A Geo-location Based Opportunistic Data Dissemination Approach for MANETs

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ABSTRACT

In mobile scenarios, location dependent data can be provided by an infrastructure, or, in case an infrastructure is not available or feasible, by opportunistic networking among mobile devices populating the region of interest. Caused by node mobility, data availability within the region of interest relies on replication and forwarding techniques.

Our approach associates data with a geo-address describing the Point of Interest (POI) of the data and proposes a decentralized algorithm for data dissemination. Mobile devices replicate data to increase data availability within a circular area around the POI. To avoid unnecessary communication overhead, the distributed algorithm *Sector Heads Aided Flooding Technique* (SHAFT) restricts the number of mobile nodes that forward data by arranging data placement geometrically in the area. Hereby, each mobile node decides whether to become a forwarding node based on its geo-location and the known scheme for data arrangement. Additionally, the algorithm adapts to the locally measured density of mobile devices in range. By applying the approach to a cooperative parking lot management system based on the Manhattan mobility model we demonstrate its usefulness. Simulation results are provided showing that SHAFT reaches similar data availability as flooding by reducing the number of packets transferred by a factor of up to 92.3% for newly created data and by up to 81.1% for data updates in scenarios of high node density.

Categories and Subject Descriptors

C2.1 [**Network Architecture and Design**]: Store and Forward Networks

General Terms

Algorithms, Design, Performance

Keywords

MANETs, Mobile Data, Geo-based Data Dissemination, Replication

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1. INTRODUCTION

For many mobile applications, data is only of local interest and can be kept local. This is in particular valid for Intelligent Transport Systems (ITS) which may inform about dangerous road conditions like wet or icy roads, speed limits, or car accidents and vehicle re-routing. Another example is cooperative information sharing between tourists. Recently, attempts have been started to exploit communication opportunities contributing to traditional wireless networks in order to increase availability or performance mainly for ITSs, but also for other networks, like Wireless Mesh Networks (WMNs). Independent of the application domain, *opportunistic networks* are highly challenged due to not predictable link conditions. Finally, they rely on sufficient node density and node distribution to remain operational at all.

To disseminate data, the network could be flooded to reach all nodes, but this would probably lead to unnecessary transmissions which will not increase availability, but only networking overhead. Our approach considers an information layer provided by spontaneously connecting mobile devices which aims at reducing this overhead while reaching a sufficient degree of information persistence within a region of interest. The approach is termed *Sector Heads Aided Flooding Technique* (SHAFT) and based on selecting a sub-set of nodes for efficiently forwarding data. Hereby, the region of interest is specified by a (geo) location, a *Point of Interest* (POI) and a configurable surrounding area. The mobile nodes cooperate by replicating data, which "belongs" to the POI. Mobile nodes only forward data in case they are positioned best for data dissemination. Hereby, the best position is determined by a geometric structure trying to reach high coverage of the area with a small set of nodes and, consequently, low communication overhead. Replication is used to increase information availability under the realistic assumption of limited communication ranges.

In contrast to other strategies considering access-based metrics to determine where to create replicas or trying to place replicas as far away from each other as possible, we address the field of geo-based replication and data dissemination. The novel geo-based data dissemination algorithm SHAFT is unique because it uses geometry information and dynamically changing area and sector ranges to adapt from sparse to high density node populations.

We evaluate the algorithm in terms of availability of information and messaging overhead by comparing it to flooding, which reaches best coverage while suffering from heavy resource usage as has been investigated by a comparison of different opportunistic routing protocols in [23]. The novelty and benefit of the SHAFT algorithm lies in using geometry information to control dissemination and, thus, to avoid that node mobility destroys a sophisticated structure. For example, topology based structuring approaches as provided by the commonly used *skip copy* algorithm for geo-location based replication (data is replicated only by n-hop neighbors), tend to suffer from mobility, since the topology-based structure is often lost and destroyed leading to dramatically increasing overhead. In mobile environments, however, this situation is likely to happen.

Although the approach is not dedicated to a specific application domain, in this paper we will demonstrate its usefulness in a particular and feasible simulation scenario. We apply the approach to the use case of *cooperative parking lot management* in a city area. We consider that on-board units sense free parking lots (using enhanced distance sensors embedded in vehicles for parking support) and communicate with one another to disseminate and replicate the information about a free parking lot within the region of interest. The POI is here a free parking lot.

The paper is structured as follows: First, we relate the concept to existing data dissemination and replication approaches in Section 2. The concept of geo-location based data dissemination with focus on SHAFT is described in Section 3. The selected use case of cooperative parking lot management is described in Section 4 as well as how the algorithm is applied to this use case. In Section 5, we describe the findings of the simulation runs for the parking lot management application and in terms of general dissemination and replication properties. Section 6 discusses the findings and open issues for future work.

2. RELATED WORK

The approach described in this paper is related to geo-based data replication including issues like replica updates and consistency, and dissemination including forwarding and messaging. Thus, we give first an introduction to related work on geo-based replication and, then, on data dissemination.

Data replication is a well known technique to improve data availability and reliability in distributed systems [6, 21, 19]. In mobile wireless networks, communication failures and limited resources cause additional challenges [22]. As a consequence, replication techniques for mobile wireless networks must lay emphasis on tolerating disconnections, network partitioning – which frequently occurs due to node mobility – and depleted node's resources [15].

In [4], three replication strategies are proposed to increase data availability in case of network partitions. In general, nodes update replicas following *relocation periods* based on a priori known data items' access frequencies. The first method stores data items with decreasing access frequencies until the node's storage is full. The other two methods reduce redundancies by assigning the same data item only to dedicated nodes, that is, once within the direct neighborhood and within groups of biconnected nodes respectively resulting in higher communication costs. Data updates can only be made by the original creator of a data item. In real environments, frequently changing access behavior impairs the benefits of these methods [9]. In contrast to these methods, our data dissemination mechanism makes use of the underlying geometry to reach a stable distribution of replicas even in spite of node mobility.

In [1], REDMAN, a replication framework for dense mobile adhoc networks is presented which tries to limit and maintain the replication degree in the network. Replication is supervised by replication managers which control the degree of replication and delegate replication. Data item owners are selected as delegates by the replication manager and choose a random neighbor for replica distribution. The replica is then distributed into the direction of the selected neighbor and stored at neighbors with k-hops distance.

In location dependent data replication, data is associated with a location like a point of interest [3, 9]. It is assumed that nodes are more interested in the data if they are closer to the point of interest. This principle allows to limit the number of replicas by considering the range of interest and to reduce the likelihood of network partitioning.

In [25], a location-based replication method is presented where data items are associated with and identified by the position of creation. It is assumed that positioning information, like obtained from GPS, is available. When a data item is created it is broadcasted to neighbors together with a hop count. Propagation of transmission is stopped when a given radius between the current node and the data item is reached. Data requests are forwarded until a node which holds the replica is reached. Requested replicas can be sent back to requesting nodes via the inverse route of the data request, or via an alternative routing protocol like AODV [17]. Data updates are performed by comparing timestamps of data items among nodes but without any consistency guarantee. Our approach is similar in the sense, that propagation depends on a region of interest and range. In contrast to topological considerations (hop count), our approach is purely based on geometric arrangement of replicas based on the location of the mobile nodes.

Data dissemination approaches in mobile wireless networks often make use of the specific characteristics of wireless transmission. Due to its inherent capacity for broadcasting, a wirelessly connected node can reach all its neighbors via broadcasting without overhead compared to unicasting [18]. In classical flooding, a source node starts a transmission of a packet to all its neighbors [5]. These neighbors make a local copy and forward the packet again to their neighbors. The dissemination process converges in a failure-free network when all nodes have received the packet. Classical flooding is robust to node failures [20] but produces redundant messages for nodes with overlapping transmission ranges which can lead to implosion [5] and broadcast storms [14]. To support efficient data forwarding among mobile vehicles, some approaches propose using opportunities of vehicle movement to forward data in the desired direction, e.g., determined by an on-board navigation system [11, 10]. These approaches are related to our approach but have been introduced for a different purpose. Differently to using nodes to efficiently carry packets in a geo-direction, SHAFT aims at keeping the data available in a given area by forwarding it among nodes that are best positioned in this area.

In [14], five general dissemination schemes are presented to overcome or reduce the broadcast storm problem: (i) a *probabilistic* scheme which rebroadcasts messages with a certain probability p; (ii) a *counter based* scheme which counts the number of occurrences of transmissions of the same packet by neighbors in range and rebroadcasts the message if a certain counter threshold is not reached; (iii) a *distance based* scheme which only rebroadcasts messages, if the distance between the sender and the retrieving node is sufficiently high; (iv) a *location based* scheme which considers intersection areas of transmission ranges and rebroadcasts only if the overlapping area is below a threshold; and (v) a *cluster based* scheme which determines clusters of nodes which are in transmission range of one another and assigns gateways between the clusters for forwarding messages.

In [18], multi-point relaying is used to limit the number of retransmissions of broadcast messages. The approach restricts the number of forwarding nodes to a small set of neighboring nodes, called multi-point relay set. The method assumes that each node maintains a list of one-, and two hop neighbors. These neighbor sets for each node are maintained by HELLO messages which include the sender node's list of neighbors. This concept is similar to the concept used by the routing protocol OLSR (see RFC 3626).

A location based approach that extends the concept of incorporating neighborhood knowledge [12] by using information about nodes which already received a message is presented in [20]. The environment is separated into predefined grid cells where internal nodes, which have only neighbors within their grid cell, are distinguished from gateways. Gateways have neighbors in multiple cells. When a message enters a cell, the gateway attaches a list of cell nodes which have not received the message yet and rebroadcasts the message accordingly. In [24], a scheme is proposed which limits redundant retransmission of messages by using cover angles of node transmission ranges. In [2], rebroadcasting of messages is limited to nodes which are near to the perimeter of the sender's transmission range. Based on geometric considerations, in [13], a virtual grid of hexagons is used for packet forwarding. The main idea is that only nodes which are located closest to a hexagon's vertices forward packets. In [16], nodes which are close to vertices of a globally defined hexagonal grid forward messages without the use of explicit neighbor information. Therefore each node delays its rebroadcast and listens if the same message is transmitted by a neighbor which is closer to the optimal position. If a neighbor closer to the optimal position transmitted the same message then the message is skipped without forwarding. These approaches are similar to our method since they also utilize geometric information.

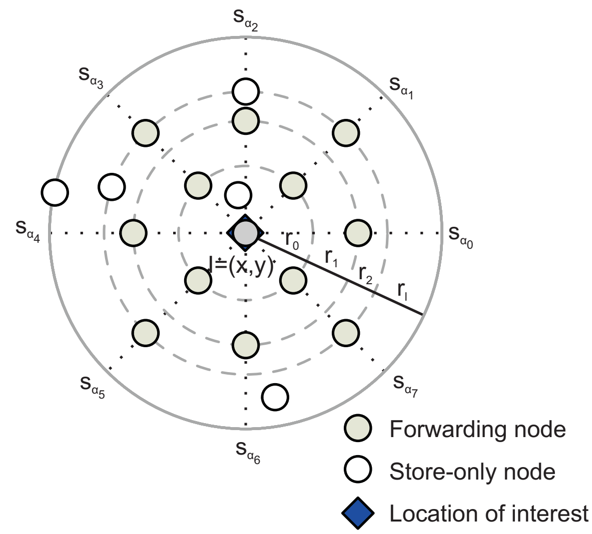


Figure 1: Overview of the location-dependent information dissemination approach.

Figure 2: Structure of a data item consisting of a position l, a dissemination radius r_l, a timestamp t, a unique creator id, a name and the payload.

3. SHAFT – THE GEO-LOCATION BASED DATA DISSEMINATION ALGORITHM

Following the vision of information bound to geo-locations and not to computers and computer addresses, we propose a new geo-information based data dissemination algorithm for mobile opportunistic networks. To make data available, data is replicated among the mobile nodes in the area of interest following a geometric structure applied to a 2D area of a circle around a point of interest. This structuring allows to select single nodes of sectors for data forwarding and, thus, to reduce messaging overhead. Due to varying mobile node densities, the basic algorithm is enhanced to adjust the geometric structure to different node densities. The selected forwarding nodes are seen as *heads* of a sector; the proposed algorithm is termed *Sector Heads Aided Flooding Technique* (SHAFT).

3.1 Assumptions and Approach

The dissemination process follows the concept of decentralized opportunistic data dissemination where nodes autonomously decide if they want to take part in the forwarding process. Each node which receives a data packet makes a local copy and forwards the data packet according to its geo-location. Therefore, we assume that nodes can measure their position with respect to their environment, e.g., through GPS receivers in outdoor environments. Nodes are further assumed to be able to connect to neighboring nodes over a wireless network, like IEEE 802.11 ad-hoc mode, and hold local scan information about the nodes currently in the surrounding area.

In Figure 1, an overview of the concept based on 2D is depicted. Each data item is related to a fixed cartesian location $l = (x, y)$. Data items are of interest for users in an area defined by a circle of radius r_l around the data item's location l. Data items are replicated only within the radius r_l. In the remainder of this paper, we refer to the data item's location as *Point Of Interest* (POI) and to the region around it as *Region Of Interest* (ROI).

The structure of a data item is depicted in Figure 2 containing header fields and a payload field. The first header field contains the position $l = (x, y)$ followed by the radius r_l defining the ROI, a timestamp t which is used for consistency checks, the unique ID of the creator, and a name. The name and the unique ID of the data item creator form a unique data item name.

Due to limited resources of mobile nodes and limited bandwidth of wireless connections [22], data forwarding by all nodes in the network can drain resources and overload the network. Further, disconnections can lead to partitioning of nodes and inconsistencies among replicas. Our approach addresses these issues by controlling data replication and dissemination in two ways. First, data items are only replicated within their ROI which limits dissemination overhead to the ROI and lowers the probability of partitioning. Second, communication overhead is reduced by separating *store-only nodes* R_s from *forwarding nodes* R_f. When an R_s node receives a data item, it just stores the data locally, whereas an R_f node also forwards the data item to its neighbors. The distinction between R_s and R_f nodes is made depending on their locations. Hereby, each node decides upon its type locally and autonomously without additional communication overhead.

3.2 Forwarding Node Selection

Based on its position and local node density, each node autonomously decides if it wants to forward messages. We basically construct several polygons around the POI at different distances which are rotated to cover the area optimally. For example, the regular polygons defined by an angle φ can be squares or hexagons. (A similar concept based on hexagonal grids for the selection of forwarding nodes has been proposed in [16].)

In detail, the ROI is divided into n sectors $s_{\alpha_{j=0}}, ...s_{\alpha_{j=n-1}}$ of equal size $\beta = \frac{360}{n}^\circ$ (note, that $\varphi = 2\beta$) and m concentric circles $r_{i=0}, ...r_{i=m-1}$ with radii of different size, where the difference between radii decreases with increasing distance to the center of the POI, so that transmission ranges of optimal placed nodes keep intersecting. Optimal forwarding positions are defined in the center of the POI and on specific intersection points between section borders s_{α_j} and circles r_i. For circles r_i with $i \bmod 2 = 0$ optimal positions are intersections between r_i and every second arc border, starting with the arc with angle $\beta, 3\beta, 5\beta$, etc. Circles with $i \bmod 2 = 1$ have optimal intersection positions every second circle sector border starting with the sector with angle 0, β, 2β, etc. By knowing these optimal intersection positions and their current positions, nodes decide to become forwarding nodes if they reside at such an intersection.

In Figure 1, a sample structure of our approach for $n = 8$, $\beta = \frac{360}{8}^\circ$ with three radii r_0, r_1, and r_2 is depicted. In Figure 3, parts of the ROI are presented which show the intersections of sector borders and circles, forwarding nodes residing at these intersections, and shaped areas in proximity of the intersections which are used to enlarge the areas of optimal positions.

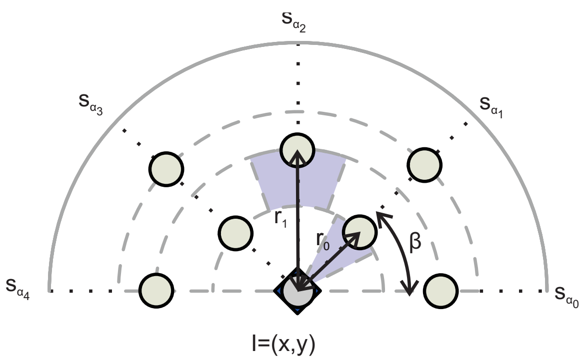


Figure 3: Detailed view of SHAFT forwarding structure.

In general, it cannot be assumed that a node exists at each optimal forwarding position. Thus, the area of optimal positions is enlarged autonomously by each node. At a given optimal position determined by the indices i and j (more precisely, determined by the radius r_i and the angle α_j), this area is limited by the section borders $s_{\alpha_j - \beta}$ and $s_{\alpha_j + \beta}$ and circle radii r_{i-1} and r_i (for $i = 0$ the area is a sector limited by the center of the POI and r_0). With increasing node density the area is reduced because it is heuristically assumed that the likelihood that a node is near the optimal position is higher than for low node densities.[1] In Figure 4, this principle is depicted for low and high node densities.

In the current implementation, the size of the area depends linearly on the node density and is defined by the angle $\gamma_k = \alpha_j \pm \frac{\beta}{d_k}$, where d_k is the local node density observed at node k. It is noteworthy that γ_k is calculated locally and, thus, γ_k may differ between nodes as depicted in Figure 5.

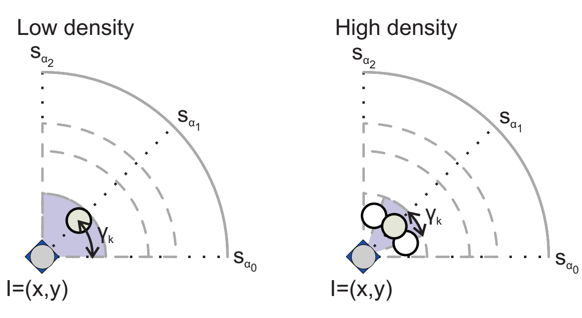


Figure 4: Segment adaptation based on local node density.

[1]Note, that for node distributions diverging from a uniform distribution of nodes in the sectors, this heuristic assumption does not hold any more.

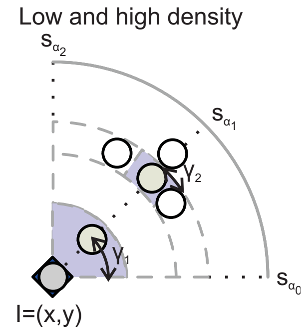


Figure 5: Segment adaptation based on local node density with nodes with different densities.

3.3 Data Dissemination

Data dissemination is triggered whenever a data item is created or modified. First, the node which modified the data item broadcasts the item together with a unique message ID to its neighbors within transmission range. Nodes which are within the ROI (the replication radius r_l is stored in the header of the message) make a local copy if they have sufficient resources, e.g., memory. Nodes on optimal forwarding positions assign themselves the R_f state and forward the data item message via broadcasting. If a message with the same unique message ID arrives multiple times at a node, only the first message is forwarded and subsequent messages are ignored.

3.4 Data Request and Reply

A node which requests a data item can identify the information either by name or by location and broadcasts a search message using this identification information. The message is assigned a unique ID consisting of a the unique node ID and a counter of the node. The message is forwarded via broadcast until a maximum hop count or a node which holds a replica of the item is reached. If the data item is found, it is transfered back via the inverse request route. At the moment, it is assumed that requests are issued from within the ROI. But this could be easily extended to requests from outside the ROI using a geo-routing protocol (e.g. [8]).

4. USE CASE: PARKING LOTS

Although the presented geo-based data dissemination approach SHAFT is a generic approach, we want to discuss its usefulness by introducing a typical use case for mobile data dissemination, i.e., *cooperative management of parking lots*. In city areas, modern cars equipped with local navigation systems guide the driver towards a specific address. In proximity of this address, the driver then searches for a free parking lot. The solution presented in this paper can be used to communicate free parking lots by car-to-car communication. Hereby, cars are expected to sense parking lots (potentially enriched with information, like the size of the free parking lot) by on-board sensors, e.g., sensors used for parking assistance by measuring distances to surrounding objects. Since a central solution or road-side units based infrastructure are too costly and information is only of very local interest, cars use opportunities to communicate free lots among each other.

In this scenario, the free parking lot is the POI and the ROI is the surrounding area determined by a configurable range. This refers to the situation, that only cars are interested in the parking lot, which are close enough to the POI. It would not make sense to distribute the parking lot information too far, since drivers would not like to

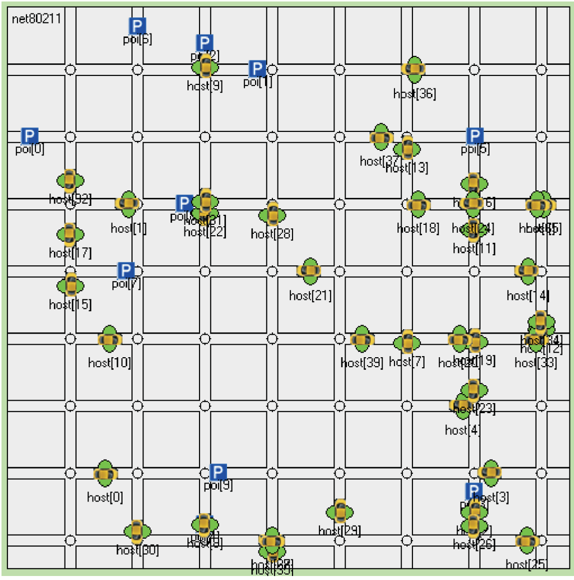


Figure 6: Overview of simulation scenario.

be guided to a parking lot far away from their desired destination. In case a car detects a free parking lot, it generates a new replica assigned to this position and disseminates the information based on the SHAFT algorithm. Cars in proximity searching for parking lots are now navigated to this position. In case a lot is occupied, replica update is performed to avoid that cars navigate because of old information.

Cars entering the area of interest are assumed to require a free parking lot. After a fixed time period, the cars leave the lot again and move out of the area. For every car moving out of the area, a new car enters the area at a random position. Figure 6 gives an overview of the simulated scenarios showing parking lots, cars, and the directions used in the Manhattan mobility model.

In the simulation setup, cars are simulated by nodes which move according to the Manhattan mobility model (moving back and forth, right and left) in an area of 500 m x 500 m. Hereby, the street areas only determine the mobility behavior, but do not model any additional features, like solid obstacles (buildings, etc.). Therefore, besides concurrent access to the wireless medium, distance is the major factor for link quality degradation and link breaks. Using different node densities allows to investigate different average distances of communication partners.

4.1 Simulation Setup Details

The experiments were conducted by means of simulation using OMNet++ [26] and the INET framework. Each simulation was run 10 times with different seeds. Each node represents a car. Nodes move on a square-shaped map of 500 by 500 meters with constant speed of 1m/s following the Manhattan mobility model with building block size of 50 meters, and street width of 10 meters. Ten parking areas are placed along streets by random. Each parking area consists of $\lceil n/10 \rceil$ parking lots, where n is the total number of nodes. So each node can find a parking lot under optimal conditions. The radius r_l of parking areas is set to 200 meters.

The number of nodes is set to 2, 5, 15, 20, 30 and 40 to measure the effects of different node densities on the dissemination approach. Nodes' pausing (car parking) duration lasts 30 minutes. When the parking duration has passed, the node is replaced by a new node which is placed at a random position.

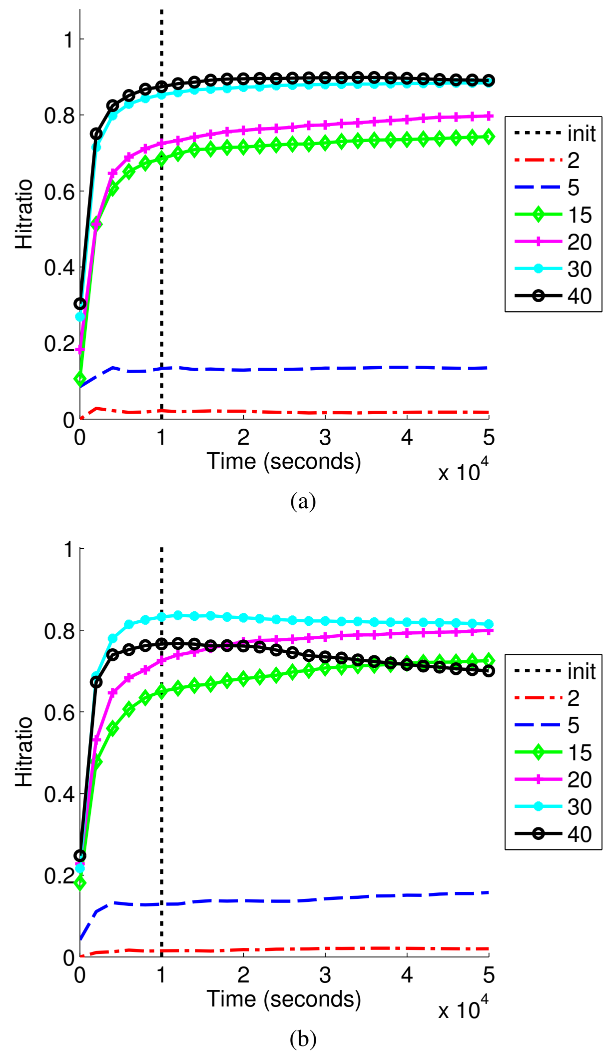


Figure 7: Hit ratio for (a) SHAFT, and (b) flooding.

The request rate of parking lot lookups is only controlled by nodes' movement. When a node enters a ROI, it issues a request which times out after 10 seconds. For SHAFT, β is set to 30°, and the radii of the concentric circles are set to $r_0 = 100$, $r_1 = 150$, and $r_2 = 175$ meters.

Nodes communicate in 802.11g ad-hoc mode with a reduced maximum data rate of 2 MBit/s and a communication range of 150 meters. For the transmission of broadcast messages, UDP broadcast is used. Other messages are sent via UDP unicast. Broadcast messages are rebroadcasted immediately by forwarding nodes. All nodes cache each received message as long as the node is within the region of interest with which the message is associated. When a node leaves a region of interest, then all messages stored by the node associated with this region are deleted.

At simulation startup all parking lots are free and no data items do exist. For evaluation, the startup phase of 10000 seconds is truncated as described in [7] because in reality some nodes would already hold replicas and parking lots might already be in use.

5. EXPERIMENTAL EVALUATION

Now, we present results for the parking lot use case scenario based on the Manhattan mobility model while using SHAFT and flooding. The flooding technique is expected to achieve utmost possible data availability in the network while causing remarkable messaging overhead. By using SHAFT, we aim at reaching similar data availability while reducing the messaging overhead significantly. We will investigate both techniques under varying node densities because different node densities cause different average distances between nodes and, consequently, determine connectivity and mutual medium access.

5.1 Metrics

For evaluation purpose, we will use both metrics describing the general performance of SHAFT and metrics demonstrating the performance of SHAFT for the particular cooperating parking lot management use case. The general metrics used to evaluate the approach are as follows:

Hit ratio: This number is the ratio between the number of received replies and the number of data item requests (successful and in-time). The hit ratio is a measure of the availability of data in the opportunistic network.

Average number of replicas: This number is the average number of replicas located at each node. By investigating this metric, insights about average memory consumed on each node can be derived and the spreading of information can be estimated.

Number of packets: This sum counts the number of packets generated in the system for dissemination, that are, newly created data items and updated data items. By comparing the number of packets, the overall messaging overhead is investigated.

Additionally to the dissemination-oriented metrics, the parking lot scenario was evaluated by using the following metrics:

Average parking lot search time: This time is the response time of the system between the sending of a parking lot request until a parking lot is found (if it can be found at all).

Successful parking query ratio: This number is the ratio of the number of successful parking lot queries and the total number of parking queries. A parking query is successful, in case a free parking lot is found.

5.2 Results

Here, simulation results for the parking lot scenario with SHAFT and flooding are presented. Results show that SHAFT reduces messaging overhead for distribution and update of data items while producing similar results with respect to hit ratio, parking lot search times, and successful parking queries.

5.2.1 Hit Ratio

The hit ratio is used to investigate data availability assured by SHAFT. In general, we expect that lower node densities cause lower hit ratios than high densities because the probability to find a node in range is lower. In Figure 7(a), the hit ratio for SHAFT is depicted (the vertical line separates the instable starting conditions from the stable system status which is used for further evaluation). For increasing node densities, the hit ratio increases and converges towards 0.02 for 2, 0.14 for 5, 0.74 for 15, 0.80 for 20, and 0.88 for 30 nodes. For higher node densities, starting with 40 nodes, the hit ratio slightly decreases after some time due to overloaded transmission queues which lead to packet loss. This behavior is also observed for flooding but already for lower densities.

For flooding, the hit ratio increases only up to the density of 30 nodes (0.02 for 2, 0.16 for 5, 0.73 for 10, and 0.8 for 20 nodes), as depicted in Figure 7(b). For higher densities the hit ratio decreases due to packet loss. It can also be seen that the hit ratio starts to decrease for 30 nodes after a while due to packet loss (the maximum hitratio for 30 nodes is 0.84 and 0.77 for 40 nodes).

5.2.2 Average Number of Replicas

Theoretically, for perfect dissemination and overlapping parking areas, the maximum average number of replicas per node would be 10 because there exist 10 parking lots. In practice, parking lots do not overlap and some nodes are out of range from others. In Figure 8, the average number of replicas in the network for SHAFT and flooding are given. It can be seen that simple flooding reaches more nodes and, thus, nodes host more replicas than by using SHAFT. But starting with 30 nodes, message overhead leads to a steep increase of dropped packets with flooding. For 40 nodes, SHAFT allows to store more replicas than by using flooding due to less packet loss.

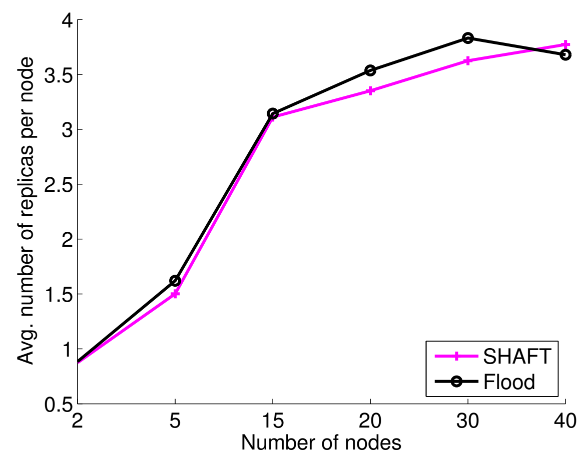
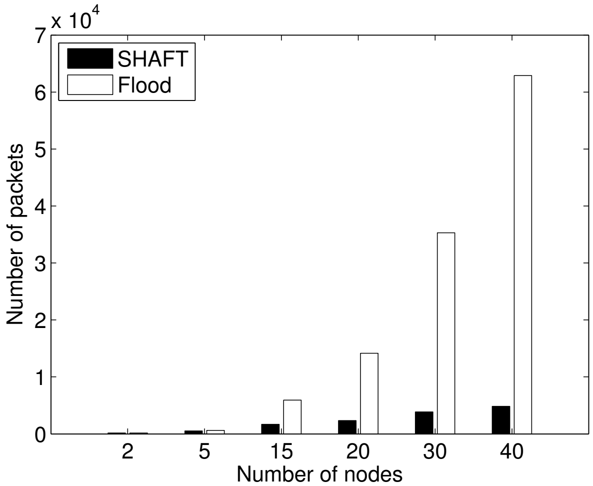


Figure 8: Average number of replicas per node for SHAFT and flooding under varying node densities.

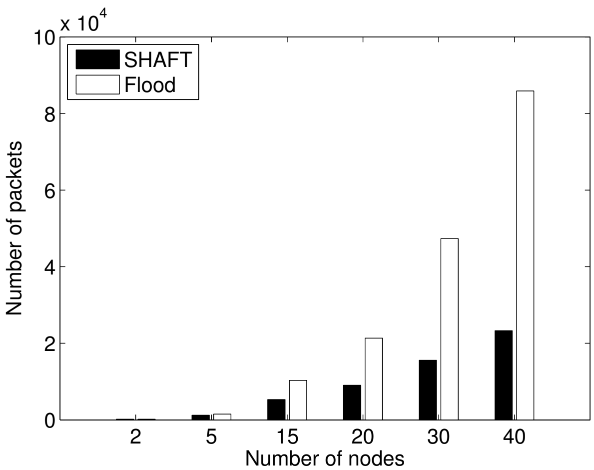
5.2.3 Number of Packets

In Figures 9(a) and 9(b), the number of packets generated for distribution of new data and data updates is depicted. Due to the little number of forwarding nodes, the number of packets remains low for SHAFT while the number of packets increases exponentially for flooding. This saving in overhead is the major benefit of SHAFT. During simulation time SHAFT generated (updated) 142 (321) packets for 2, 503 (1725) packets for 5, 1670 (6997) packets for 10, 2318 (11363) packets for 20, 3831 (19407) packets for 30, and 4835 (28118) packets for 40 nodes. Flooding leads to 144 (326), 603 (2114), 5917 (16219), 14135 (35487), 35292 (82638), and 62897 (148804) packets for 2, 5, 10, 20, 30 and 40 nodes respectively.

Compared to flooding, SHAFT achieves a reduction in message overhead by up to 92.3% for newly generated data items and 81.1% for updates. These encouraging results demonstrate that SHAFT can significantly avoid messaging overhead.



(a)



(b)

Figure 9: Packets generated during simulation for distribution of (a) created and (b) updated data items for SHAFT and flooding.

5.2.4 *Use Case Specific Investigations*

For the selected use case, two investigations should demonstrate the usefulness of the approach: (i) the average parking lot search time and (ii) the ratio of successful parking lot queries.

In Table 1, the average parking lot search times for SHAFT and flooding are depicted. It can be seen that both methods produce similar results (although, as demonstrated before, SHAFT generates less traffic).

Now, we will investigate the success of parking queries. A parking query is issued when a replica is received with information about a free parking lot. A parking query is not successful if a node arrives at a parking lot which is already occupied. In Figure 10 the ratio of successful parking queries is depicted for SHAFT and flooding. For densities of 2 and five 5 (cars) the success rate is higher than for higher densities because the probability that a parking lot is already in use is lower (only 2, respectively 5 cars share 10 parking lots), while for higher densities only one parking lot exists for each car. It can be seen that flooding slightly outperforms

	SHAFT		**Flooding**	
Nodes	**Mean**	**Std**	**Mean**	**Std**
2	178.11	14.45	185.60	11.76
5	185.46	7.38	189.12	9.20
15	179.04	11.16	173.61	13.02
20	205.63	11.98	207.92	16.76
30	219.78	11.20	222.31	11.59
40	229.47	5.94	228.34	6.92

Table 1: Mean and standard deviation of average parking lot search times in seconds for SHAFT and flooding for different number of nodes.

SHAFT up to 30 nodes. For 40 nodes, SHAFT performs better, again due to less packet loss.

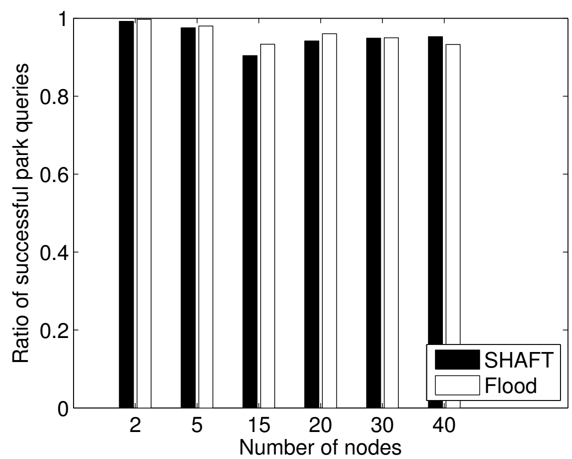


Figure 10: Rate of successful parking queries for SHAFT and flooding.

6. CONCLUSIONS

We have introduced the *Sector Heads Aided Flooding Technique* (SHAFT) which allows to keep data available around a point of interest in an opportunistic mobile network. While SHAFT aims at achieving data availability similar to flooding based data dissemination, it aims further at reducing the communication overhead significantly. SHAFT achieves this improvement by selecting nodes for forwarding which reside at specific perfect positions determined by an underlying geometry. These sets of perfect positions can be increased by including additionally the area nearby the perfect positions in case node density is low. Thus, SHAFT assures good performance even in case of low node density.

We applied the approach to a cooperative parking lot management simulation where nodes move according to the Manhattan mobility model and navigate towards parking lots. The results achieved are promising. While SHAFT reaches similar data availability and parking lot service success rates as flooding, it allows to reduce messaging overhead by up to 92.3% (highest density) for newly created data and by 81.1% for update messages (again highest density).

In future work, we plan to investigate the approach in more detail with particular focus on the usefulness for distributed replication, like, investigating the achievable replica consistency.

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