. DHTR system is mainly composed of two elements: replica managers and cluster heads. Huang et. al [17] proposed in DRAM, each mobile node first exchanges its motion behaviour with some neighbours. Then, a decentralized clustering algorithm is used to cluster mobile nodes with similar motion behaviour into mobility groups. Hence, clusters which are likely to connect with one another later merged into an allocation unit to save the aggregate storage cost. Finally, data items are replicated according to the resulting allocation units. DRAM maintains the mobility groups in an adaptive manner which keeps the number of information broadcasts as small as possible and hence reduces the generated network traffic.

3. System Model

In this paper we assume an environment where each mobile host access the data items held by other mobile hosts in MANET, allocates replicas and care for the divergence of values (d-consistency) in different regions. The divergence of the values is considered as in between local consistency and global consistency [10]. The area in which mobile hosts move around is divided into several regions and consistency of the data operations on replicas is managed based on the regions. When the cluster head moves from one region to another region, the cluster head copies its replica from other region to new elected cluster head or other node in the region. The detail description of the model is as follows:

- Each mobile node knows its current location using GPS system and moves around the regions.
- Each mobile node has unique identifier that identifies each node in the network.
- Each mobile node communicates with each other through a wireless link using any existing routing protocol.
- Each node knows the position of cluster head node present in the region. For example it natural that every member knows group leader who act as cluster head. Even members do not know each other, a new node has to register its participation to the cluster head to join the MANET. All nodes can know all others at the configuration phase of the MANET.
- The set of regions in the entire network is denoted by $R= \{R_1, R_2, R_3 \ldots R_n\}$, where n is the total number of regions and R_n (i = 1, 2...n is the region identifier).
- The protocol is not restricting to any particular architecture design because in real situation regions are geographically defined according to requirements from the application.
- If nodes are not with in direct communication range of their neighbor nodes the communication packet are forwarded in multi hop manner.
- Data are handled as a collection of data items. Each data item is identified by unique data identifier= $\{D_1, D_2 \ldots D_m\}$, where m is the total number of the data items.

- Each node performs read write operations to any data item. We here assume that each transaction consist of a single database operation either read or write. Thus consistency of the data operations on the replica is defined such that every read operation is a valid replication. Valid replication is the latest version in a specific region according to the consistency type (either local or global consistency).
- Every cluster head and node has unlimited memory space for creating replicas and thus it replicates all data items in the entire network. When data items of small volume are shared, such as location information and statistical information of collaborative works, this assumption is reasonable.
- We have assumed that cluster head knows the replication performed by the nodes in its regions. This can be done by sending the information on replica held by the nodes to the cluster head when the nodes participate in the new region.
- The consistency on the data is also be maintained to get the updated and similar information in the entire network.

The model is shown in figure 1. We have considered that each node is associated with region and each region has a cluster head. Each node and cluster head maintains information of data. When a cluster head have new data item it updates its table and broadcasts these to the cluster heads of other regions. The data server maintains the whole information of the network. When the node moves within the region it maintains local consistency protocol. The consistency of data operations on replicas is required only within the region of interest. This consistency protocol weakens the strictness of consistency.LC requires that in each region every read operation issued by any node in the region necessarily reads a replica of the latest version in the region, means replica was written by the latest write operation in the region. When the nodes move out of the region it maintains global consistency protocol. The consistency of data operations on replicas is required in the entire network. This consistency protocol provides stronger consistency .In GC protocol every read operation issued by any node necessarily reads a replica of the latest version in the entire network, means a replica that was written by the latest write operation issued in the entire network. Each region have assigned a cluster head, that keeps whole information of the nodes existing in the region like node id and also receive request for data items which they require[14]. The cluster head node refresh its memory after a time interval, the data item which is requested most deleted from the cluster head. The cluster head sends the requested data items to the respective node. If data is not available in the cluster head node then it request for data items from the data server. The data server sends the requested data to the respected region cluster head. If the cluster head node goes out of region the nearest node to the cluster head becomes the new the cluster head for the region and keep copy all the information from the old cluster head node. It also keeps the data items information with it, if new region requires that information then it sends information otherwise delete it, this is known as divergence of data values from among the region.

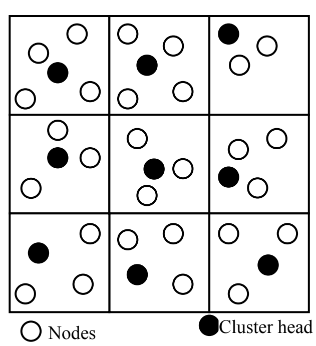

Figure 1. System model for execution of lC,GC protocols

4. Classification Of Consistency Levels

Data Consistency may be defined as the usability of data. Data Consistency problems often arise in a single-site environment during recovery situations when backup copies of the data are used in place of the original data[5]. The process provides synchronization and guarantees that record has been successfully written before the write I/O of record can be issued by the application [9].Data consistency is used to check validity, accuracy, usability and integrity of related data between applications. In this each device have a consistent view of the data, including changes made by the device own transactions (read/write) and transactions of other devices or processes.

In MANETs environment it is very difficult and sometimes not possible to apply traditional consistency management strategies because of the divergence of the values among the regions. Caring for the divergence of the data, two consistency management strategies are required i.e. local consistency and global consistency [9,10]. Moreover, there are many kinds of applications possible in MANETs such as information sharing by a rescue service team and parallel and distributed processing of sensing data in sensor networks. Thus, we propose local consistency and global consistency levels among replicas in MANETs. Based on applications, node can select the desired level of consistency while accessing the data items at the time of divergence.

Global Consistency (GC) This consistency applies data operations on replication in the entire network. Global consistency requires that every read operation issued by any cluster head necessarily reads a replica of the latest version in the entire network, i.e., a replica that was written by the latest write operation issued in the entire network. Such a strong consistency requires many nodes of message passing.

The example of global consistency is rescue service. We consider a situation in which members of a rescue service are divided into several groups each of which is responsible for a certain region and the information on the progress of tasks assigned to each group is shared in the entire network. In this case, the shared information is used for administrative decisions at the highest level such as allocation of machine or human resources, and scheduling of new tasks. Thus, the consistency of data operations must be maintained strictly in the entire network.

4.1 Local Consistency (LC)

The consistency of data operations on replication is required only in each region of interest. This consistency level weakens the strictness of consistency from the spatial perspective. Local consistency requires that in each region, every read operation issued by any cluster head in the region necessarily reads a replica of the latest version in the region, i.e., a replica that was written by the latest write operation issued in the region. The example of local consistency in rescue service is a situation where the members of the rescue service share the information on the damages such as the number of injured persons and destroyed buildings, which can separate data items according to the extent of the damages. This information is used locally by the cluster head of each region to decide the resource allocation and task scheduling in the group. Since this information is referenced only by the cluster head and members in the same group, it is not necessary and too costly to keep the strict consistency in the entire network. Therefore, in this case, local consistency is suitable.

4.2 Divergence of Data

The degree of divergence among data items based on the strength of connection among physical regions, by keeping the divergence small in instances of high bandwidth availability and allowing for greater deviation in instances of low bandwidth availability. The divergence of data may be defined as maximum number of transactions that operate on data copies appropriately bound the number of weak transactions at each physical region [4]. In the case of a dynamic region reconfiguration, distribution of weak transactions at each region must be readjusted. The maximum number of updates per data item not reflected every copy of data. Divergence is used to maintain data consistency and integrity whether information artifacts are divergent, or not, at a certain moment. Divergent information means that the information retains its meaning though there may be a conflict existence with other information objects. Managing divergent information avoid the loss of information meaning. This can be achieved by supporting and solving the usual problems of distributed object manipulation, such as replication. Therefore, consistency preservation may conflict with strategies to enhance information availability (such as replication) and it may actually lead to incompatible changes between two, or more, copies of some piece of information.

4.3 Data Replication

Ad hoc data replication problem (ADRP) was first introduced by Hara [8,13] which was further extended to incorporate various network connectivity related issues. Replication allows better data sharing and approach for achieving high data availability. It is suitable to improve the response time of the access requests, to distribute the load of processing of these requests on several servers and to avoid the overload of the routes of communication to a unique server. The access is generally carried out on the nearest replica of data, the global traffic is decreased [11]. The creation of replicas also allows to better data sharing since even in the case of disconnection of a node holder of data, the other nodes can continue to have access to a replica of data on another node[12].

4.4 Cluster Head

In MANETs, mobile nodes move freely, disconnections occur frequently, and this divide the network into groups/regions/zones and then create a virtual backbone between delegate nodes in each group, this operation is called clustering, giving the network a hierarchical organization. A cluster is a connected graph including a cluster head responsible of the management of the cluster, and some ordinary nodes. Each node belongs to only one cluster. Clustering has several advantages. First clustering allows the reuse of resource which can improve the system capacity, in the way that information is stored once on the cluster head. Secondly clustering may optimally manage the network topology, by dividing this task among specified nodes which can be very useful for routing since any node is identified by its identity and the identity of the cluster-head of the cluster to which it belongs, simplifying by this way the forwarding of messages. Various cluster based technique properties are discussed in table 1.

	CDRA[14]	DHTR[16]	K-HO P DAG [15]	DRAM[17]
Architecture	Decentralized	Centralized	Decentralized	Decentralized
Cluster formation	High	High	Low	High
Data consistency	Medium low	Medium low	Medium	Medium low
Energy aware	No	Yes	Yes	No
Localized	No	No	Yes	No
Maintenance cost	High	High	Low	High
Read only	No	No	No	Yes
Replication cost	O (n)	Not known	O (n/f(k))	O (n)
Query cost	O (n+ √n)	O (n+ √n)	O (K)	O (√n)
Update cost	O (n+ √n)	O (n+ √n)	O (n+k)	Not known

Table 1. Comparison of various cluster based techniques

5. Simulation

5.1 Simulation Model

In our simulation experiments we have assumed the situation of rescue operation. Here members are engaged in a collaborative work to share information for efficiency of their own task. The members are divided into groups, each of which assigned a specific region. They are equipped with mobile terminals with a wireless communication facility. The network consists of mobile nodes. Cluster heads are chosen with already proposed method CDRA (cluster based data replication algorithm) [14].

Mobile hosts exist in an area of [X]* [Y] m^2, which consists of 12 regions of X/3* X/3, R={R_1….R_{12}}. Here, ratio X : Y is kept to 3:4. In our model we have taken X as a changed variable parameter in the range from 300 to 600 m. Changing the value of X is almost identical to those varying the number of mobile nodes and the radio communication range because all of them affect the connectivity among mobile nodes. The number of mobile nodes in the entire system is 240, M= {M_1…..M_{240}}. Here {M_1….M_{12}} are the cluster heads and { M_{13}…M_{240} }are the nodes. The numbers of data items are 500 for the entire network and all are of the same size.

Each node moves according to the random waypoint model, where each host selects a random destination in its assigned region. In the mobility model, each node moves according to the random waypoint model, where each host selects a random destination in the whole area. The pause time and the maximum movement speed are set as 0 second and 2 m/s. The communication range of each mobile host is a circle with a radius of 50 m. Every message and data transmission is routed via the shortest path from the source to the destination. We examine the success ratios of read and write operations for local consistency, global consistency and divergence levels during 10,000 units of time.

Success ratio (ratio of successful read/write operations to the number of all request of read write operations issued during the simulation time) are taken from Table 2. The simulation model chosen for the simulation of proposed method are given as:

- The nodes were randomly deployed using random waypoint model over simulation area as shown in figure 2.
- The network is divided into regions.
- Each region chooses cluster head randomly from the nodes.
- The Area in which nodes were deployed X*Y [m^2].
- All Nodes connected to each other through wireless link and knows the location of the node.

Parameter	Value
Simulation area X*Y[m^2]	600m (300~600)
Total number of regions	12
Total number of mobile nodes	240
Total number of cluster heads	12
Total number of data items	500
Pause Time and maximum movement speed	0s and 2m/s
Read Write frequencies	0.02/s ,0.002/s
Maximum simulation time(units of time)	10000

Table 2. Parameters for Simulation

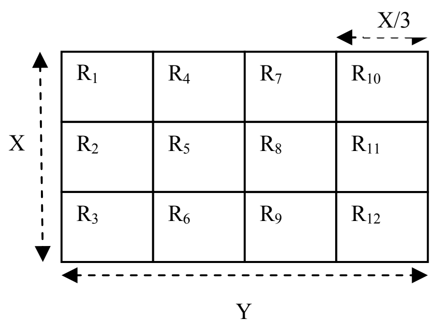

Figure 2. Simulation area

5.2 Area Size Vs. Success Ratio

In figure 3(a),(b) horizontal axis shows the Area Size and vertical axis shows Success ratio for write and read operation. Here we compare the success ratio for both read and write operation in global and local consistency protocol and divergence of data. From the graph we analyze that as the area size increases the success ratio for GC, divergence and LC gets lower.

This is because as the area size increases the connectivity among nodes becomes lower. The cluster head that receives an operation request cannot set the number of locks to replicas with high probability.

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As the area size gets larger than 400 the success ratio for divergence and global consistency gets lower but in local consistency it does not get lower. This is because in local consistency the connectivity among the mobile nodes and cluster head in the inter region is high while in divergence and global consistency the connectivity among the nodes and cluster head is lower due to intra region. This is due to random way point model of mobility in which nodes tends to locate near the center of the region.

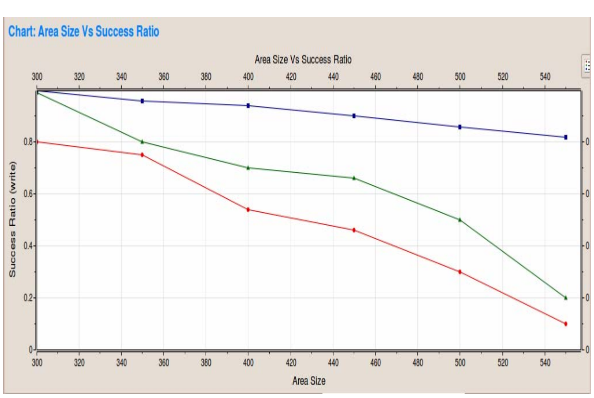

Figure 3. (a) Area Size vs Success Ratio (write)

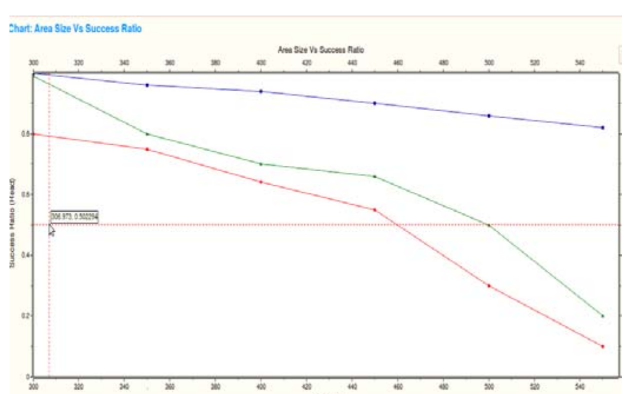

Figure 3. (b) Area Size vs. Success Ratio (read)

5.3 Write Frequency Vs. Success Ratio

In figure 4(a),(b) horizontal axis shows the write frequency and vertical axis shows success ratio for write and read operation. The success ratio of write and read operation in global and local consistency protocol and in divergence are not affected by write frequency because the mobile nodes hold more recently updated replicas and more chances to access valid replica.

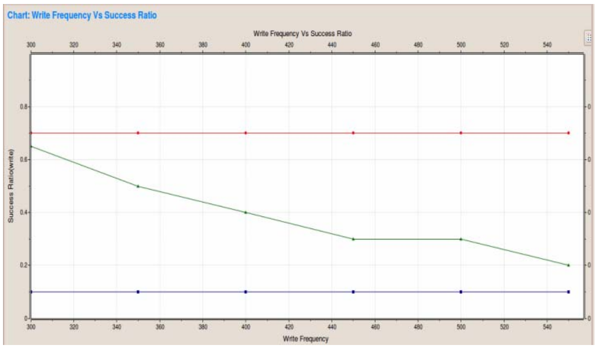

Figure 4. (a): Write frequency vs. Success Ratio (write)

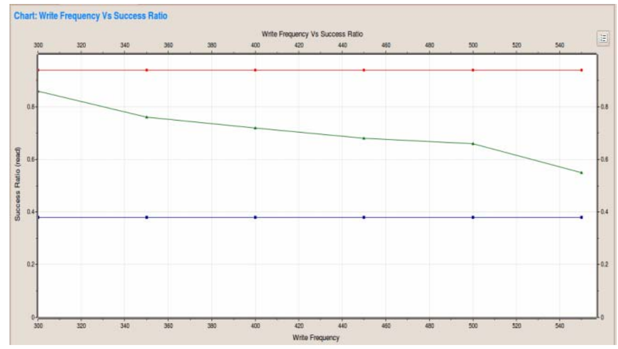

Figure 4. (b): Write frequency vs. Success Ratio (read)

6. Conclusion

In this paper, we have discussed the divergence when data moves from local consistency region to global consistency region. In MANETs nodes disconnection causes frequent network partitioning, it is difficult and, in some cases, not desirable to provide traditional strong consistency of data operations. We have conducted simulations to investigate the behaviors and features of our proposed protocol. From the result, it is shown that the performance of the proposed protocols differs with each other and that we should choose LC rather than GC in terms of success ratio if applications do not require the strict consistency in the entire network. We should restrict replication at the cluster replicate all or most of the data items.

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