Weighted Dynamic Bi-connected Group based Replica Allocation method for Mobile Ad Hoc Networks

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Abstract

Accessing remote services and data is one of the most important applications in Mobile Ad Hoc Networks. Data replication is one of the most popular techniques used to increase data availability by replicating frequently accessed data items locally or nearby. In MANETs, data replication helps to avoid data losses in case of unpredictable network partition and also aids in reducing the number of hops that a data is transmitted from source to destination. In this paper, an extension to DCG (Dynamic Connectivity based Grouping) [5] is proposed called W-DCG (Weighted Dynamic Connectivity based Grouping), which aims at addressing the limitations of DCG and most of the other proposed protocols in literature. The proposed protocol considers node properties such as memory capacity and remaining battery power while replicating data on nodes to achieve better load-balancing. Moreover it uses dynamic access frequencies to replicate data items which are currently in demand. Data sharing is done in large groups, which are stable to reduce duplicity of data. This type of collaborative replication increases the availability of different data items in a group. Extensive simulations are performed to analyze and compare the behaviour of W-DCG with DCG and No replica framework for different network scenarios generated by varying parameters such as network size and relocation period. The performance evaluation of W-DCG through simulation indicated that the proposed protocol increases the data accessibility and achieves better load-balancing in comparison to DCG and no-replication.

KEYWORDS
Replication, ad hoc, bi-connected components.

1. Introduction

Mobile Ad-hoc Networks (MANET) are an emerging area of research in the field of wireless communication. Past work in MANETs was mostly centred around routing issues. The core of every communication is to transfer or share data between communicating nodes. All of the MANET applications like vehicular ad hoc networks, sensor networks, personal area networks etc. focus on data sharing; hence data or information sharing is one of the most important functionalities to be supported by MANETs. However data sharing in MANETs is a challenging task due to the unique network characteristics such as, node mobility, frequent topology changes and limited availability of resources. To effectively share data and to increase the availability of data, multiple copies of data need to be created at different places in the network.

Due to the dynamic nature of MANETs, mobile hosts move freely which results in frequent disconnection of links between mobile nodes, sometimes causing network partitions. If network partition occurs then data items held by mobile hosts in one partition become inaccessible to mobile hosts in the other network partition. Thus, data accessibility and availability in MANETs is comparatively much lower than fixed networks. Besides network partition, power consumption is also a significant issue in data sharing as nodes in MANETs have limited battery power.

The key solution to increase the data availability in MANET like environments is to replicate the data items on mobile nodes that are not the owner of original data items. Primarily there are two different approaches to create copies of data at different nodes: first is caching and the second is replication [1]. Nodes cache frequently heard data from the passing by queries which means caching is a reactive process; on the other hand replication is a proactive process in which replicas of data items are to be created before communication starts. Replication improves data availability more than the caching approach. This is due to the fact that replication protocols execute the replication process independently of client queries. This paper proposes a new data replication scheme for ad hoc networks.

Data replication improves the query response time in large MANETs and also balances the load across query processing servers by replicating data on different nodes in the network [2]. Hence data replication increases the robustness and fault tolerance of the network. Since, MANETs are prone to network disconnections and power failures, a good data replication should be aware of these issues and adjust itself dynamically to changing network topology.

A number of data replication protocols have been proposed for MANETs in the literature. A survey of these protocols is given in [3, 4]. Most of these protocols assume that the memory size of each node is same but in real scenario different devices that from an ad hoc network may consist of heterogeneous nodes having different characteristics. Some of the proposed protocols assume that the access frequencies of devices to data items are same at every time but in real scenario access frequencies may be different at different times.

In this paper, an extension of DCG (Dynamic Connectivity based Grouping [5]) called W-DCG (Weighted Dynamic Connectivity based Grouping) has been proposed, which aims at addressing the above limitations of DCG and most of the other previous replication protocols. The new protocol takes into consideration various node properties while replicating data to achieve better load-balancing. It also considers dynamic access frequencies to replicate data items which are currently in demand. The simulation study of W-DCG indicates that the proposed protocol increases the data accessibility and achieves better load-balancing in comparison to DCG and no-replication.

Rest of this paper is organized as follows: Section 2 gives a literature survey of existing data replication approaches. Section 3 presents W-DCG in detail. System simulation model and implementation details are describe in section 4. In section 5, simulation results and analysis of the results are presented. Finally, section concludes the paper and gives possible future extensions of the current work.

2. Literature Survey

There are several issues related to data replication in MANETs which have already been discussed in [7]: These are server mobility, client mobility, server power consumption, client power consumption, time-critical applications, network partitioning, scalability, and consistency management.

Hara [5] has proposed three data replication methods to improve data availability: Static Access Frequency (SAF), Dynamic Access Frequency and Neighbourhood (DAFN), and Dynamic Connectivity Based Grouping (DCG). All these methods assume finite node memory and predefined constant access frequency of each node towards data items. In SAF, each node creates replicas of its frequently accessed data items without considering data items replicated by its neighbours. In DAFN, firstly SAF method is executed, then every pair of neighbouring mobile hosts compare their replicated data items to eliminate duplication and hence increase the number of data items that may share between two nodes. The DCG method first divides the nodes into stable groups by finding the bi-connected components and then shares replicas in larger groups of mobile nodes by considering group access frequency. Here group access frequency of each data item is calculated as a summation of access frequencies of nodes in the group to the data item. Extensions to the above methods have also been proposed in [6], to handle periodic and aperiodic updates. Hara also proposed another extension to the above three methods by considering the link stability between connected nodes; DAFN-S1, DAFN-S2 and DCG-S1 [7]. The methods aim to eliminate duplicate replicas of data items between two nodes if the wireless link that connects them is stable. The methods assume that each node equipped with GPS device and using speed and location information are able to predict the time at which two neighbouring nodes will be disconnected. The main drawback of all these approaches is that the relocation period is constant, and hence cannot adapt to changing network topology. Moreover, all these methods assume that all the nodes of the network know the access frequencies to data items and these frequencies do not change. Shinohara et. al. [8] proposed a replica allocation method called Weighted Expected Access and Battery (WEAB) which balances the power consumption among mobile nodes. In this method, along with access frequencies, the remaining amount of battery power is also considered while taking replica decision. Thanedar et al. [9] proposed an Expanding Ring replication scheme for pull based environment where nodes query the server for data items they need. This scheme is lightweight since, it reduces the burden on a mobile node by giving replication related work to server. Server replicates the hot data (most demanded) such that it increases the likelihood of node finding the required data within its neighbourhood. Wang et al. [10] proposed a power aware dynamic adaptive replica allocation algorithm which is based on mobility of nodes. PADARA is executed by each replica node periodically, replica nodes collects local access request information from its neighbours and decides whether to do replica expansion, replica switch or replica contraction in order to reduce the power consumption. Chen. et. al. have used cross layer design concepts to take replication decisions at nodes in mobile ad hoc networks [11].

A number of cluster based data replication protocols have also been proposed in literature which share data among clusters so that to increase data availability within the group is increased[12, 13, 14, 15, 16]. In [17, 18], authors have applied the concept of economic models to the problem of data replication in mobile peer to peer networks. Similarly in [19], game theoretic techniques have been applied to the data replication problem in MP2P networks to take care of the selfish behaviour of nodes which try to replicate only their popular data.

3.1. System Model

The system environment is considered to be an ad-hoc network where each mobile host can create replicas of up to its memory size including its original data items. When a mobile host generates a request for a data item, the request is immediately satisfied if it holds the original/replica of that data item in its memory space; otherwise, it sends the request to its one-hop neighbours which again check for the requested data item else the request fails.

In order to simplify the simulation study following assumptions have been made:

The set of all nodes in the system is denoted as M={M1, M2…. MN}, where N is the total number of nodes in the network. Each mobile host Mi is the owner of data item di , where the set of all data items is denoted as D={ d1,d2,…..,dN}, where N is the total number of nodes. Initially access frequencies to each data item from each mobile host are known. The access frequency is then after calculated dynamically. Each mobile host shares its data items and does not exhibit any kind of selfish behaviour. The data items are assumed to be unchangeable during simulation, so that no updates to data items and related consistency problems are considered.

Every node has different memory and different battery power.

Size of the each data item is same and can be allocated in single network packet.

3.2. W-DCG Replication Technique

The main goal of a good replication technique is to increase the percentage of successful data requests while reducing the time to satisfy these requests. The new data replication protocol takes into account heterogeneity of nodes while replicating data items. The protocol first creates groups by finding the bi-connected components of the network and then replicating data items in the groups as in DCG [8]. But unlike DCG, it considers node properties like memory and remaining battery power while replicating data items on node. DCG assumes that the access frequency of nodes to each data item is static but in the real scenario access frequencies are dynamic means, access frequencies are re-calculated every relocation period. Also in DCG, the algorithm to find the bi-connected components is executed by the node having lowest index in its connected mobile nodes and group's access frequency is also calculated by the node having lowest index in its group at every relocation period. This increases the load on nodes having lowest indices. In the new data replication protocol the access frequencies of the data items is based on the data requests issued by nodes and to ensure fairness among nodes, the algorithm to find the bi-connected components is executed by node having highest remaining battery among its connected mobile hosts and calculation of group's access frequencies is carried out by node having highest remaining battery in its group.

The new replication protocol consists of three algorithmic components namely, *MANET Bi-Connected Components Algorithm, Replica Allocation Algorithm and Replica Access algorithm.* These components are described in following sub-sections:

3.2.1. MANET Bi-Connected Components Algorithm:

A graph G(V,E) is bi-connected if and only if it contains no articulation point. A vertex v in a connected graph G is an articulation point if and only if the deletion of vertex v together with all edges incident to v disconnects the graph into two or more nonempty components [20]. W-DCG uses this property of bi-connected components to logically divide the network into stable groups. Sharing data items in groups reduces the redundancy and increases the number of data items that can be stored in a group. Grouping based on bi-connected components increases the stability of group because if one node disconnects from the group due to its mobility or one link is disconnected, the group is not divided. The algorithm described in [21] is used to find the bi-connected components of the graph formed by the nodes of ad hoc networks.

3.2.2. Replica Allocation Algorithm

The Replica Allocation Algorithm is executed by the node having maximum remaining battery power in its group; this node is called the group head among all nodes in its group. The group head also maintains information about all the nodes in the group. The group head first calculates the group access frequency of each data item, which is the summation of access frequency of all nodes in the group. Then, it creates the list L of data items in descending order of their group access frequency. After that, it creates the list of nodes N in its group in descending order of their weights. Each node in the network is assigned a weight value which is the weighted sum of their memory capacity and remaining battery power. The formula for weight calculation is given below:

$$W= w_1*\text{RemainingBattery} + w_2/\text{MemorySpace} \qquad (1)$$

where w_1 and w_2 are the weighting factors for the remaining battery and memory space for node respectively and their sum should be 1.

When every group head finishes the creation of lists L and N. It sends message to first node M_i in list N, to replicate first Mem_i data items in list L where, Mem_i is the memory space of M_i available for holding data items. Then it sends message to second node M_j in the list N to replicate next Mem_j data items in list L and so on, until the memory space of all nodes in group becomes full. Here, replicas of data items which are held as originals by mobile hosts in the group are not allocated.

To illustrate the working of Replica Allocation Algorithm, consider the example MANET topology in figure 1. Here, dotted ovals represent the groups and rectangles represent the node's memory space to replicate data. At the starting of this algorithm every node contains its original data item in its memory space like, node 1 contains data item D_1, node 2 contains data item D_2 and so on.

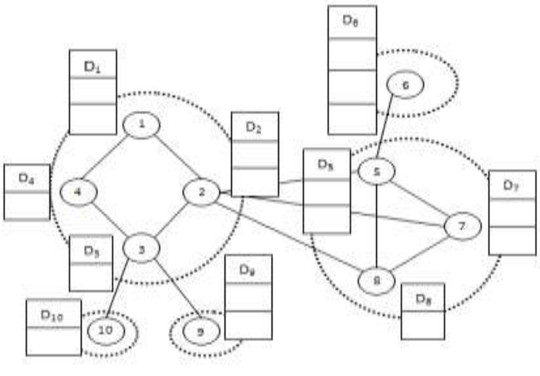


Figure 1 MANET groups with memory size

Suppose the node whose remaining battery is highest is node 1. Node 1 sends the group information to each group head which is given in table. Then, G_1 sends a message to node 4 to allocate the data item D_6 because node 4 has highest weight among its group nodes and D_6 has highest access frequency in G_1 as shown in table 1. Like this other group heads send messages to their group members to replicate data items in their descending order of access frequency. The network status after the replica allocation is shown in figure 2.

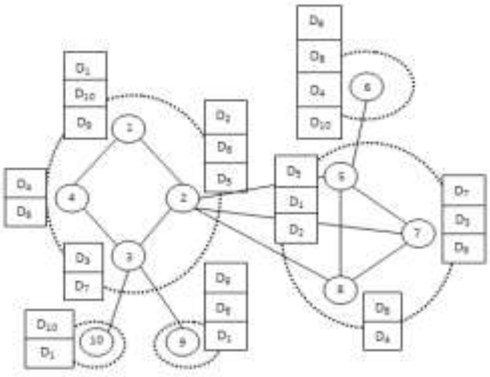
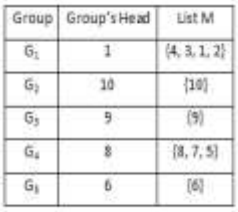


Figure 2 Network status after Replica Allocation

3.2.3. Replica Access Algorithm

Requests are generated using AODV routing protocol. When data access request for a particular data item is issued then the node first checks its local memory space for original/replica of that data item. If the node finds that data item in its memory then the data request is immediately satisfied otherwise the node broadcasts the data request in the network with a predefined TTL instead of blind flooding as in AODV.

Table 1: Group Membership & Group Access counts



Group	Group's Head	List M
G_1	1	{4, 3, 1, 2}
G_2	10	{10}
G_3	9	{9}
G_4	8	{8, 7, 5}
G_5	6	{6}

Data	Group				
	G_1	G_2	G_3	G_4	G_5
D_1	17	4	5	10	4
D_2	14	2	1	8	3
D_3	15	1	3	13	3
D_4	13	2	2	15	5
D_5	14	3	3	14	4
D_6	20	3	6	8	6
D_7	18	3	4	7	4
D_8	17	2	2	7	7
D_9	16	3	3	9	3
D_{10}	18	5	3	6	5

When a node receives the data request, it checks its memory for original/replica, if it is found then node sends reply to requesting node from the reverse path which is created as in AODV otherwise, the node rebroadcasts the data request further. For example, as shown in figure 3, when node 4 generates a request to access data items D_5, then it first checks its local memory, as D_5 is not there in its memory, it floods the RREQ for data items D_5 as shown in figure by arrows. As node 1 and 3 are in range of node 4 they receive the RREQ and checks their local memory for D_5, again they re-broadcast the RREQ. Finally, the RREQ comes to node 2 which has replica of D_5, node 2 sends RREP through the reverse path shown by dashed arrows, for its first received RREQ of data item D_5.

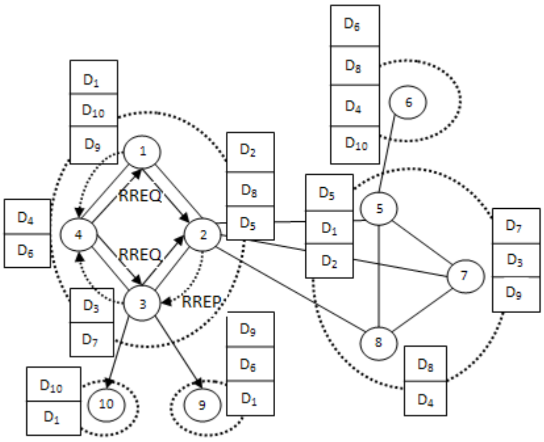


Figure 3 Replica access mechanism

3.3. Complete W-DCG algorithm

The data replication W-DCG scheme is executed at every relocation period (specific period). The algorithm is as follows:

1. At the start of every relocation period, each mobile node broadcasts a hello message which also contains its weight (i.e. weighted sum of its memory and residual energy) and access count information to different data items. Such broadcasting helps node to identify its connected neighbors, their weights and their access pattern.
2. The mobile host having highest remaining battery (G) among its connected mobile hosts executes an algorithm to find bi-connected components. Then a group head is assigned to each bi-connected component.
3. Mobile host M_i sends group information to every group coordinator (M_j) which is having highest remaining battery among their group. Since, every node knows the properties of its connected mobile nodes.
4. Every group coordinator calculates the access counts of the group to each data items which is summation of access counts of mobile nodes in group to data items. It then prepares a list M of their group nodes, in descending order of their weight (W) as calculated through equation 1.
5. In the order of access counts of the group, replicas of data items are allocated to nodes in the order of list M, until the memory space of all nodes in the group becomes full. Here, replicas of data items which are held as originals by mobile nodes in the group are not allocated.

4. Simulation Environment

The simulation experiments are run for a small-scale (from 20 nodes) to medium-scale (up to 100 nodes) mobile ad hoc network in Qualnet simulator [21]. In simulation, all nodes implement IP (Internet Protocol) and UDP (User Datagram Protocol) as network and transport layer protocols, respectively. Every node is equipped with IEEE 802.11b capable wireless communication cards operating (in ad-hoc mode) on the 2.4 GHz band with communication range of 100 meters. Number of nodes in the simulation is varied from 20 to 100 in order to analyze the scalability properties. When we increase the number of nodes in the simulation, we also apply a proportional increase to the simulation area while keeping the density of all areas constant. Our motivation for a constant-density network is to avoid the side effects of possible collusion and contention on the shared wireless channel. Density of a network is calculated given as follows:

$$\text{Density} = (N*S)/A$$

where, N is the total number of nodes in the simulation, S is size of the coverage area of a mobile node and A indicates the total simulation area size.

Simulation area is a square-shaped two-dimensional $100\text{x}100\text{m}^2$ surface in which every node may move freely without any obstacles. Node movements are based on one of the most widely used model called Random waypoint mobility model. Nodes select a random speed within the human walking speed limits (1 to 3 meters/second) during the simulations. The number of data items in the entire network is 20. M_i (i=1… 20) holds D_i as the original. All simulation experiments are run for 700 seconds. A summary of simulation parameters is given in Table 2.

Table 2 Simulation Parameters and Values

MAC protocol	IEEE 802.11b
Network protocol	IP
Transport protocol	UDP

Radio comm. Range	100 m
Radio frequency	2.4 Ghz.
Number of nodes (N)	20
Maximum memory	7 data items
Relocation period	300 secs
w_1 and w_2	0.5 each
Maximum battery	1200 mAhr

Due to its popularity and reactive nature, Ad-hoc On Demand Distance Vector (AODV) routing protocol has been elected as the underlying protocol for our base-case data lookup simulations. AODV is a source-initiated reactive (on-demand) protocol, which initiates a route discovery whenever a node requires a path to a destination.

The performance of the new W-DCG data replication scheme has been compared with the data lookup using an underlying ad hoc routing protocol (no-replication) and the well-known data replication approach developed for MANETs by Hara called DCG as given in [5].

5. Performance Metrics and Parameters

The performance of W-DCG has been analyzed and compared with no-replication and DCG in terms of four main parameters as mentioned below:

Data Accessibility: This is an important criterion for both a data lookup and a replication protocol. Basically, data accessibility is the ratio of the number of successful access requests to the number of all access requests issued. A data replication (or caching) protocol aims to increase the accessibility of data items in the network. Different than conventional static networks, in mobile environments achieving 100% data accessibility is nearly impossible, due to mobility of nodes and changing network topology.

Average Query Deepness: The average number of hops traversed by a successful query when finding the requested data is called as average query deepness. Essentially, query deepness is the distance of the requester to the requested data item in terms of number of nodes on the successful path found. W-DCG with replication aims to replicate the data items in groups in order to decrease the query deepness of a data request. Number of hops that a data item found is also directly related with query completion delay. Some of the networking applications (such as VoIP (Voice over IP), real-time video broadcasting applications, etc.) require strict timing constraints. Lower average query deepness values result in lower delay for data requests.

Control Overhead: Control overhead is an overhead incurred during the relocation of replicas. It is the number of control messages sent from all nodes during the simulation for replica relocation.

The simulation parameters play an important role in the performance analysis of a protocol. Furthermore, they are helpful for understanding the protocol response to different network conditions and by this way provide more comprehensive analysis. We define simulation parameters and then present the effects of each parameter to the performance of W-DCG.

Number of nodes in the simulation: We perform simulations from 20 nodes to 100 nodes to study the scalability of different approaches. In order to keep the node density of a network at a constant rate, we created a density versus number of nodes concept to find an appropriate simulation area size for each density level. Our aim is to keep the average connectivity of a network at a constant rate while increasing the number of nodes in the simulation.

Relocation Period: Since, the replicas are reallocated periodically; we perform simulations for varying Relocation period T to show its effect on Data Accessibility, Average Query Deepness and control overhead.

5.1. Effect of Number of Nodes

Figure 4 shows the variation of data accessibility with varying number of nodes in the networks in all the three replication methods. As the number of nodes increases, the number of data items to be replicated in the network also increases , hence the data accessibility reduces.

The graph in figure 4 illustrates that W-DCG provides slightly higher data accessibility than DCG essentially due to the three reasons; first in case of W-DCG, replica allocation of data items is based on their current access counts, while for DCG replica allocation is based on their static access frequencies. However, since DCG does not consider current access counts of data item, it may allocate replica of data item whose access frequency is higher at start but after some time access counts of other data items gets higher. Second, W-DCG allocate hot data items to nodes having small memory, thereby ensuring short waiting times for queries at the job queues of these nodes and consequently reduced query response times. Third, W-DCG also considers the node battery power while replicating data item, instead if this DCG doesn’t consider the node battery power which may results the allocation hot data item on a node having less battery power or which are going to exhaust quickly.

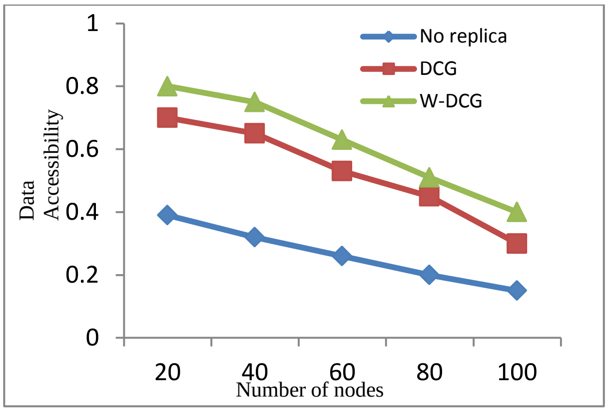


Figure 4 Data Accessibility vs. Number of nodes

Figure 5 shows that as the number of nodes increases the average query deepness for each method also increases. For, W-DCG and DCG, average query deepness increases slightly but for No replication scheme it increases exponentially as the number of nodes increases in the path between source and destination. Average query deepness increases with increase in number of nodes because memory space to allocate replicas is constant for each node but the data items to replicate are increasing as the number of nodes increases. So, it may possible that a group coordinator cannot able to replicate all kinds of data items in its group which results; a query has to traverse more hops to get success.

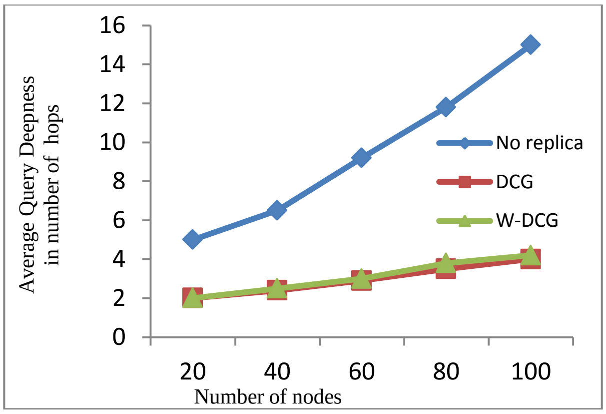


Figure 5 Average Query Deepness vs. Number of nodes

Figure 6 displays the variation of control traffic with varying number of nodes. It is easily visible that as the number of nodes in the network increases, the control traffic for W-DCG and DCG also increases because every node broadcasts its properties and as the number of nodes increases groups also increase. This results in increase in number of messages for group allocation and broadcasting. Control traffic is zero for AODV because it does not replicate data items.

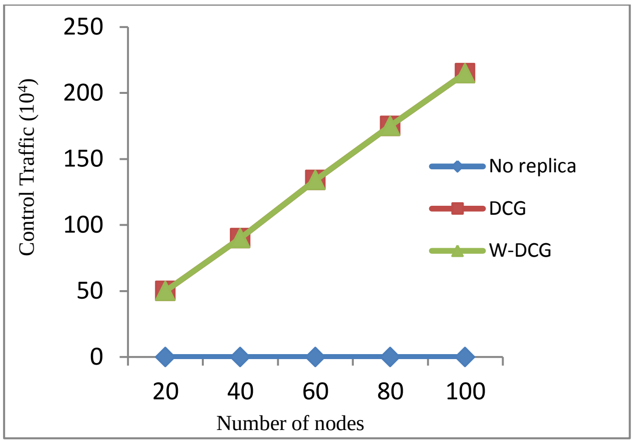


Figure 6 Control Traffic vs. Number of nodes

5.2. Effect of Relocation Period

We examine the effects of relocation period on each of the three methods. Figure 7, 8, and 9 shows the variation of the data accessibility, average query deepness and control traffic with changing relocation period respectively

Figure 7 shows that data accessibility for W-DCG is slightly higher due to reasons discussed in section 5.1, data accessibility for W-DCG and DCG are higher than No replica framework. As the relocation period gets longer, the data accessibility of proposed method W-DCG gets slightly lower because a shorter relocation period can detect the changes of network topology and access counts sensitively. For long relocation period, W-DCG can provide better data accessibility than DCG because while replicating data DCG doesn't consider the node's remaining battery. So, sometimes it may happen that it replicate most frequently accessed data item on a node which is having low battery power and going to exhaust in near future.

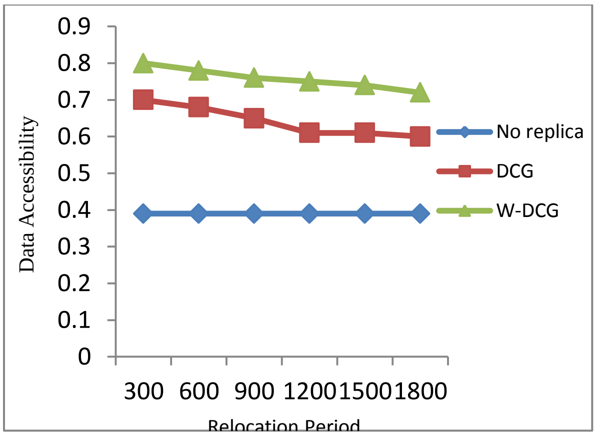


Figure 7 Data accessibility vs. Relocation Period

From figure 8 it is visible that average query deepness for W-DCG and DCG is approximately the same but less than the No-replica framework. As the relocation period increases the average query deepness also increases slightly because for large relocation period nodes may move from their stable group due to mobility, causing number of hops to increase.

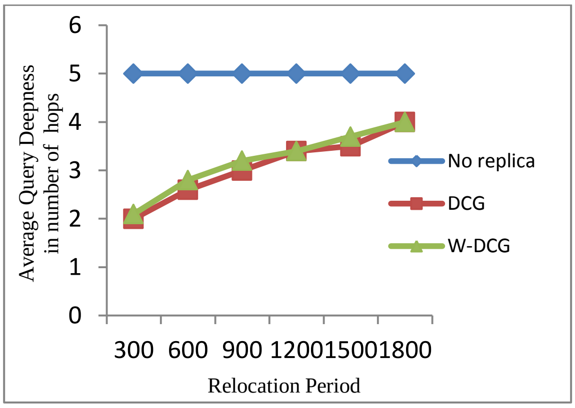


Figure 8 Average Query Deepness vs. Relocation Period

Figure 9 show that the control traffic caused by W-DCG and DCG is inversely proportional to relocation period because as the relocation period increases control traffic for W-DCG and DCG slightly decreases. This is because a longer relocation period causes replica relocation and broadcasting to happen after a long period which results reduction in messages for grouping after every relocation period. If relocation period is short then replica relocation has to done in quick succession which results in increase of number of control messages.

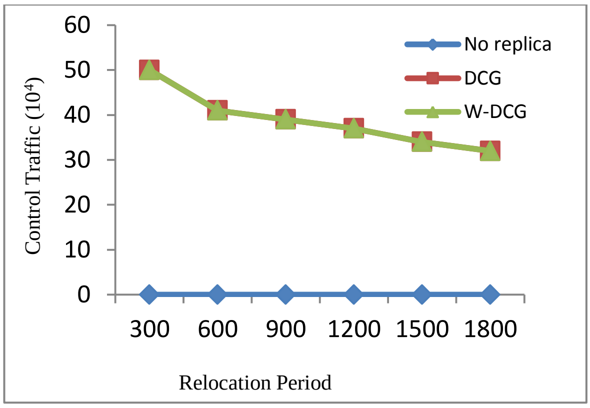


Figure 9 Control Traffic vs. Relocation Period

6. Conclusion and Future work

A novel data replication technique for MANETs and its analysis has been presented in this paper. The proposed technique is based on the Hara's DCG [5] technique. Most of the data replication techniques in the literature assumed that every mobile node has same memory size and have static predefined access frequency to data items.

The new data replication protocol W-DCG is best suited for those data sharing applications of MANETs where mobile nodes have different properties and access frequencies of mobile nodes to data items are dynamic.

The protocol consists of three main parts: finding bi-connected components, data replication approach and data access approach. Grouping of mobile nodes based on bi-connected components increases the efficiency of this protocol. Sharing the data items in larger groups makes different data items available at node's nearby and also reduces the chances of replica duplication between neighbours. By considering, the memory size of nodes and node's remaining battery while replicating data this protocol replicate the most frequently accessed data item on under loaded node. Moreover dynamic access frequency consideration helps to replicate the frequently accessed data items in most recent times. The performance of W-DCG is compared with Hara's DCG [5] technique and a no - replication technique. The simulation results prove that the new W-DCG replication scheme provides better load balancing and data accessibility than DCG. In comparison to no-replication method, this protocol increases the data accessibility and reduces the average delay but at the cost of increased message overhead.

A possible extension of this work may be consideration of additional node parameters such as running average speed of nodes and link stability of nodes in addition with memory size and remaining battery while replicating data on mobile nodes.

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