Movement synchronization for improving File-Sharing efficiency using bi-directional recursive data-replication in Vehicular P2P Systems

Constandinos X. Mavromoustakis
Department of Computer Science,
University of Nicosia
46 Makedonitissas Avenue, P.O.Box 24005
1700 Nicosia, Cyprus
mavromoustakis.c@unic.ac.cy

Muneer Masadeh Bani Yassein
Jordan University of Science and Technology,
P.O. Box 3030,
Irbid 22110, Jordan
masadeh@just.edu.jo

Abstract—**Recent research in opportunistic networks address the diffusion policy and the practicality considerations in utilizing device-specific applications. Intermittent connectivity between mobile nodes and the random behavioral patterns of the users, make modeling and measuring the performance of opportunistic networks very challenging particularly in the case of file/object sharing among these devices. As the cache-and-forward replication policy plays a major role targeting the availability of requested resources, there should be a mechanism for controlling the minimization of the redundant replicas and the uncontrolled diffusion effects onto the communicating nodes. In this work the diffusion policy of requested replicated objects is examined with regards to the probabilistic synchronized movement of the devices, quantifying the parameters that affect the reliable transmission and the availability of requested resources by any node. The assigned scheme takes into consideration the movement synchronization of the moving devices and applies a recursive adaptive caching cooperation scheme in community-oriented relay regions. The scheme also uses the Message Ferry (MF) mobile Peer in a bi-directional mode, in order to enable higher degree of reliability in the availability of the requested resources. Conducted simulation experiments using real-time traffic traces show that the proposed scheme offers high throughput and reliability response for sharing resources on-the-move while it minimizes the redundancy of replications.**

Keywords- bi-directional recursive data-replication; partially synchronized mobility scheme; object sharing scheme; reliability and availability of resources; resource exchange efficiency; evaluation through simulation.

I. Introduction

On-the-move reliable resource exchange has been a fertile ground for enabling researches to explore further techniques for successful resource diffusion according to users' demands. In this direction a catalytic factor has been the Wireless technologies growth which represents another orthogonal area of growth, in both wide-area applications like 2.5G/3G and local area applications like 802.11b/g and Bluetooth. Many constraints exist in such networks like resource availability whereas the topological scheme followed in these infrastructures should be combined with the availability of the requested resources and the time-access for sharing resources with the synchronized motion within a specified time duration *t*. A Vehicular Ad-Hoc Network (VANET) is a technology that uses moving cars as devices/nodes in a dynamically changing network to establish a mobile network connectivity. In this paper a reliable file sharing scheme for vehicular Mobile Peer-to-Peer (MP2P) devices is proposed taking the advantages of moving devices within a specified roadmap with different pathways like in real time vehicular networks. This work exploits the movements of the devices and the passive device synchronization to increase end-to-end file sharing efficiency through vehicular users [1] and Mobile Infostations [1][3]. Through geographical roadmaps landscapes where mobile Infostations are set and initialized, the passive synchronization enables through the replication policy to create a replicated object in order to establish reliable file sharing. Role-based Mobile Infostations (MIs) are selected based on their velocity, residual energy, remaining capacity etc and are assigned according to the passive Message Ferry peer. This scheme proved its robustness in node's density since it does not require the knowledge and the global figure of the number of users. Additionally it does not require spatial distributions to efficiently spread information while enables reliability in supported mobility without the scheduled 'rendezvous', whereas it effectively passes the requested replicas to designated users.

The organization of the paper is as follows: Section II discusses the related work that has been done on similar schemes which use similar approaches for establishing and maintaining end-to-end file sharing efficiency. Section III then introduces the proposed model based on [1] where instead of using a uni-directional replication mechanism as in [1], this work utilizes a bi-directional recursive data-replication mechanism for opportunistically connected vehicular P2P Systems. The proposed mechanism optimizes significantly the work done in [1] by using the movement exploitation in a synchronized form, to increase end-to-end file sharing reliability and hosts a stochastic measure to estimate the end-to-end capacity within the path where the requested replicas were created. Section IV shows the experimental simulation-based performance evaluation of the proposed scheme and the comparisons done under different convergent parameterized conditions. Particular focus was given to the impact of certain probabilistic movements made by Vehicular-Peer-to-Peer (VP2P) devices where multi-client applications, dynamically demand resources directly from certain nodal vehicles on-the-move. The stochastic model introduced in [1] is being used measuring the end-to-end capacity and the dynamic caching activity of the requested objects onto opportunistic neighboring devices. In addition the proposed model takes into consideration a number of parameters, in order to limit the potential inadequacies of resource sharing process due to intermittent connectivity, whereas through these parameters it enables further accuracy in the resource sharing process. A resource assignment cooperation engine is hosted under the proposed framework considering the proposed Go-back-N caching cooperation scheme taking place in a bi-directional mode using cluster-based approach with ranked requests.

II. RECENT SCHEMES AND WORK DONE

Mobile resource sharing policy needs to be supported by a reliable mechanism which will guarantee the resource exchange in an end-to-end available manner. A great amount of research effort has been invested to facilitate mobile applications in the last few years hosting approaches that can be categorized into three types: network layer–based approaches, transport layer–based approaches, and proxy-based approaches. A significant and common goal of these approaches is to maintain the connectivity for mobile users even when they perform vertical handoffs between different networks [2]. As mobility in opportunistic and autonomic communication is an essential parameter and along with the user's demands they pose the vision of what self-behaving flexibility should encompass in next-generation self-tuning behavior [1], the resource exchange apparatus should guarantee the consistency and reliability by using assisted mechanisms using resilience metrics [2] for enabling delay sensitive resource sharing. The capacity of the nodes which are traversed in the requested path, can be reduced significantly particularly if we are dealing with delay sensitive traffic or bursty traffic [1] whereas the underlying end-to-end supporting mechanism should be aware of the dynamic movements in a Peer-to-Peer manner. Obviously, if the transmission-range of a node increases, then the interference it causes will increase and probably the number of nodes which will have copy/copies of the packets that should be forwarded, will increase. Toumpis and Goldsmith [4] define and study capacity regions for wireless Ad-hoc networks with an arbitrary number of nodes and topology. These regions describe the set of achievable rate combinations between all source-destination pairs in the network under various transmission strategies for EC content sharing and power control. In this work we consider the capacity but in an end-to-end path-request manner, and take into consideration the variations caused by the dynamic movements of the devices/vehicles. Most existing architectures (including Grace [5], Widens [6], MobileMan [7]) rely on local information and local devices' views, without considering the global networking context or views which may be very useful for wireless networks in optimizing load balancing, routing, energy management, and even some self-behaving properties like self-organization.

Further to the research work done in [1] where, author associates the synchronized movements and the related connectivity aspects among vehicles, this work proposes and utilizes a scheme where the end-to-end file sharing efficiency, increases in vehicular MP2P devices. The scheme in [1] extends the advantages offered by the Hybrid Mobile Infostation System (HyMIS) architecture proposed by Mavromoustakis and Karatza, in [8], where the Primary Infostation (PI) is not static but can move according to the pathway(s) of the roadmaps. HyMIS adopts the basic concept of pure Infostation system in terms of capacity service node but it avoids flooding the network with unnecessary flow of information (redundant diffusion of unnecessary resources). This node plays a role of control storage node (backup capacity node) as Haas and Small mention in [9]. Taking the advantages of the proxy caching [10] and the cache-and-forward apparatus work done [2] this work proposes an exploitation of the mobility characteristics of each user by utilizing the MI peer to be dynamically selected according to characteristics such as the residual capacity of the device based on the push-based activities by other nodes. Additionally with the work done in [1] the innovating research aspect is that the proposed resource assignment cooperation scheme enables the caching mechanism to affect the degree of reliability using the variable window size into the requested replicas by N-hop peers. The proposed Go-back-N caching cooperation scheme takes place in a bi-directional mode in order to enable availability of requested resources (ranked requests) by certain peers in the community cluster. Heavy emphasis of this work has been put on push-based dissemination explored in [9] by Little and Agarwal, and in [12] by Lochert et al, and analytical dissemination through vehicle-to-vehicle propagation proposed by Wu, Fujimoto and Riley [13] as well as on some recent findings on practical systems as in [14] [18] by Lee et al, and Mahajan et al respectively, for pull-based diffusion activities. The proposed cache-and-forward replication scheme targets the availability of requested resources by using an index-based mechanism which will enable the selection of the *MI* in a formed cluster *L* (as in [1]). The following section explores the passive synchronized mobility model in the end-to-end path and presents an analytical model for the end-to-end capacity estimations.

III. CACHE AND FORWARD COOPERATION SCHEME USING SYNCHRONIZED MOBILITY AND CAPACITY CONSIDERATIONS MODEL

A. *Communicating scheme in Vehicle-to-Vehicle communications*

The interactions with roadside equipment for exchanging resources can be characterized accurate, whereas most vehicles have restrictions in their range of motion. As an example vehicles cannot follow other vehicles and they are subject to constraints for following a certain 'caravan' of vehicles in a highway. Therefore resource sharing can be performed using any web technology -pure Infostations approach [1], [2]- available in the car. According to recent literature [15] [16] for a better delivery ratio and in order to reduce broadcast storms, a message has to be relayed by a minimum of intermediate nodes to the destination. In order to have this achieved, nodes are organized on a basis of a set of clusters, in which one node or more (Cluster Head) gathers data in his cluster and send them after to the next cluster. By using cluster-based solutions for disseminating the requested information into a "locally" limited number of nodes (that potentially will maintain their connectivity for time t (according to the path followed in the roadside)), these solutions provide less propagation delay and high delivery ratio with also bandwidth equity. In [14] the authors use a distributed clustering algorithm to create a virtual backbone that allows only some nodes to broadcast messages and thus, to reduce significantly broadcast storms. As recent studies have reported that intermittent network connection is inevitable for mobile users on a daily basis [15] [16] [17] have also shown that network capacity can be increased dramatically by exploiting node mobility as a type of multiuser diversity. As a result the opportunistic nature of the ad-hoc connections can be useful for "virtually" extending the coverage of wireless communications by using the notation of the cache-and-forward replication policy. There are two distinct approaches that allow mobile users to request and transfer data on the go: namely, the cache-based approach or the static Infostation-based approach. Cache-based approaches facilitate mobile file transfer by prefetching popularly requested files (e.g., commercial ads, movie trailers, and song previews) to a local storage. In this work the cluster's local storage is provided with a role that is being utilized and processed by any node within the virtual cluster. The Infostation-based approaches, on the other hand, support on-demand FTP requests by deploying dedicated servers as bridges between the Internet and mobile networks. However, the capability of these approaches for mobile file transfer is limited because they are basically centralized and have non-autonomic control over the resource sharing process, and as a result they fail to exploit and reflect the diversity and properties of network mobility.

This work uses the cache-oriented apparatus to facilitate mobile resource sharing/file transfer by prefetching popular requested files for a certain time duration onto any other nearby node within a specified number of hops. A significant aspect of the reliability and the availability of the requested resources in wireless systems, is the sudden partitioning of the connectivity, namely intermittent-connectivity experienced by nodes. This work differs from [1] in the sense that it combines the strengths of cache-based approach (i.e., prefetching the most likely requested files to a local storage, Figure 1) in an adaptive way by considering a window size model for estimating scheduled retransmissions of the requested file chunks. In addition the model considers the relay epoch and the mobility considerations for each node in the k-hop path for efficient end-to-end dissemination, and to further utilize the opportunistic communication in a reliable manner.

In order to avoid any sudden -unpredictable- network partitioning problems and prevent the exchange of any requested information a cache-based approach replication policy is used. Requested object replication [12] [27] and replicas redundancy [9] face the requests' failures whereas they create severe duplications. However these approaches aggravate the capacity of the end-to-end path whereas, as the path remains relatively small in terms of hops, these approaches can face the resource sharing problems adequately. On the other hand if the path is 'long' hosting many hops then the redundancy of duplications of the requested packets, aggravates the system's performance geometrically with the number of hops [24]. Considering all the extracted factors above this work enables the resource sharing process to be performed via the the Passive Opportunistic Synchronized Approach (POSA) [1] using a certain likelihood for this resource synchronization. Figure 2 shows the vehicular P2P resource sharing process using the push and pull procedure in a certain path. The scheme uses the Passive Opportunistic Synchronized Approach in order to share resources and enable duplications to nearby requesting nodes(nodes that are requesting certain resources/i.e.,file).

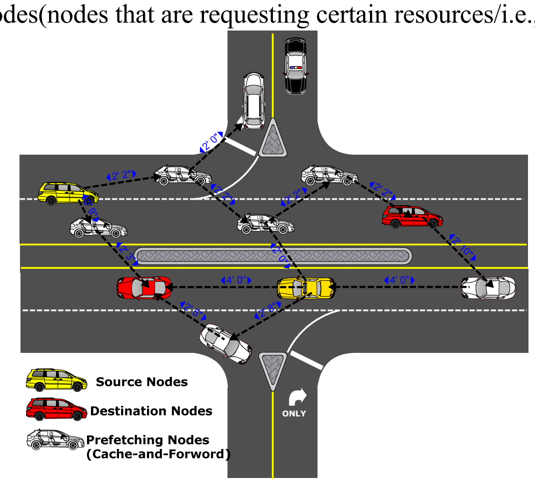

Figure 1. Cache-and-Forword (Prefetching configuration) of popularly requested file chunks for a certain time duration onto any other nearby node within a specified number of hops for Vehicular MP2P devices while moving in probabilistic paths.

Any vehicle/device can communicate directly with any other vehicle within the transmission range of each device. Therefore on a hop-by-hop basis each vehicle can push and pull information using the transmission channel of each node that it communicates. The system environment is assumed to be a dynamically changing MP2P network where mobile hosts access data items held as originals by other mobile hosts. Data items are periodically updated and ranked according to the ranking criteria of the intercluster and intracluster requests [8] [21] [28]. Each mobile host creates replicas of the data items which were highly ranked, and keeps the replicas in its memory space. When a mobile host issues an access request for a data item, the request is considered as successful in either case: (a) the request issue host itself holds the original/replica of the data item or (b) at least one mobile host (which is not directly necessarily connected) has the file (packets) of a replica of it. Figure 2 also shows the proposed vehicular MP2P *push* and *pull* procedure where the *i-th* vehicle is assigned as MI and can pull requested resources to *i-1, i-2, i-3, i-k*, whereas the vehicle which the MI follows can then push any of these resources to the $i+1$, $i+2$, $i+MI_k$ vehicle (dash lines denote the push procedure which takes place and solid lines denote the pull procedure). Both procedures take place until the next and preceding MI is reached while *i-th node* is sharing resources, respectively. These notations can also be seen in a more clear form in the Figure's 5 pseudocode, which shows a single step for the vehicle's MI transition.

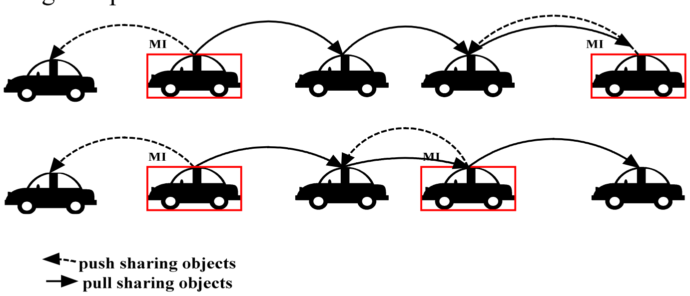

Figure 2. The push and pull configuration for Vehicular MP2P devices while moving in predetermined paths.

In order to reduce significantly the rendandancy of replicated packets, the HyMIS [3] [8] scheme is used where the primary Infostation is non-static (PI) but can move as the pathway allows according to certain likelihood. The PI is called Mobile Infostation (MI), and enables recoverability for any requested object in the end-to-end path while it maintains the sharing reliability. As vehicles are moving from one direction to the other the *i-th* vehicle (MI) can pull requested resources to *i-1*, *i-2*, *i-3, i-k*, where *k* is the number of peer vehicle in the end-to-end path requesting resource R_i. As Figure 4 shows, a cluster of replicated objects upon creation, considering the trajectory of the synchronized devices through their mobility and the likelihood in accessing the certain path using cluster interactions, the update rate of the requests, the cost of the *n-hop* replications.

Let k-hop path be the path that follows a certain $\vec{d}$ direction. Then $\vec{d}'$ notation consists of the converse direction of $\vec{d}$, and the path namely j-hop path. As the problem of saturation was faced in work done in [1], this work in order to avoid any saturation issues of the non-ending replications, certain criteria were set for all the requested high ranked file chunks as in [30]. In addition, it considers the opposite lane j-hop combination-comparisons of file chunks' requests with the requests of all the nodes in the j-path (of the converse pathway/Cluster C_j). Considering that the above scenario is used in real-time like in a vehicular raw-lane network, where requests of the j-hop may have a different direction, then it stands that for $Rank(i_N)$:

$$Min[Rank(i_N)]\forall N \notin C_i \tag{1}$$

where (1) is minimized for the node that the resource was downloaded at least once or when the distance d (Figure 5 pseudocode) is over a certain threshold D_{thress} from the k-hop peer- which means that the requested resource(s) set on this node have been redirected to any other path. Equation 1 sets the rank of the node containing the requested resource to minimum, for the nodes that are not members of the cluster where the resource was requested iff *d* is over a certain threshold D_{thress}. If the D_{thress} increases then the resource is isolated and it no longer belongs to the C_i. This enables the prevention of huge duplicated information delivery, whereas it considers the nodes which are located far from source node and to maintain only the j-hops duplications-after the performed comparisons- avoiding redundant transmissions.

Considering the k-hop scenario of Figure 2, the evaluated duration of the requested file chunks is evaluated as follows:

$$C_d = k \cdot E_i \tag{1.1}$$

where C is the caching duration that is allowed for node *i* and E_i is the relay epoch according to the number of hops permitted [3]. Therefore, it stands that the greater the number of hops, then the greater the time duration that is allowed to be achieved. The delay epoch duration is modelled according to the derivation of the *Definition 1.1*, taking into account the hop-count path, ping delays and the total delays from the end-to-end perspective.

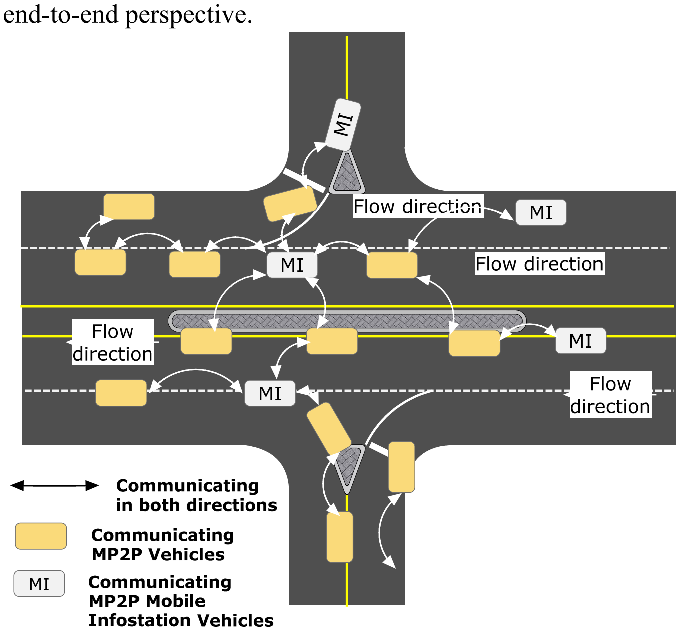

Figure 3. File chunk's blocks and segments are replicated using the HyMIS scheme in order to enable resource availability. High ranked resources that are requested are replicated in the cluster in order to be available according to ranking requests.

Definition 1.1 (Dense population region): We consider the concept of dense population region of a certain transmitter–relay node pair (u,w) traversing n paths/clusters is defined as the relay region which has any end-to-end connectivity in the relay path at a given time as follows:

$$\Delta R_{u\to w} = \{(x,y,u) \in \Re^2 : W_{u\to w\to(x,y,u)} > P_{u\to(x,y,u)} \forall u \in P_n\}. \tag{1.2}$$

Thus in an end-to-end path $\forall u \in P_n$ the minimized ping delays between the nodes in the end-to-end path the minimized evaluated delay is according to the:

$$d_p = Min\sum_{i=1}^{n} D_i \quad (1.3)$$

where Di is the delay from a node i to node j, and d_p is the end-to-end available path. Therefore the delay epoch $E_{i(t)}$ of each node is defined as a function of the number of created replicas on the j-hosts as follows:

$$E_{i(t)} = d_{r_{i\to j}} \cdot {r_{i\to j}}/{Total\_d_{r_{i\to j}}} \quad (1.4)$$

where D is the delay via the ping assigned durations, $r_{i\to j}$ is the number of replicas form node *i* to *j* in the *j-hop* path and $Total\_d_{r_{i\to j}}$ is the total duration that all the requested replicas can be downloaded from the j-hop path.

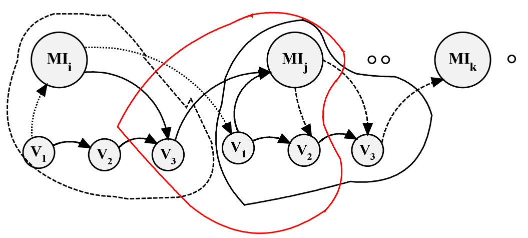

Figure 4. The Replication policy with respect to the different Clusters which are created on-the-move using the Mobile Infostation (MI) model for the Inter-cluster outsourcing, according to the ranking requests.

```
Set communication Path(A,B, N)
{

If (MI criteria meet==TRUE)
  Set MI in the Path(A,B, N);
else
   form Path(A,B, M) ∀M_i ∈ N
 //Inter-cluster info
  For any request in the C_i split chunks into
n blocks and do {
  { Check_delay_epoch(peer A, peer B)
while
((communication==1)&&(D_delay_epoch()==valid))
{
   If delay criteria meet
       { if ((exists(A)==LOCAL_CLUSTER)&&
            Measure_delay_epoch(C_i)==valid)&&
            (Rank(i)==Max(Table(res))) {
            If (Total_delay_epoch<D_threshold){
      while ((file_chunk==EXISTS)&&
  (TOTAL_delay()<Tlim(filechunk))){
     if (duration_interaction(node A, node B,
range(true, duration=true))==valid)

      // K_valid ∈ C_N

         {
           Check_CLUSTER();  //initialize  the
intracluster chunk sharing
```

```
push_requestedObj(Ob_id, Cap, Peers,
estimated_delay);

}
```

Figure 5. Pseudocode for a pull-based procedure by the vehicle's MI transition in order to enable object replication placement scheme between synchronized moving peers.

B. *Multi-hop probabilistic mobility model and user's capacity in the end-to-end path*

Resources availability problems can be also faced using a local summary of the global system-or clustered information for the subsystem- by using the property of aggregation in distributed systems concept introduced by Renesse et al in [14]. MP2P systems require to guarantee the availability any requested resources as well as to enforce appropriate access control policies. In our application scenario, we assume that a common look-up application is being used in order to enable nodes to interexchange locally the requested information objects. As a starting measure we estimate the synchronized cooperative movements of each vehicle by measuring the motion performed while measuring at the same time the reserved capacity by each vehicle. Since vehicles are moving in an organized and in a predictable way, the pull and push model aggravates the capacity of each device, as in a MP2P environment. Through the proposed resource exchange scheme for Vehicle-to-Vehicle communications as well as through the additional parameters that are being considered (like the evaluated end-to-end relay epoch/latency, the mobility pattern and the time frame for the allowed promiscuous caching introduced in [21] by Mavromoustakis), the proposed model enables efficient capacity manipulation in the end-to-end relay region and efficient data manipulation in the intercluster communication.

By adopting the modified scheme of Mavromoustakis and Karatza [8] and by assigning the role of MI to be adjusted into the vehicular devices, the PI and MI are being implemented by a certain frontal vehicle, where only unidirectional sharing and connectivity occurs.

When mobility is considered, the design of efficient rendezvous data dissemination protocols is complex for enabling efficient manipulation and availability of resources, whereas the existing solutions do not consider the random probabilistic movements of devices while disseminating data. In order to measure the direction movement we enable a probabilistic model for the direction of the movement of each device. Each device is associated with a random variable which represents the direction movement. For the motion, this work considers a probabilistic Random Walk in a predefined pathway represented as a Graph (G) where this G enables as a random variable the weights of these random movement. A device can perform random movements according to the topological graph G = (V,E) where it comprises of a pair of sets V (or V(G)) and E (or E(G)) called vertices (or nodes) and edges (or arcs), respectively, where the edges join different pairs of vertices. This work considers a connected graph with *n* nodes labeled *{1, 2, . . . , n}* in a cluster L^n with weight $w_{ij} \geq 0$ on the edge (i, j). If edge (i, j) does not exist, we set $w_{ij} = 0$. Each node moves from its current location to a new location by randomly (probabilistically) choosing an arbitrary direction and speed from a given range. Such a move is performed either for a constant time for a constant distance traveled. Then new speed and direction are chosen. According to the probabilistic Mobility model, the mobility is described as a memoryless mobility pattern. This occurs because it retains no knowledge concerning its past locations and speed values. In this work a Probabilistic optimized approach of the Random Walk Mobility Model is used, as in [27] by Ibe. In this model the last step made by the random walk influences the next one based on the stationarity and the correlations between the movements. Under the condition that a node has moved to the right, the probability that it continues to move in this direction is then higher than to stop the movement. This leads to a walk that leaves the starting point much faster than the original random walk model. Given that the device/vehicle is currently at node i, the next node j is chosen from among the neighbors of i with probability:

$$p_{ij}^{L} = \frac{w_{ij}}{\sum_k w_{ik}} \tag{2}$$

where in (2) above the p_{ij} is proportional to the weight of the edge (i, j).

Node mobility impacts the effectiveness of opportunistic resource sharing process. Previous studies have shown that the overhead carried by epidemic- and/or flooding-based routing schemes can be reduced by considering node mobility in a probabilistic manner as Section B presents. For instance, The proposed scheme takes the mobility pattern into account—that is, a message is forwarded to a neighbor node if and only if that node has a mobility pattern similar to that of the destination node. This is performed according to the probabilities explored in (2), following the probabilistic model for the direction of the movement of each device. Thus, if a device follows another device with a certain probability (Figure 6) where the device followed, follows it turn another device, this obeys to the following equation:

$$P_{i\to N} = norm\left[\frac{1}{N-1}\sum P_{i,j}\right]^{0..1} \forall P_{i,j} > P_{Thress} \tag{2.1}$$

where should be over the range of values for $P_{i\to N} > P_{Thress}$. After consecutive experiments the values of $P_{Thress} > 0.31$ is found to be ideal in contrast to the density of the devices and the topology formation factor mentioned in [21]. This evaluation is performed in order to enable probabilistic resource sharing among users taking into consideration the probabilistic mobility and the effects of the total aggregation of this likelihood in a normalized manner as equation 2 presents.

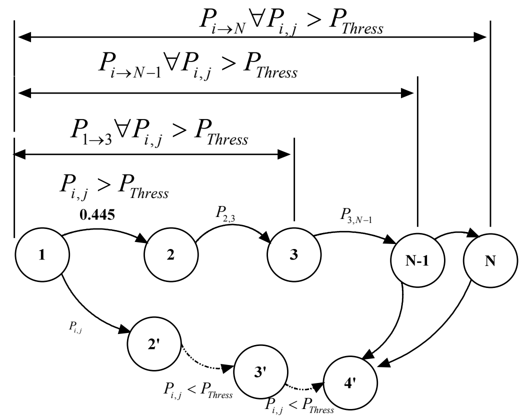

Figure 6. Probabilistic pathway followed by devices in the same path.

Therefore, if the threshold is satisfied then the replication takes place according to the replication policy explored by the HyMIS [3] and follows the limitations set by the adaptive replication scheme using the Go-back-N caching cooperation presented in the next Section.

C. Cooperation and storage model using passive message ferries and bi-directional resource's replications

In order to define which requested objects should be outsourced onto preceding m-peers a ranking model has been applied as follows: To find the rank of an object $a1$ $a2$ . . . a_m, one should find the number of objects preceding it. It can be found by the following function:

function rank($a_1, a_2, \ldots, a_m$)
rank← 1 ;
for $i \leftarrow 1$ **to** m **do**
for each $k<a_i$
$rank \leftarrow rank + N(a_1, a_2, \ldots, a_{i-1} \mid k)$

Then the new ranked sequence of shared objects will cache onto other nodes in the path the first i-requested objects in regards, to the given for each node, k parameter, where k is defined as a function of the remaining capacity onto each device as:

$$|k| = \inf\left(\frac{\sum_{N=i}^{N}(1-\rho_N)}{N}\right) \tag{3}$$

where ρ_N is the utilized capacity and N is the number of hops in the requested path. Nodes in the path are moving according to the 2-D plane mobility model $L \subset \Lambda, \Lambda \subset \Re^2$. A moving square (the $\{\Lambda_1, \Lambda_2, \Lambda_3, \ldots\}$ bounded area) is divided into multiple sub-squares, called cells as in [1], and time is divided into slots of equal duration. At each time slot a node is in and can be only in one cell. The initial position of a node is uniformly chosen from all cells. At the beginning of each time slot, the node jumps from its current cell to one of its adjacent cells with equal probability. Two mobile nodes can communicate with each other whenever they are within a distance of d, the transmission range of the mobile node. In order not to have an optimistic assumption a low density population network is assumed with regards to the number of traversing nodes per Λ_i. We assume that no conspiracy policy exists where, nodes somehow conspire together not to meet each other forever and move at $d>D$ and in parallel.

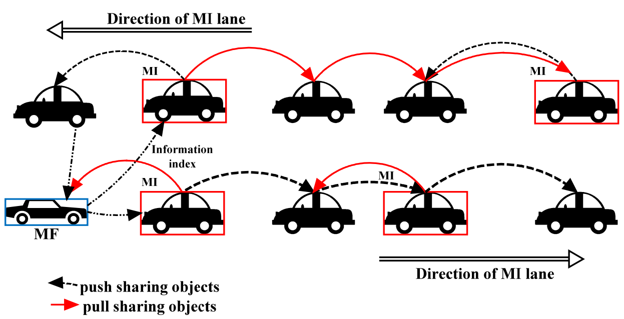

Figure 7. Passive message ferries where any other device can play the role of the messanger regarding the information index.

The *index* of each node is being transferred using the message ferries that are passively passing from any other pathway within the distance of communication range of each device. Figure 7 shows this approach where the message ferries are passing from an opposite pathway whereas at the same time they are in the transmission distance range with each device they communicate. As a result the MFs are forwarding information from one node to another by using an opposite lane and pathway. This configuration enables the bi-directional resource replication of high ranked requested resources.

Taking into account the delay characteristics, let N be the number of source peers in the network (*N* different end-to-end paths) and $C_i(t)$ be the service capacity of source peer *i* at time slot *t*. An end-to-end download can be then depicted as a function of time as derived from Chiu and Young Eun in [16] and the $w^L{}_{ij}$ of the end-to-end path in the cluster L as:

$$T = \min\left\{ s_{ij} > 0 \mid \sum_{t=1}^{s} C(t) \geq F \right\} \tag{4}$$

where F is the file capacity defined as $\{f_1, f_2, f_3, f_4, \ldots f_n\}$ equi-divided file chunks and *s* a given end-to-end bounded allowed delay for this file to be downloaded from any numbers of peers in the end-to-end path. The obtained eq. (4) derived from Wald's equation introduced by Ross in [17] can therefore be expressed as:

$$F = \mathrm{E}\left\{ \sum_{t=1}^{T} C^L(t) \right\} = \mathrm{E}\{C^L(t)\}\mathrm{E}\{T\} \tag{4.1}$$

where we can easily extract the slotted amount of file chunks that are shared in the end-to-end path. The $A(\vec{c})$ is the minimum average capacity offered by each link in the path as:

$$A(\vec{c}) = \frac{1}{N}\sum_{1}^{N} \inf(C_{ij}(t)) \tag{4.2}$$

where $A(\vec{c})$ is the requested and available arithmetic mean for the capacity in the path. The average capacity offered by the end-to-end path considering all the links in the path of the requested file F, can be denoted as $A(\vec{c}) \big/ \mathrm{E}\{C_{ij}{}^L(t)\}$ .the average download time is:

$$\mathrm{E}\{T_{F_{ij}}\} = \frac{F_c}{A(\vec{c})} = \frac{N \cdot F_c}{\sum_{1}^{N} C_{ij}(t)} \forall w_{ij} \in L \tag{4.3}$$

while it stands that for $C_{ij}(t) = \min(\inf(C_{ij}(t)) | \mathrm{E}\{T_{F_{ij}}\}$.

Let $t_\lambda = \max(\Theta_{MI,j})$ be the contact rate estimation and $\Theta_{MI,j}$ is the estimated contact time between MI and a moving node *j*, then it stands that a vehicle remains as a MI in the path if the following is satisfied:

$t_{\lambda_{ij}} \geq \dfrac{A(\vec{c})}{BW_{ij}}$ where $t_{\lambda_{ij}}$ is the contact rate in the path between i,j and BW_{ij} is the associated bandwidth in the path between i,j. The estimation of $t_{\lambda_{ij}}$ is essential since it can determine the time that a mobile node can remain as a MI.

1) *Adaptive replication scheme using the recursive Go-back-N caching cooperation*

One important aspect in P2P vehicular communication is the limitation of the redundant replications that are performed while requests are taking place in the peer-to-peer connectivity. When resource sharing process occurs in a region, the packets that are sent are considered to have a bounded time delay τ to reach any specified destination. This work proposes the utilization of a methodology that enables the replication of the requested file chunks using a specified window size. The proposed method uses the adaptive precision Go-back-N caching cooperation where the number of files N that were requested can be re-selected to be securely replicated onto node according to the contact criteria using the random walk framework and the $P_{i,j} > P_{Thress}$ (subject to equation 2.1). Assuming a file which consists of N chunks as follows:

$$N_{chunks} = \{1, 2, 3, \ldots n\} \tag{5}$$

Where N_{chunks} are the chunks that are selected according to the contact and request rate and depicted as missing file chunks according to the movements and the state as: (k, $\Delta\xi_k$), where k is the location of the walker, where a move to a neighbor indicates a success (increase the $\xi_k \forall P_{move}$) and a move to a $d_t<d_{t+1}$, where d_t is the distance between two nodes in current contact, indicates a failure (decrease the $\xi_k \forall w_{ij}$); and $\Delta\xi_k$ is the result index, which is defined by $\Delta\xi_{ij}(t) = \frac{dij}{D_{ij}}$

where d_{ij} denotes the number of hops in the path for node i to j and D_{ij} depicts the total number of hops in the end-to-end path. Therefore the increase and decrease of the likelihood for the Correlated Random Walk is respectively $\xi_+ = \frac{P_{move(i\to j)}(t-1)+\Delta\xi_{ij}}{1+\Delta\xi_{ij}}$ and $\xi_- = \frac{P_{move(i\to j)}(t)}{1+\Delta\xi_{ij}}$.

$P_{move(i\to j)}$ is the probability of moving in the *i* to *j* path, and (1- $P_{move(i\to j)}$) of abandoning the path and the cluster C_i. This enables the estimation of whether a mobile node will follow a certain pathway or not. The mobility is modeled according to the Section B (Equation 2) where the replication policy follows the Equation 2.1.

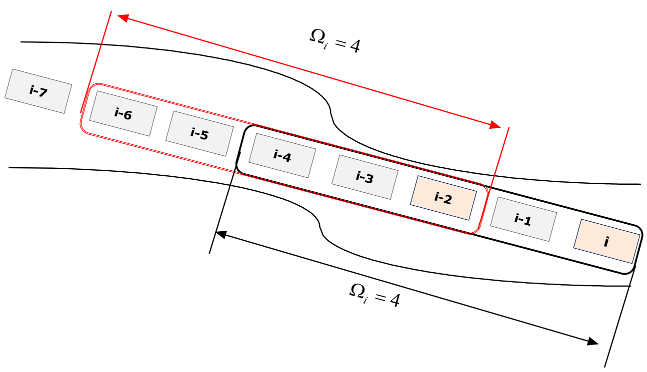

Figure 8. The Adaptive Go-back-N caching cooperation scheme with respect to the number of file chunks that the device-i requests, and considering the missing chunks that should be reached in order to be available to the requests. The Adaptive Go-back-N caching enables the parameter to be adaptively tuned in order to enable the recoverability in the resource exchanging cluster, where –in any other case- the missing chunks will affect the end-to-end completion of the file.

Taking further into consideration that the request rate is incremental and satisfies the:

$$\sup(R_i(\tau,\rho_i)) > \sup(R_i(\tau-1,\rho_j))\forall i \neq j, \tau > \tau - 1 \quad (5.1)$$

where R_i is the request rate for the certain point/location ρ_i for the time τ. The proposed scheme adaptively calculates the N cached chunks using the:

$$\Omega_i = R_i \cdot L_i + R_i \cdot L_t \text{ for time } t \quad (5.2)$$

where t is set in $[\tau, \tau + t]$ and R_i is the request rate for the certain point/location, L_i is the delay length between interarrival time of the requested file chunks, and L_t is the delay length of the repeated requests of the missing file chunks. The parameter Ω_i represents the number of file chunks that the *i* requests and should be outsourced to nearby neighbors in the cluster path. Figure 8 shows the related concept for $\Omega_i = 4$.

D. Considering contact interactions for collaborative streaming

In this section we propose a number of social interaction parameters which take place in collaboration with the file chunk outsourcing of the previous section. The metrics are community-oriented and are considering the number of created clusters $C_N(t)$ in a specified Relay region of a certain transmitter–and a number of receivers (1, N] under the relay node pair (u,w $|MI_i$) -as a modified definition of [18]- as follows the:

$$C_N(t) = \frac{2|h_N(t)|}{|I_{C(N)}(t)| \cdot (|I_{C(N)}(t)|-1)}, \text{ iff } P_{u\to w\to(x,y)} > W_N(t) \quad (6)$$

where *W* is the Community streaming factor and is defined as the number of existing communities in the intercluster communicational links at a given time instant. The $h_N(t)$ is the number of hops in the existing clusters and the $I_{C(N)}(t)$ is the number of interconnected nodes N in the cluster $C_N(t)$. *W* can be defined according to the download frequency of the file chunks in the intercommunity as follows:

$$W_N(t) = \frac{DldRate \cdot \#sharingChunks}{Total\#dlds(t) \cdot \#inactiveChunks} \quad (6.1)$$

where in (6.1) the download rate is considered in contrast with the number of chunks being shared in a specified instant time *t*.

IV. PERFORMANCE EVALUATION, EXPERIMENTAL RESULTS AND DISCUSSION

A. Dedicated Short Range Communications (DSRC)

To emulate the scenario described earlier, a possible realistic environment must be achieved. Dedicated Short Range Communications (DSRC) was used for the evaluation of the proposed scenario which is two-way short- to medium-range wireless communication channels specifically designed for automotive use and utilizes a corresponding set of protocols and standards [19]. Considered to be short to medium range communication technology it operates in the 5.9 GHz range. The Standards Committee E17.51 endorses a variation of the IEEE 802.11a MAC for the DSRC link. DSRC supports vehicle speed up to 120 mph, nominal transmission rage of 300m (up to 1000 m), and default data rate of 6 Mbps (up to 27 Mbps). This will enable operations related to the improvement of traffic flow, highway safety, and other Intelligent Transport System (ITS) applications in a variety of application environments called DSRC/WAVE (Wireless Access in a Vehicular Environment). In the evaluation of the proposed scheme we evaluated the Peer-to-Peer/Ad hoc mode (vehicle–vehicle) scenario and took into account the signal strength parameters and the minimized ping delays between the nodes in the end-to-end path according to the $d_p = Min\sum_{i=1}^{n} D_i$, where D is the delay from a node i to node j, and d_p is the minimized evaluated delay in the end-to-end available path. Moreover, considering the need of bandwidth for the wireless devices, it is necessary to apply efficient routing algorithms to create, maintain and repair paths, with least possible overhead production. The proposed scenario uses the trajectory based routing (i.e., SIFT) [26]. The number of nodes varies depending on the mobility degree and the distance variations of each user within a connectivity scope. The user's transition probability arises from a specified location where certain information is pending to be received by this user. In this way the likelihood varies based on the demanded by users, requested resources.

B. *Simulation results of the proposed scenario and discussion*

In this section, we present the results extracted after conducting the discrete time performance evaluation through simulation of the proposed scenario. The simulation used a two-dimensional network, consisting of 250 nodes dynamically changing the topology on a non-periodic basis (asynchronously as real time mobile users do). It stands that after random time each node moves at a random walk to one of the possible destinations (north, east, west, south) in an organized vehicular way. Each link (frequency channel) has max speed reaching of 4*Mb per sec,* according to the regional EU standards of the DSRC. The propagation path loss is the two-ray model without fading. The network traffic is modeled according to the traffic sources modeled modules of the ns-2 simulator [29]. Initially there is a transient and initialization stage that is responsible to extract the resources (i.e., certain files) requests among users. All mobile nodes collaborate via a shared application that uses a distributed look-up service, for the shared resources. Radio coverage is small, and is assigned according to the DSRC specifications, whereas, nodes cannot contact each other directly when sharing resources. Each source node transmits one 512-bytes (~4Kbits) packet. Packets during initialization period are generated at every time step, destined for a random destination uniformly selected. Nodes have at any time incoming file-sharing requests by other peers whereas, during the time of the requests, the details of the requested resources are being transferred to any potential destination node. In addition, the modeled simulation environment considers the probabilistic mobility [1] taking also into account the traffic lights' patterns and the randomized vehicular events that may occur. The results show that the proposed bi-directional scheme significantly outperforms previous approaches in all test cases, while its traffic overhead remains moderate and the nodes have generated adequately enough replications for the peer-devices, avoiding in this way the redundancy.

Figure 9 shows the network dimensions with the data and capacity exchanged through the created clusters. Figure 9 shows that even when the files that are being exchanged are greater than the network dimensions, the system can handle more than one resource per user. This result outperforms the previous findings where the dimension of the network bottlenecks the number of resources that are interexchanged in the moving cluster. The proposed scheme effectively handles the end-to-end transmissions and enables the complete download whereas, for this evaluation, two measures were taken into consideration: the data exchanged within the cluster i and the data exchanged with other clusters both versus the capacity limitations (with limited capacity and unlimited capacity onto users devices).

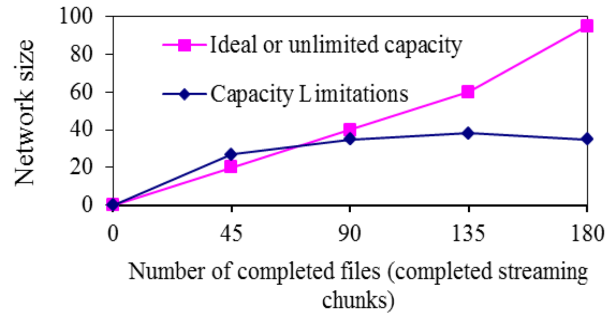

Figure 9. Indication of Network dimensions with the data and capacity exchanged through the clusters formed.

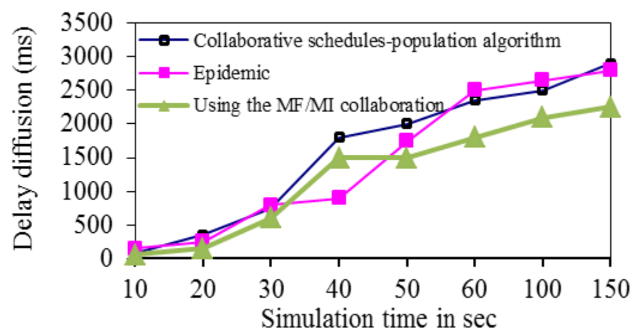

Figure 10. The delay of the diffusion outsourcing process with the simulation time compared with Epidemic and collaborative schedules schemes.

Figure 10 shows the delay of the diffusion outsourcing process with the simulation time compared with two different in implementation schemes: the epidemic and collaborative schedules schemes. It is easily spotted that Figure 10 shows the better performance of the proposed scheme for this specific scenario in vehicular P2P systems. It presents also the effectiveness with the significant robustness in the delay diffusion process-which is further minimized. Figure 11, presents the number of successfully received transmissions over of total of 25 transmissions in the path/clustered end-to-end transmission, with the mean number of sessions created in the system. Figure 12 shows the number of transmitted packets with the number of lost packets for three different traffic classifications: heavy, moderate and light traffic. The proposed scheme shows that it can successfully treat the traffic with limitations and transmission deadlines accurately by minimizing the losses in regards to the number of transmitted packets. The number of participating nodes with the number of high ranked resources over the timeline's limitation of the transmission is shown in Figure 13, whereas Figure 14 shows the performance of the bi-directional scheme in contrast to other existing schemes like the Most Recently Claimed and the passive/generic caching. The latency for the proposed scheme outperforms of the other compared schemes, in regards to the requested file chunks and the number of created replicas onto N-hop nodes. In Figure 15 the VBR requests per cluster with the successfully shared capacity is presented, whereas Figure 16 presents the average available capacity per user with the successfully shared MBs, depicting the efficiency of the proposed scheme in handling 250 users concurrently. It should be noted that the exchanged resources cannot be unranked and this is due to the availability of requested resources which should be kept consistent, unless a low ranked resource will be highly outsourced and becomes highly demanded. Figure 17 shows the number of users sharing resources with the capacity that is shared in for different users' capacity measurements. Figure 17 depicts the response of the system in contrast to the shared requested capacity and the storage capability of each user.

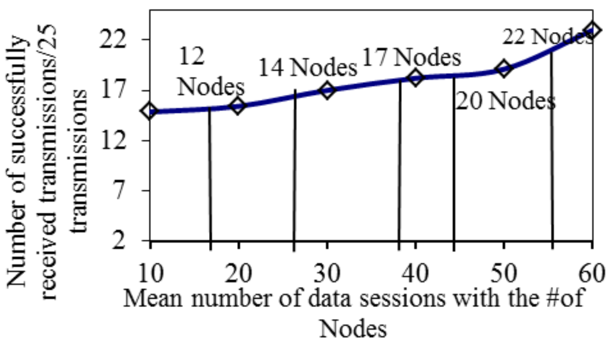

Figure 11. The number of successfully received transmissions over of total /25 transmissions with the mean number of sessions created in the system.

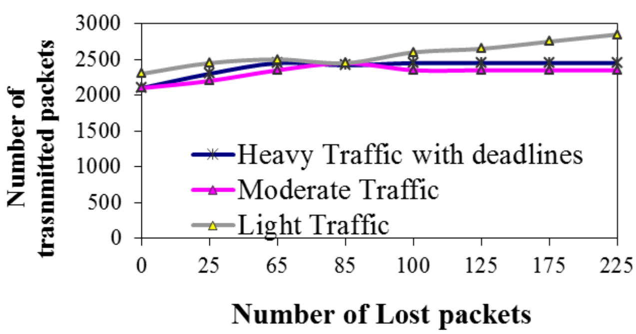

Figure 12. Number of transmitted packets with the number of lost packets for three different traffic classifications: heavy, moderate and light traffic.

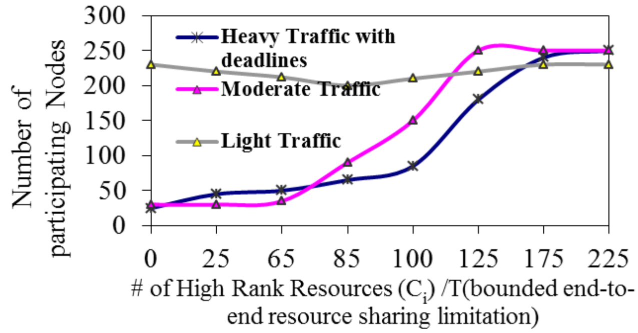

Figure 13. Number of participating nodes with the number of high ranked resources over the timelines' limitation of the transmission.

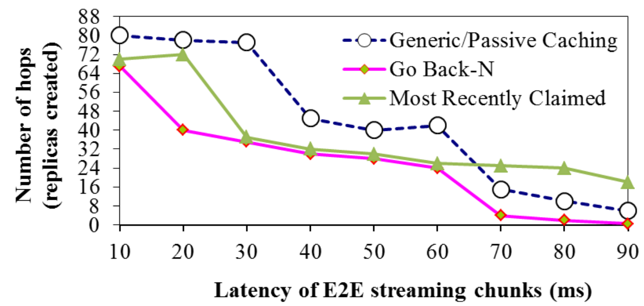

Figure 14. The latency of the streaming requested file chunks and the number of created replicas onto N-hop nodes.

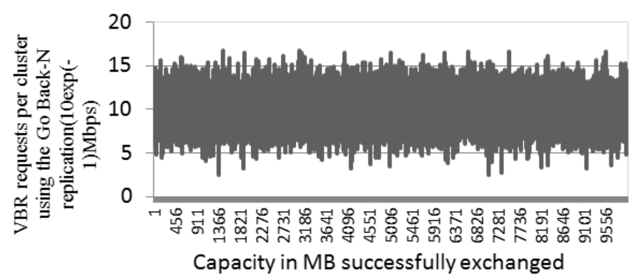

Figure 15. VBR requests per cluster with the successfully shared capacity.

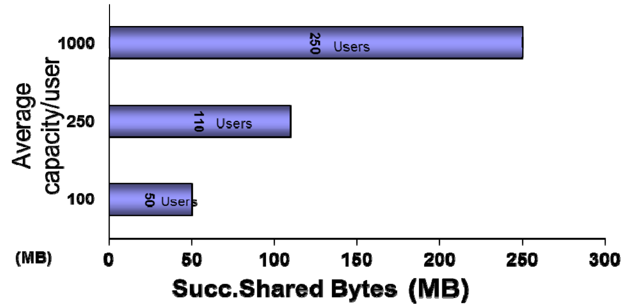

Figure 16. Average available capacity per user with the successfully shared MBs.

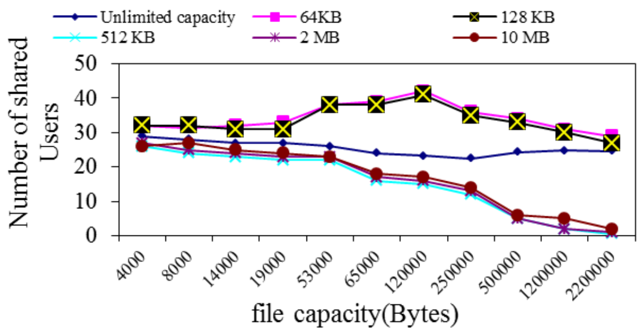

Figure 17. Number of users sharing resources with the capacity that is shared in for different users' capacity measurements.

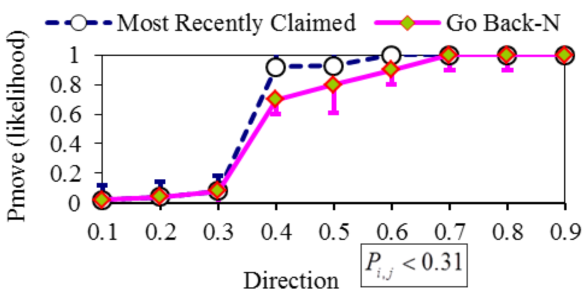

Figure 18. Likelihood of the movements with the direction of each device according to the modeled estimations.

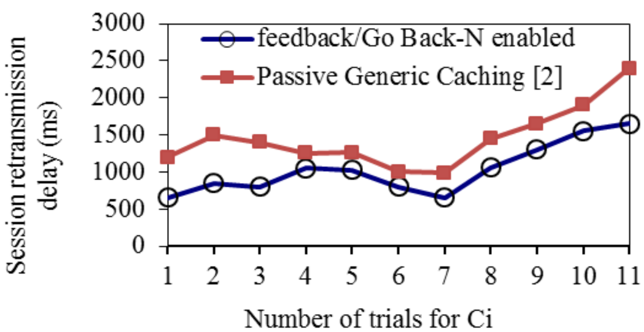

Figure 19. Number of trials with the session retransmission delay in msec.

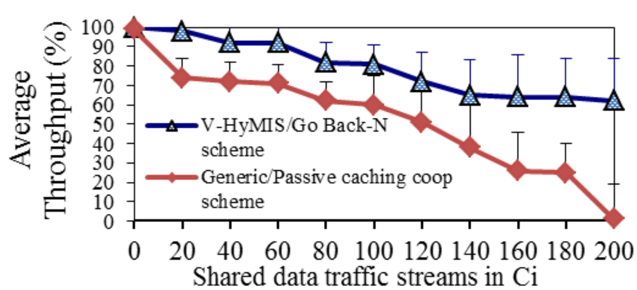

Figure 20. Performance of the Cluster with Bidirectional outsourced traffic requests compared with passive caching scheme.

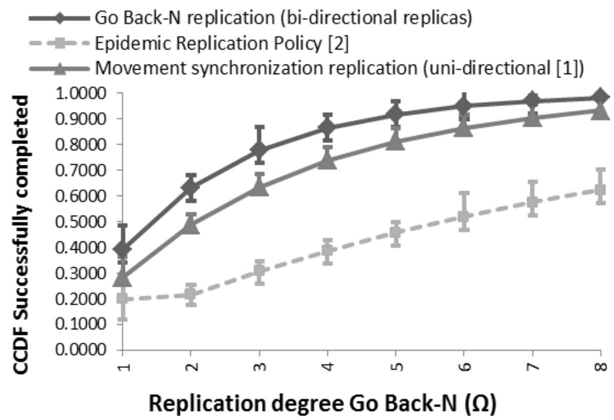

Figure 21. Complementary Cumulative Distribution Function (CCDF or simply the tail distribution) with the replication degree of Go back-N for successfully transmitted packets and completed downloads.

The likelihood of the movements with the direction of each device according to the modeled estimations is shown in Figure 18. In Figure 18 the likelihood corresponding to 0.31 is considered after consecutive simulations as the ideal to set it as a threshold for the movement of each node. Any value for the likelihood below this value indicates that the device will soon change a direction and will not follow a synchronized motion with other devices. Figure 19 presents the number of trials with the session retransmission delay in *msec*, where the trial's measure corresponds to the intra-cluster retransmissions with the associated delay measures. In Figure 20 the performance of the Cluster with Bidirectional outsourced traffic requests compared with passive caching scheme is shown. Finally, Figure 21 shows the Complementary Cumulative Distribution Function (CCDF or simply the tail distribution) with the replication degree of Go back-N for the successfully transmitted packets and completed downloads. The distribution of successfully shared resources can be adequate even if the replication of resources using the Go back-N is kept low. During the simulation process we have extracted different confidence intervals for the three compared schemes where, these are shown in Figure 21. The proposed replication policy exposed significant improvement for the reliability degree, in contrast to the Epidemic replication proposed in [2] and the work done in [1]. It is undoubtely true that Figure 21 shows that by using the Go Back-N in a bi-directional way, the CCDF for resource sharing can be significantly improved along with the reliability degree. In addition, it also presents the reliability increment, by using the CCDF tail distribution of the successfully completed exchanged resources, when compared with similar schemes for Vehicular-based resource exchange.

V. CONCLUSION AND FURTHER RESEARCH

This work extends and re-considers, under a different approach in the resource sharing policy, the work done in [1] in a recursive bi-directional replication manner in order to promote resource availability among moving devices. The resource assignment policy takes into consideration the number of synchronized peers in the resource sharing cluster, and assigns resources according to the modeled Go back-N scheme, for replicating the requested resources onto N nodes. The scheme takes into consideration the probabilistic synchronized motion of the nodes that are requesting resources. According to the likelihood of the motion expressed by the node, the requested resources can be outsourced and replicated onto other nodes in the range of communication. As the process of exchanging resources is characterized by bounded end-to-end delay, the scheme considers also the time frame that these ranked requested resources should be potentially completed; otherwise they are outsourced to nearby nodes in order to be available for future requests by other nodes. Finally the methodology encompasses the assignment of the resources and the cache-and-forward scheme by using and assigning the role of a Mobile Infostation (MI) peer to a certain vehicle whereas, this is done in a bi-directional way with the introduced Message Ferry (MF) mobile Peer. Passive message ferries are utilized as a resource index for the end-to-end path in order to efficiently enable delay sensitive streaming. Extensive simulation experiments that were conducted have shown that the proposed scheme improves the existing scheme, whereas in comparison with the Epidemic and the passive replication schemes it outperforms them in major performance estimations. Moreover, results have shown that the scheme offers high throughput and significant end-to-end reliable exchange of resources whereas it offers high SDR for completed files.

Current and future research directions include the modeling of the mobility pattern of the peers by using different stochastic approaches like the fractional Brownian motion taking into account the global requests and different network partitioning parameters.

ACKNOWLEDGEMENTS

We would like to thank the University of Nicosia Computer Installation Center, for helping us with the terminals' simulation software installation in order to perform exhaustive evaluations of the proposed scheme and extract results from different machines. These machines' runs significantly helped us to derive the confidence interval among extracted results.

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