

# Efficient Caching and Mobility Adaptive Popular Data Access in Mobile Ad Hoc Networks

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## Abstract

**Background:** Caching technique is widely used to cope up with the resource constraints and to improve the data accessibility in MANETs. The key constraints are reducing the data access time, overhead and energy cost. **Methods:** This work proposes a Popularity-driven Caching and Mobility adaptive query Searching (PCMS) to achieve the constraints. The PCMS consists of Cache Node selection, popularity and data size driven replacement (POP) algorithm and mobility adaptive searching for cache data. With the aim of reducing the access delay of popular data, the PCMS selects a node that is closer to the destination in a route to cache the frequently requested data item and serves the future requests. The PCMS takes into account the data popularity and size to decide caching and replacement policy and thus significantly improves the performance of caching. The mobility adaptive searching for cache data looks for an item in Query Directory (QD) nodes and redirects the request to the concerned caching node. It updates the cache information at QD by adhering to the mobility prediction scheme. **Findings:** The PCMS considers the data popularity and size as key factors to decide caching and replacement policy for the better utilization of cache memory. The PCMS has successfully reduced the network traffic and improves the Cache Hit Ratio by adhering the mobility prediction based update scheme. **Applications/Improvements:** The proposed system achieves appreciably better performance in simulation than the existing caching systems by utilizing minimum battery power, bandwidth and access delay.

**Keywords:** Cache Replacement, Mobility Adaptive, Mobile Ad Hoc Network, Popularity Based

## 1. Introduction

Data caching plays a significant role in improving the efficiency of information access in Mobile Ad Hoc Networks (MANETs)<sup>1</sup>. Data access from distant source nodes for every request is a serious problem. Cache Nodes (CNs) store the data in its memory temporarily and recover it when requested by others. Caching helps in reducing communication delay which result in saving bandwidth as well as battery energy. Existing cooperative caching schemes describe caching of the data item by multiple nodes in the network for improving the accessibility of

data items. However, data caching is a complicated task due to two reasons. Firstly, MANETs are multihop networks without any central base station. Due to dynamic mobility and lack of central authority, networks are partitioned into independent networks when implementing the caching techniques in MANETs for data communication. Hence, access to data from Cache Nodes gets cut off.

Secondly, the MANET is resource constrained in terms of channel bandwidth or battery power. The data replacement is exploited to cope up with the energy consumption in caching and this technique has received much attention in caching. However, most of the

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techniques on cache replacement strategies are limited to infrastructure based wireless networks in which the mobile nodes communicate with the base station which generates invalidation reports for the cached data items and broadcast them frequently to the Cache Nodes<sup>2,3</sup>, but not suitable for energy constrained infrastructure-less MANET. Moreover, some of them proposed for MANET assume that the caching update takes place much faster than the network topology change due to unpredictable node mobility. However, it is not suitable for energy constrained MANET.

Some of the caching techniques utilize the Query Directory (QD) nodes and the role of QD is to redirect the submitted queries by the requesting mobile node to the Cache Node<sup>4</sup>. The Cache Node performs the task of giving a response to the query presented by QD to the requesting mobile node. This scheme is mainly focused on cache invalidation to improve the efficiency of caching. Instead of distributing the invalidation message to all the nodes in the network, simply it is forwarded to the QD among one of the nodes in the network and the QD takes that responsibility to distribute invalidation messages to the concerned Caching Node. This organization reduces the network traffic and also updates the process efficiently. However, during cache update phase the traditional techniques follow constant interval for update by viewing the topology as static, but this mechanism is not applicable for real-time topology. This work proposes the Popularity-driven Caching and Mobility adaptive query Searching (PCMS) system for balancing the energy consumption and access delay of data over MANET.

## 1.1 Contributions

- The proposed PCMS aims at the caching and reducing the access delay of popular data over MANET, by selecting an optimal Cache Node and accessing the desired data from the nearest cache.
- Reducing the data searching space and implying a substantial energy cost, the PCMS caches the frequently requested or popular data and redirects the queries from query directory nodes to the corresponding Cache Node.
- Compromising with hit ratio and energy consumption, the PCMS accommodates the newly arrived popular data item by evicting some of the cached data items according to the popularity and data size.
- Reducing the overhead and increasing the lifetime of energy-constrained mobile nodes, the PCMS provides

mobility adaptive query directory update phase which optimizes the frequency of cache update in cache and query directory nodes.

Several data cache algorithms have been proposed for MANETs<sup>5,6</sup>. Even though data caching enhances the efficiency of wireless data access, it is essential to deal with the cache replacement and invalidation in the dynamic network topology. Moreover, while caching, the query processing is the most recognizable task and it is maintained to provide immediate response for query node. The memory of the query node is not sufficient for caching all the data and therefore, the selection of popular data is necessary for efficient cache usage.

## 1.2 Data Caching Algorithms

Cooperative caching is an effective approach to enable multiple nodes to cache the same copy and reduce data access cost in MANETs. Extensive research work has been conducted for cache discovery<sup>7</sup>, which combines the passive and active query technique. The technique imposes a cluster-based hierarchy on MANET and focuses on constructing the hierarchy and discovering the nearest Cache Node present inside and outside of the clusters. The Global Cluster Cooperation (GCC) caching reduces the cache discovery overhead and access delay while providing better cooperative caching performance. The caching algorithm<sup>8</sup> attempts to solve the problem of openness feature of wireless links by considering the contention status of the link during Cache Node selection. More precisely, the access delay of these Cache Nodes is measured regarding contention caused by concurrent requests. In<sup>9</sup>, the Voronoi diagram based cooperative cache discovery mechanism limits the update frequency of cache information in a single Voronoi diagram and reduces the data access cost. The caching policy proposed in<sup>10</sup> takes into account the remaining energy of a node for cooperative caching decision and data replication. It exploits the strengths of both Cache Data and Cache Path and facilitates caching decisions at intermediate nodes. Also, it efficiently balances the data access delay and energy consumption of the nodes in the network. To limit the energy consumption, the replication schemes<sup>11,12</sup> allow only two replicas of the data item and also its index in the query directory. The cache and query directory nodes are chosen according to the node density<sup>13</sup> and cost minimization model, but not considering the node mobility.

### 1.3 Cache Invalidation Techniques

Distributed Cache Invalidation Mechanism (DCIM)<sup>14</sup> is a pull based algorithm and it exploits the adaptive Time To Live (TTL) to perform the correct update and efficient replacement. With the DCIM, frequently accessed items are pre-fetched and it adapts the TTL value using opportunistic validation requests. The adaptive validation requests refresh a set of data items based on the popularity. In contrast to DCIM<sup>14,15</sup> optimizes the cached route TTL according to the node mobility and data traffic. It minimizes the routing overhead by developing a numerical model for determining the optimal route cache TTL. A push-based replication scheme<sup>16</sup> propagates the updates to cache and query directory nodes and it also utilizes the advantage of pull-based caching for establishing communication between client and server. Full replication of the indices of data items in the query directory and two partial replication of the data items improve the efficiency of caching technique. The Consistency based Data Replication Algorithm (CDRA)<sup>17</sup> considers the factors of data consistency, load balancing and data availability in modeling the data replication algorithm. By allowing the sharing and coordination of cached data among multiple nodes, the cooperative caching technique<sup>18</sup> solves the connected facility location problem which formalizes the optimal cache placement. A holistic caching framework, SplitCache<sup>19</sup> enables a node to cache the frequency of access of the data item and their presence in the network and it takes the cache size as an important factor for leveraging data caching in an energy constrained MANET. Finding an appropriate update interval is necessary for reducing the misrouting overhead<sup>20,21</sup>. The server based consistency scheme<sup>22</sup> adapts the data update according to the popularity of data and handles disconnections of both the cache and query directory nodes. However, the conventional works consider only the mobility model and system characteristics but fail to investigate the influence of the mobility. The agent based consistency technique<sup>23</sup> maintains a log in the client and server. The information related to each client data cache is maintained in the server log which is used by the server agent to send update information. The client agent keeps monitoring the broadcast value and updates itself. This system invalidates the existing data and maintains cache consistency. There are three models proposed in this paper. Thread Based, Multiple Server Based and Cluster Based cache consistency model.

## 2. Problem Statement

There are many constraints in MANET such as dynamic mobility, limited battery power, limited memory space and bandwidth. Storing of all access data items in cache leads to insufficient memory problem and also consumes more battery energy. Nowadays, because of the unexpected growth of the wireless networks and non-infrastructure network, the same data is being distributed to most of the nodes from source nodes. The task of accessing data from the Cache Nodes and its maintenance in query directories becomes the major problem in the highly dynamic network topology, because the random mobility of the node in the network leads to frequent topology changes. The efficient caching scheme is essential to withstand under mobility. The cache replacement and invalidation are performed according to the popularity of the data item. A cache replacement policy has to be adopted to evict data from the cache according to the popularity and data size when new data arrive. Caching a large sized data in multiple nodes is likely to reduce the performance of routing protocol in MANET. Moreover, an efficient caching scheme must reduce the average number of hops between the requester and the node that has the requested data. Thus, the proposed work takes into account both the popularity and size of cached data in nodes for cache replacement and provides mobility adaptive query

## 3. Overview of the Proposed Work

The PCMS includes three components such as Selecting Cache Nodes for Popular Data, Popularity and Data Size-driven Cache Replacement and Mobility Adaptive Searching for Cache Data. Firstly, the Cache Node selection algorithm efficiently discovers and caches the requested data items from most of the nodes. When a node forwards several requests for the same data and different destinations, that node is selected as a Cache Node. The PCMS extracts the frequently requested data item from routing information and evicts the lesser amount of requested data for effective usage of the cache memory of the node. Secondly, the Popularity and Data Size-driven Cache Replacement takes into account the data popularity and size to decide on what data items to be cached and when it has to be replaced to improve the performance of the PCMS system. This decision making renders a clear utilization of cache memory. Thirdly,

the Mobility Adaptive Searching for Cache Data looks for an item in QD nodes, which receives a request from mobile nodes and redirects the request to the concerned Caching Node. This process successfully reduces the network traffic by adhering to the mobility prediction based update scheme.

### 3.1 Selecting Cache Nodes for Popular Data

Accessing the data frequently from a distant source node is a serious problem in an energy constrained MANET. The caching technique enables one or more intermediate nodes to store the popular data and to serve future requests, instead of fetching data from the distant source node. Thus, it minimizes the traffic and access delay of popular data in the network. The main challenge in data caching is to select the optimal Cache Node for a popular data item.

In PCMS system, each router maintains a field for popularity entries of particular data and  $D_i$  finds the Cache Node in an efficient manner. The routing layer enables the router to attach the popularity entry of  $D_i$  in each RREP packet. The popularity entries of a router demonstrate the number of times the data  $D_i$  have accessed through it for distinct destinations. The new access of a data  $D_i$  through the same router increases the entry by one. On observation, it is not an efficient entry to increase the popularity entry for two different Route REPLY (RREP) packets with the same destination ID because the data that is a popular one, only when multiple nodes frequently access it. The source decides the router which has attached high popularity entry in the RREP packet as a Cache Node for a corresponding data  $D_i$ . Initially, the source node transmits the data packets to one or more destinations with the sign of Cache Node. Thus, the nodes in the selected paths know about the Cache Node and the others need not store the

data in its local cache. The Cache Node stores a Data item ( $D_i$ ) that are requested by most of the nodes in its memory temporarily. For instance, the same data item both M7 and M10 request  $D_i$  in M1 through M8 and the node M8 is selected as Cache Node by source node M1. The M8 caches the data item and if it receives the request for data item  $D_i$  through any one of the nodes in future, it is served by M8 and there is no need to get it from the source node.

#### 3.1.1 Fast Data Access via Query Directory

Instead of storing both the data items and their queries in Cache Nodes, the PCMS exploits the QDs to store the queries and also associate these queries with the nodes that cache the corresponding data item. The main aim of the QD node is to take the responsibility of redirecting the requests of mobile nodes to the concerned CN. To reduce the access delay of popular data in the network, the identifiers of the query that is stored in every CN node is transmitted to the QD periodically. In the selection of QD, the network is divided into four equal quadrants. In each quadrant, a node that has high-quality attributes including high memory space and the remaining energy is elected as a QD. Initially, every node broadcasts the control message to initiate the QD election within the quadrant of the network area. In this technique, every node floods the attributes with their ID to the local neighborhood and the packet has a TTL value of  $h$  number of hops. The node that receives high votes is elected as a QD. After the QD selection, the ID of QD is broadcasted to all nodes in the corresponding quadrant with similar TTL value. This algorithm is executed in each quadrant of the network periodically.

#### 3.1.2 Inter and Intra Quadrant Query Directory Update Phase

For Cache Management, the PCMS attempts to coordinate the query caching and data retrieving mechanisms effectively while minimizing the communication cost among QDs. For giving priority to the cache data items as primary and secondary, two rules are applied such as inter-category rule and intra-category rule. Inter-category of QD gives priority for primary or data items stored in its quadrant CNs rather than secondary data items (data from other quadrants). Each CN sends the query details to the QD when it is changed and each QD exchanges their list with others for every max-interval. The periodicity of inter and intra QD updating is controlled to reduce the overhead. The QD executes the Cache Discovery

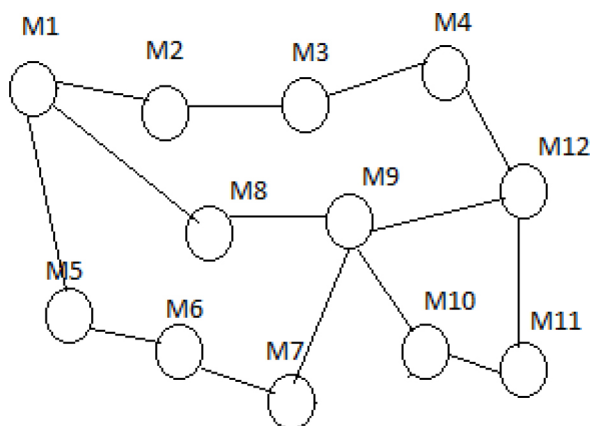


Figure 1. Mobile Ad Hoc Network.



algorithm to deliver the requested data item from CN nodes to the corresponding destination efficiently when it receives the data request. For requested data item, QD first checks in its local cache, if the requested item is found in the cache, then it intimates the CN, otherwise looking into the cache of the neighboring QD that it redirects the data request to the corresponding CN in some other quadrant.

### 3.2 Popularity and Data Size-driven Cache Replacement

The primary problem is that the caching node does not have enough memory to store the large data item and store the most popular item requested by most of the nodes in one or more intermediate nodes lead to insufficient data storage. To overcome these problems, the PCMS introduces the POPularity (POP) algorithm. In the POP algorithm, the data items are classified depending on the access frequency of the data item. The data item is classified into popular and ostracized data item. Nodes in the network mostly request the popular data item and conversely ostracized data items are not accessed frequently. Because of limited memory space in MANET, the PCMS gives preference to popular data items for caching. When the cache is full and new data is waiting for caching, the cache replacement algorithm is used to replace the unwanted data item with the new data item. Thus, the separation of the unwanted data item is not a trivial task and it is performed by taking into account the data popularity and size.

The separation of popular and the ostracized data item is accomplished by finding out from the popularity entry field. Saving the most appropriate data item is called as a popular data item. During the execution of the POP algorithm, weight is provided for both popularity and size of the data item and cost of cache data is measured using the Equation (1). Where, the values of weights W1 and W2 are 0.6 and 0.4 respectively. Finally, the PCMS system replaces the high-cost data items rather than randomly removing the data item from the cache.

$$\text{Data cost} = W1 * (1 / \text{Popularity}) + W2 * (\text{Data size} / \text{Memory of Cache Node}) \quad (1)$$

The PCMS focuses on maintaining popular and small sized data item in the cache. When a new data item is placed in the cache of any node, the POP algorithm optimizes the data replacement concept and improves the performance of PCMS system.

### 3.3 Mobility Adaptive Searching for Cache Data

In a highly dynamic network topology, the cache maintenance is tedious. To optimize the performance of PCMS system, the update phase of the inter and intra-quadrant query directory need to be adjusted based on the topology changes. When a CN moves to other location, PCMS enables the CN to remove the cache list. Moreover, the QD corresponding to the mobile CN informs others to remove the stale information. If a mobile node is a QD, it has to hand over the query table to the new QD in the quadrant. In mobility prediction mechanism, the frequency of query update adapts packet generation rate based on the node mobility. Thus, it withstands under high mobility and provide accurate data delivery while balancing the energy consumption. However, during a small movement of CN, no need to delete the cached data in CN. To overcome this, the PCMS introduces the cache retention time. At the cache retention time, information stored in the cache remains unaltered under the little movement scenario. However, static retention is not possible due to the rapid topology changes of the network. Dynamic retention time is designed to achieve a high hit ratio with low access latency. When CN enters or leaves the network is predicted by the neighboring QD node. The QD illustrates the coordinates of others and CN as a time series for velocity and direction. The QD creates an ideal mobility model for CN using the previous location reported by the CN. The position of the node is predicted from the past moving direction and velocity as shown in the Equation (2).

$$G(L) = K + \sum_{i=1}^h \psi(i) * G(L-i) + \xi(L) \quad (2)$$

This formula is used to estimate the current location of CN from the previous location information. It estimates the current location of the node from a series of the weighted linear sum of past h terms observed from historical data. Where h is the length of the series,  $\psi(i)$  is an auto degeneration coefficient,  $\xi(L)$  is Gaussian coefficient and K is constant. The CN deletes the data and QD deletes the information regarding the CN when the CN moves for a long distance. In the case of prediction error, the CN announces its presence to the corresponding QD using hello packet. Moreover, the mobility impact of QD is overcome by selecting a high-quality neighbor node as new QD. The new QD announces its ID to the entire quadrant. Finally, the proposed system achieves appreciably

better performance by utilizing both the popularity and data size, driven by cache replacement and mobility adaptive query update phase.

## 4. Simulation Setup and Results Analysis

The performance metrics of caching algorithms under various constraints such as node density and mobility have been simulated using NS2. The performance of the proposed PCMS is implemented on Destination sequenced distance vector (D-PCMS) protocol and it is compared with the Overhearing-based Data Caching (OHB)<sup>18</sup> based DSDV (D-OHB). The simulation is determined by a trace file and performance of the system is compared to node density and mobility. The network simulator-2 is used to simulate the functions of cache and query directory nodes to extract the popular data item based on routing information. During cache replacement, the unwanted large sized data items are replaced rather than a popular data item that is requested by most of the nodes and also simulate mobility adaptive query update under random mobility model. The number of nodes varies from 10 and 50 and simulation is executed for 80 seconds. The speed of the nodes ranges from 10 m/s to 30 m/s. After the mobile node reaches its destination, stops for a short period (pause time), then, again randomly selects a destination and proceeds further until the simulation ends. Pause time is set at 20 seconds. The simulation Table 1 shows the values of simulation parameters.

**Table 1.** Simulation Model

Simulation Parameters	Values
Number of Nodes	10-50
Network Size	500m x 500m
Nodes Transmission Range	100m
Node Speed	10-30 m/s
Node Pause Time	20 sec
Node Initial Energy	300 Joules
Number of Data Items	100
Routing Protocol	DSDV
Transport Agent	UDP
Application Agent	CBR
Mobility Model	Random Way Point
Simulation Time	100 Sec

### 4.1 Performance metrics

The performance of the proposed caching is evaluated for the performance metrics such as Cache Hit Ratio, Energy Consumption, Average End to End Delay and Average Query Message cost

#### 4.1.1 Cache Hit Ratio

It is defined as the ratio of the number of successful requests to the total number of requests. A high hit ratio is obtained when the response is obtained immediately for requested data without any interception and a lesser number of hops.

#### 4.1.2 Energy Consumption

Energy consumption is the average energy consumed by the nodes in the network.

#### 4.1.3 Average End to End Delay

Average end to end delay is the average time taken for a data item to reach its requested node.

#### 4.1.4 Query Message Cost

Query message cost is the ratio between control messages used for retrieving the data item and the total number of data packets. If a query hits in the cache of same requesting node, the cost is equal to the number of control messages used for data update. Otherwise, the cost is equal to the ratio of a total number of control messages transferred to the total number of data messages routed.

### 4.2 Simulation Results

#### 4.2.1 Cache Hit Ratio

Figure 2 shows the comparative performance of the proposed D-PCMS with D-OHB by varying the number of nodes from 10 to 50. The Cache Hit Ratio of both the protocols declines when increasing the nodes. The difference in Cache Hit Ratio becomes apparent with a huge number of nodes. The periodic local and network-wide data update messages in D-OHB saturates the network capacity and reduces the successful delivery of data update messages as well as Cache Hit Ratio, especially in high traffic network scenario, since the nodes fail to overhear the packets. Compared to D-OHB, the D-PCMS updates the cache information adaptively using the mobility prediction technique which reduces the cache overhead

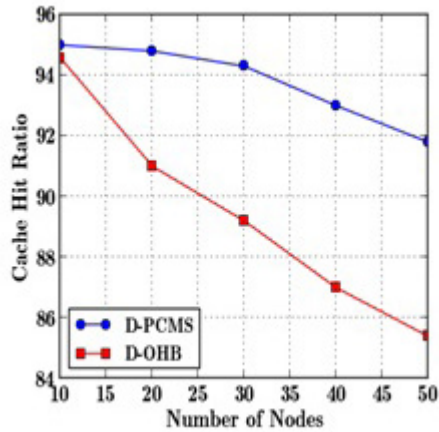


Figure 2. Number of Nodes Vs Cache Hit Ratio.

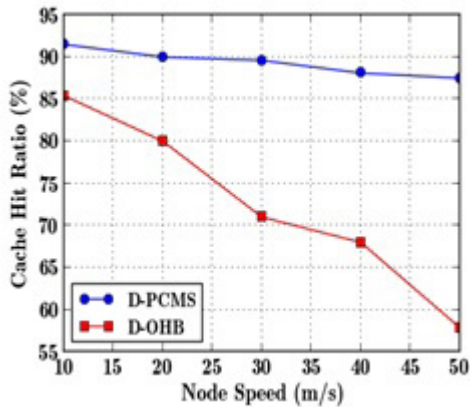


Figure 3. Node Speed Vs Cache Hit Ratio.

while improving the cache hit ratio. For instance, when the number of nodes is 10, the Cache Hit Ratio of D-PCMS and D-OHM are closer to 95%, however, the D-OHM decreases by 6.8% when the number of nodes is 50. In a low-density network scenario, the nodes can easily identify the popular data and its validation and thus, it increases the Cache Hit Ratio. When the number of nodes increases, the nodes are likely to fail to capture the update messages for popular data due to network congestion.

In Figure 3, the proposed D-PCMS and the existing D-OHM protocols are compared by varying the node speed from 10 m/s to 50 m/s. Figure 3 shows the result of Cache Hit Ratio. In a MANET, mobile nodes vary dynamically and cause frequent topology changes. Cache Hit Ratio is the ratio for quick access to data from Cache Node. The D-OHM is not sufficiently adept under dynamic mobility;

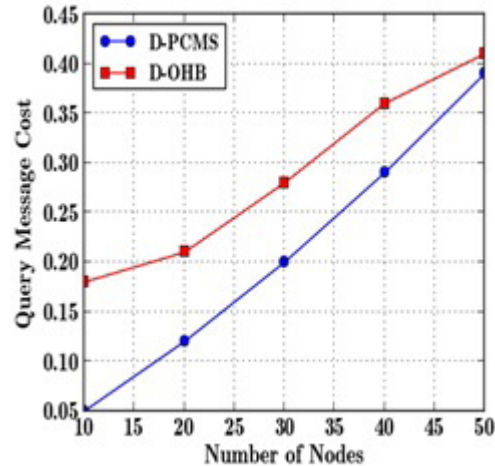
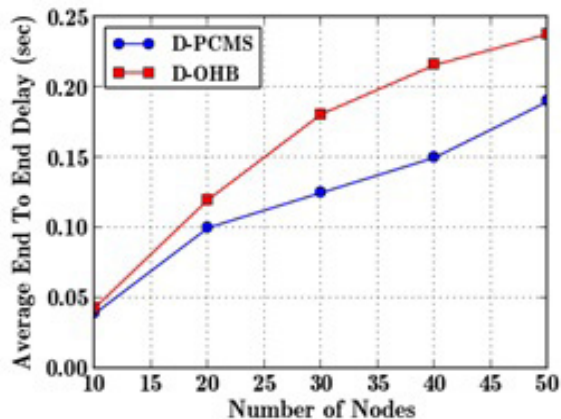


Figure 4. Number of Nodes Vs Query message Cost.

a low Cache Hit Ratio is obtained because of update messages of cached data for cache and the query nodes take a long time. In the proposed approach D-PCMS, the Caching Hit Ratio increases because of auto update of its own and query directory node information in the network. Even under random mobility of the nodes, D-PCMS manages dynamic mobility and also obtains cache update messages properly when compared to the existing D-OHM. D-PCMS increases the Cache Hit Ratio significantly, for instance, the D-PCMS attains 91.5% of Cache Hit Ratio, whereas the D-OHM manages to reach 85%.

#### 4.2.2 Query Message Cost

In Figure 4, the proposed D-PCMS and the existing D-OHM are compared by varying the number of nodes. The query message cost of both the protocols increase as the number of nodes increases. In the low-density scenario, the D-PCMS algorithm performs better than D-OHB. However, in high dense network D-PCMS cannot place data copies in multiple nodes, so query message cost escalates for each request for data access. The query message cost includes the direct control messages for data forwarding and delivering the reply, as well as the message cost of updating the cache information. An efficient cache placement algorithm of D-PCMS introduces mobility adaptive cache additions and deletions, which certainly reduces additional message cost. However, when the number of nodes increases, the message cost becomes costlier due to location error and thus it attains the query message cost similar to D-OHM. For instance, the D-PCMS reaches the query message cost of 0.05. However, the D-OHM reaches 0.18 when the number of nodes is 10.



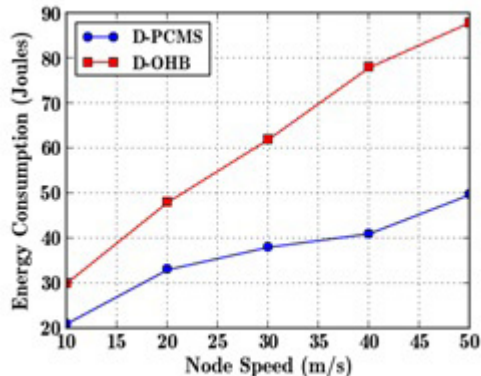
**Figure 5.** Number of Nodes Vs Average End To End Delay

### 4.2.3 Average End To End Delay and Energy Consumption

Figures 4 and 6 evaluate the impact of dynamic network topology on the D-PCMS protocol performance in terms of delay and energy consumption by varying the number of nodes and node speed respectively. In existing D-OHM routing technique, the delay is intended for responding to the data request. However, the delay prolonged when the number of nodes gets increased because of the overhearing failure. Nevertheless, the proposed D-PCMS reduces the access delay rather than existing caching since there is automatic updating of cache information based on moving direction and velocity. Thus, a precise caching is established to reduce the access delay of the network. In D-PCMS, due to the prediction of nodes mobility and position by a mathematical computation, there is a less chance for transmitting the update messages for cache and query directory nodes. This technique successfully reduces the energy consumption in D-PCMS. For instance, the energy consumption of D-PCMS is 30 joules, when the node speed is 10 m/s, whereas the energy consumption of D-OHM has increased by 43% more than that of D-PCMS when the node speed has been 50 m/s.

## 5. Conclusion

This work proposes an efficient PCMS, a caching technique for reducing the access delay while improving the energy conservation over MANET. By discovering the Cache Nodes, data items requested by most of the nodes



**Figure 6.** Node Speed Vs Energy Consumption.

are cached as well as the query directory nodes store the queries associated with the Cache Nodes. The cache memory of a mobile node is effectively used by extracting the frequently requested data item from routing information and evicting the lesser amount of requested data in PCMS. To decide what data items to be cached and when it has to be replaced, the PCMS takes into account the data popularity and size and thus, it offers a better utilization of cache memory. The proposed scheme has effectively reduced the network traffic and improves the Cache Hit Ratio significantly by supporting the mobility prediction based update scheme. The proposed PCMS is integrated with the DSDV protocol to analyze the performance using the NS2 simulator. The simulation results reveal that the proposed D-PCMS is suitable for data caching over dynamic network topology.

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