Information Hovering: A New Approach for Performance Acceleration of Wireless Push Systems

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***Abstract*—Wireless data broadcasting systems are typically assigned limited operational bandwidth due to their usually wide spatial coverage. This limitation raises issues of increased client waiting times, especially as the total size of the data to be disseminated increases. This problem could be partially or fully resolved by offloading part of the data to local mobile ad hoc subsystems. To this end, a novel merging of wireless data broadcasting and information hovering is proposed. The information hovering subsystem handles the least popular data items, allowing the most popular ones to be efficiently disseminated through the central wireless broadcasting. Both bandwidth-greedy and bandwidth-conserving cooperation algorithms are proposed. The validity of the proposed merged scheme is evaluated through simulation in a realistic MANET with locality of data demand. The results show considerably decreased mean waiting times in any case.**

***Index Terms*—information hovering; wireless push; MANET;**

I. Introduction

Recent years have witnessed profound advances in telecommunications and mobile computing. The trend is to provide ubiquitous access to a seemingly ever growing amount of information. However, the sharp increase of the online users and the number of provided services pose an issue of efficient data dissemination, since any wireless channel has limitations in the rate of data that can be transferred successfully. In related literature, two generic solutions to this problem are the reduction of transferred data through the exploitation of self-correlation, and the collaborative networking of the users.

The first category can be considered as a server-side solution and a most representative example is wireless data broadcasting. In this case the system's architecture typically considers a large number of clients dispersed over an area covered by a single wireless system. The clients are interested in a common set of data, albeit with varying individual preferences. A central authority creates a common data broadcast schedule and transmits it over the covered area. The objective is to minimize the clients' mean waiting time or other similar metric. The central authority is more or less initially unaware of the popularity of each data item. This knowledge is acquired gradually, typically through a lightweight, client feedback mechanism, and the schedule is adapted accordingly. This technique is typically applied to Instant Messaging Services, Tweets and audio-video broadcasting (e.g. DVB/H, DAB+).

Information Hovering is a relatively new information dissemination paradigm in Mobile Ad Hoc Networks (MANETs), and a typical example of collaborative networking of end-users. Hovering allows decoupling information from its host and promotes coupling this information with a specific geographical location. The information hovers from one mobile device to another, in a quest to remain in the vicinity of its anchoring geographical location, and be available to users that are entering or present in this. The main requirement of a single piece of hovering information is to keep itself attached to its location, despite the unreliability of the mobile device on which it is stored. The Information Hovering concept can be used in a variety of applications in MANETs with characteristic usage examples provided in [1].

In the context of the present work a novel MANET-oriented merging of wireless broadcasting and information hovering is presented. The logic of the merge follows the fact that any wireless broadcast system is typically assigned bandwidth that is inversely proportional to its area of coverage. Thus, in order for the system to achieve adequate mean waiting times, a portion of the data dissemination task can be offloaded to a local hovering scheme. The number of items to be offloaded is defined heuristically. Two cooperation schemes are proposed, targeting solely mean waiting time (MWT) minimization and MWT-hovering bandwidth conservation balancing respectively. Simulation under realistic conditions yielded performance superior to stand-alone approaches, in all cases.

The remainder of this paper is organized as follows: Section II provides an overview of the related work on data broadcasting and hovering. Section III presents the novel merging of the two data dissemination schemes. Validation through simulation takes place in IV. Conclusion and future work insights follow in Section V.

II. Related Work

A. Wireless Data Broadcasting

Research on optimal data broadcast scheduling initially focused on the minimization of the clients' MWT. [2] presented the lower bound of the MWT, showing that the knowledge of the data items' request probabilities and sizes is sufficient for achieving it. A scheduling algorithm was also defined, which

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achieved the minimum MWT at the cost of inhibitory computational complexity. [3] introduced a "reservation" system which favors client waiting time in the case of big sized items.

In light of the high complexity of the initial scheduling algorithms, several approaches have been proposed to simplify the data broadcasting problem, a most influential being the Broadcast Disks model [4]. A great deal of work has been done based on this model, studying data prefetching, caching and indexing, hybrid data broadcasting, as well as scheduling strategies and noise interference. An overview of all these concepts can be found in [5]. More recent works have focused on the minimization of psychometrics [6] instead of the mean waiting time, in an effort to provide QoS.

Authors in [7] have introduced adaptivity for wireless push systems with locality of demand, by employing a learning automaton to process the incoming client feedback in. More efficient feedback schemes for dynamic environments where formulated in [8], employing the principle of maximum entropy to speed up convergence. Finally, broadcast scheduling algorithms with minimal complexity and optimal performance where presented in [9, 10].

B. Information Hovering

The term of Information Hovering was first introduced in [11], and formally defined later in [12]. A more detailed description is provided in [13]. The efficiency of the hovering relies on the data routing scheme employed both inside and outside the hovering area.

Flooding based schemes, such as *epidemic routing* [14] can be applied to the entire network to effectively serve such a paradigm, achieving high percentage of nodes in the hovering area receiving the relevant message (high reachability). However, this is done at the expense of a large number of redundant messages which strain the communication channel and lead to extensive contention and large latency of message delivery. In order to make efficient use of the available resources, one may choose to apply epidemic routing merely in the hovering area. However, this approach may also reduce the achieved reachability in cases of low traffic density. Low traffic density in the hovering area may cause the network to become intermittently connected. This implies that sections of the network within the hovering area which are partitioned from the information sources may never receive the messages, thus decreasing the achieved reachability.

One approach to address this challenge is to allow controlled exchange of messages outside the hovering area. The reasoning behind this approach is that informed nodes outside the hovering area can serve as information bridges towards partitioned uninformed areas, thus increasing message reachability. In addition, since epidemic routing is avoided, the number of exchanged messages is reduced. Authors in [15] follow this reasoning to allow epidemic dissemination of messages in an extended area beyond the hovering area. They demonstrate through simulations that such an approach can increase the recorded reachability. Authors in [16] adopt an alternative approach which involves employing epidemic routing within the hovering area and probabilistic flooding outside the hovering area. This approach allows controlled exchange of messages in the entire network thus offering a wider choice of available paths. In [17], the authors extend their work in [16] to render the proposed protocol adaptive in the sense that the rebroadcast probability outside the hovering area is adaptively regulated based on estimates of the traffic density within the area. They demonstrate through simulations that the proposed scheme is successful in satisfying the design objectives and outperforms other candidate hovering protocols.

III. Description of the Proposed System

In an area covered by a wireless broadcast system, several mobile clients need to be informed of some random local events. In a VANET scenario these events could be the availability of parking, notifications on accidents, traffic conditions etc. which have varying degree of importance to each client. The popularity of each event is made known to a central broadcast scheduling authority through a feedback mechanism, as in [7]. The authority then creates a common broadcast schedule of these events and transmits it over the whole area in a streaming fashion. The clients simply listen to the stream and retrieve the information they are interested in.

The problem is that as the number of events increases the theoretical lower bound of the clients' mean waiting increases as well [2]. The same thing happens should we increase the needed amount of information per event. In light of these facts, the question posed is the following:

Could we reduce the clients' mean waiting time below the theoretical lower bound by allowing event information to hover around the area it refers to?

To answer this question we must define which events will be offloaded to the local hovering subsystem and which will remain at the jurisdiction of the wireless broadcast dissemination scheme.

A. Offloading the Wireless Broadcast System

We adopt the following notation: N is the total number of events, e_i denotes the i^{th} event, $i = 1 \dots N$. Each event e_i has:

- A request probability $\pi_i \in [0, 1]$ (event popularity metric).
- A description of l_i bytes.

Intuitively, the number of data items to be assigned to the hovering subsystem is a function of the total strain on the mobile users. In other words, one could greedily assign all data items to the hovering subsystem, leaving nothing for the wireless broadcasting. This would obviously drop the mean waiting time to minimal levels (assuming of course that the serving time due to hovering is tantamount to data pulling and therefore trivial). It is imperative to keep the strain on the hovering in check in order to achieve tunable cooperation with the wireless broadcasting system.

Following the conclusions of [17] we define the $b_i \in [0, 1]$ parameter as the probability of a client succeeding in being

informed via the hovering. In other words, hovering cannot guarantee absolutely successful data delivery to every interested client in the hovering area. In the best case scenario it holds that $b_{\max} \approx 1$. We can then define the following metric:

Rule 1: Let b_i be the efficiency of the hovering, regarding the event e_i. A metric of the total strain on the hovering can be expressed as $B = \sum_{i=1}^{N_H} b_i \cdot l_i$ (Measured in data size units). N_H is the total number of events assigned to the hovering.

Explanation: See Appendix. ■

Based on this metric we can define the number of pages to be assigned to the hovering subsystem via the following rule:

Rule 2: Assume a sorting I of the events $e_j, j \in I$ by ascending $\frac{\pi_j}{l_j}$ value, and a given strain B_o. One should assign to the hovering subsystem the first N_H events for which it holds that:

$$\sum_{j=1}^{N_H} b_j \cdot l_j \leq B_o, \sum_{j=1}^{N_H+1} b_j \cdot l_j > B_o \qquad (1)$$

Explanation: See Appendix. ■

Based on Rule 2 we can define a bandwidth-greedy algorithm that seeks solely to minimize the clients' mean waiting time. We assume that the central scheduling authority has acquired the events' popularity $\pi_i, i = 1 \ldots N$ through the feedback mechanism of [7]. At this point, the central authority chooses the events to be hovered according to rule 1. For every chosen event e_i the authority sets a flag on the event's description and broadcasts it over the covered area. The package also includes the coordinates of the event's location center and its radius. Upon receiving this marked package, *all* users near the event's location initiate its hovering. In this way the hovering efficiency of the event b_i has the potential to reach the maximum value b_{max}. However, no bandwidth may be left for hovering other local events in this area. This scheme is formulated as Algorithm 1 (GREEDY-COOP).

Algorithm 1 The GREEDY-COOPeration algorithm.

Input: The events $e_i : \{l_i, \pi_i\}, i = 1 \ldots N$; The total strain B_o.

Output: The events to be assigned to the hovering subsystem.

1: Produce a sorting I of the events by ascending $\frac{\pi_j}{l_j}, j = 1 \ldots N$.
2: Set $B = 0$;
3: **for** $j \in I$ **do**
4: Set $B = B + b_{max} \cdot l_j$.
5: **if** $B < B_o$ **then**
6: Set hovering flag to ON;
7: **else**
8: **break;**
9: **end if**
10: **end for**

The GREEDY-COOP algorithm disregards any concern of bandwidth limitations in the hovering subsystem. All active local clients are asked to participate in the hovering of the information related to event e_i. However, it is possible that approximately the same mean waiting time could be achieved even if just a portion of the active clients hovered the specific event information. This approach is reflected in Algorithm 2 (PRESERVE-COOP). The scheduling authority embeds the $\widehat{b}$ quantity in the event information, instead of the binary flag of Algorithm 1. Upon reception of this packet, any local client *flips a biased coin* with $\widehat{b}$ probability of participating in the hovering. In this way, bandwidth in the local hovering subsystem can be saved for use in other applications (or for hovering other local events).

Algorithm 2 The PRESERVE-COOPeration algorithm.

Input: The events $e_i : \{l_i, \pi_i\}, i = 1 \ldots N$; The total strain B_o; The desired hovering efficiency $\widehat{b}$.

Output: The events to be assigned to the hovering subsystem and the probability a client participating in the hovering.

1: Produce a sorting I of the events by ascending $\frac{\pi_j}{l_j}, j = 1 \ldots N$.
2: Set B=0;
3: **for** $j \in I$ **do**
4: Set $B = B + b_j \cdot l_j$.
5: **if** $B < B_o$ **then**
6: Set event's hovering probability to $\widehat{b}$;
7: **else**
8: **break;**
9: **end if**
10: **end for**

Having defined the offloading scheme, we proceed to describe the employed hovering subsystem in detail.

B. Description of the Employed Hovering Protocol

The hovering protocol utilized in this work is based on the protocol proposed in [17]. As demonstrated in [17] the protocol is able to achieve high reachability within the hovering area with low number of exchanged messages, as required.

The protocol applies epidemic routing within the hovering area and probabilistic flooding outside the hovering area. The use of probabilistic flooding suggests that mobile nodes (e.g. vehicles) lying outside the hovering area, upon receiving a useful message retransmit the message with probability *p*, which is calculated based on a probability function *f*. The probability function of choice is a Gaussian-like function as shown in equation (2).

$$p = e^{-\frac{d^2}{2\sigma^2}} \qquad (2)$$

where d, is the distance of the node from the hovering area and σ is the standard deviation. The value of σ is a measure of the area in which critical message forwarding is allowed with high probability. The size of this area and thus the value of σ must be adaptively regulated based on the connectivity of the network within the hovering area. The smaller the connectivity is, the larger σ must be, in order to provide more message forwarding opportunities. The parameter which is known to affect network connectivity, when the transmission range is constant, is the node density within the hovering area. The



Fig. 1. Road map of the reference model used in all simulation experiments. It represents a section of the road network in the cities of Bellevue and Redmond in Washington.

higher the node density is, the higher is the probability of high connectivity and so a lower value of σ suffices to guarantee high reachability and low number of exchanged messages. The function, mapping the node density to the desired value of σ is determined using several simulations runs and considering a least squares fit between the obtained curves. The exact shape of the function can be found in [17].

The node density within the hovering area, which is required to calculate the rebroadcast probability, is a global quantity which is impossible to calculate accurately in a distributed fashion, in cases where the mobile network is intermittently connected. Estimates of the node density are thus required. The metric used to estimate the node density, is the average number of neighbors of the nodes residing in the hovering area. The average number of neighbors in the hovering area is calculated using a weighted moving average algorithm. The relationship between node density and the average number of neighbors is derived in [17] and is shown in equation (3):

$$w = n\frac{4Rr + \pi r^2 - r^2}{8R^2} \tag{3}$$

where w is the average number of neighbors in the hovering area, n is the number of nodes in the hovering area, r is the transmission range of nodes and R is the radius of the hovering area.

IV. Experimental Evaluation

The proposed merging of wireless data broadcasting and hovering is tested through simulation. The efficiency of the proposed GREEDY-COOP and PRESERVE-COOP algorithms is tested in terms of achieved mean waiting time. Hovering bandwidth requirements are also discussed for both algorithms.

A. Simulation configuration

The reference model used in all simulation experiments, represents a VANET in a section of the road network in the cities of Bellevue and Redmond in Washington. It includes congested arterial streets and a saturated freeway as shown in Fig. 1. The dimensions of the area are $4.5 \times 2.5Km$. The modeled freeway includes lanes for general traffic, HOV/Bus lanes, 3 closely spaced interchanges, 6 ramp meters, and 2 collector-distributor roads. The total number of vehicles is approximately $3,000$. We conduct all the simulation experiments using VISSIM [18], a microscopic simulation tool.

We identify $N = 100$ random hovering areas in this road network and an equal number of events $e_i, i = 1 \ldots 100$ referring to e.g. traffic jam, parking availability, road conditions etc. Each event has an associated description of size $l_i \in [1, 50]Kbytes$. The popularity of the events is assumed to follow the ZIPF distribution [19], with all simulations being repeated for the values $[0.1 : 0.1 : 0.6]$ of the ZIPF skewness parameter θ. Before each simulation $250,000$ random event queries are generated based on the ZIPF distribution, and are distributed equivalently to all $3,000$ clients. A client may have only one query pending at any given time. Each simulation run lasts until the depletion of all client queries.

The mean net bitrate of the wireless broadcast system is set to $25KBps$. In order to simulate noise and interference, any broadcasted data item has a 0.95 probability of successful delivery.

Each simulation experiment runs with a different seed number. The output of each simulation experiment is a text file which contains records for a number of fields such as the vehicle's id, the simulation step, the coordinates of each vehicle at every step, etc.

In order to simulate the information hovering scheme presented in Section III-B we have developed an application in C++ which processes the text files generated by the VISSIM simulator. The application takes a number of input parameters:

- *Vehicle Transmission Range*: Each vehicle selects its transmission range in a min - max interval according to a uniform distribution. The min and max values are the input parameters.
- *Hovering Area*: it can be defined as a circular area with input parameters the coordinates of the center and the radius of the circle.
- *Successful transmission probability*: In order to model problems in the communication channel which may lead to messages being lost, every transmission is characterized by a probability of successful delivery.
- *Scanning Frequency*: This parameter sets the frequency with which each vehicle scans in its transmission range for any vehicles to exchange information with.

In terms of hovering we consider the following parameter values: *Frequency of Scanning*: 0.5 seconds, *Transmission range*: 140-220m, *Successful Transmission Probability*: 0.8.

Finally, we assume that the system has undergone an initialization procedure so that at its initial state, the central scheduling authority has a good approximation of the events' popularity distribution, and all vehicles within the hovering areas possess the useful message.

B. Results

The comparison of the mean waiting times achieved by the GREEDY-COOP, the PRESERVE-COOP and the stand-alone broadcasting (no hovering) are shown in Fig. 2. The

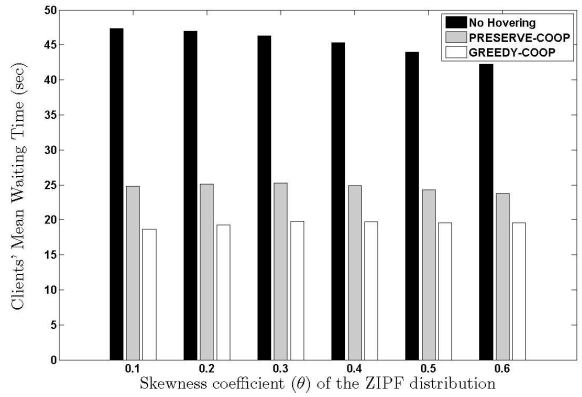


Fig. 2. Achieved mean waiting times by GREEDY-COOP and PRESERVE-COOP and comparison with the case of no hovering (wireless broadcast only). The x-axis represents gradual increase in the similarity of the users' preferences. The cooperation schemes perform more than 50% better.

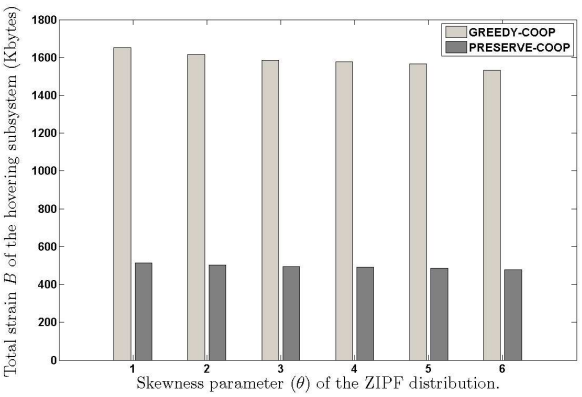


Fig. 3. Total strain imposed on the local hovering subsystems by the GREEDY-COOP and the PRESERVE-COOP. While both algorithms achieve similar mean waiting times, GREEDY-COOP strains the hovering subsystem ≈ 3 times more than the PRESERVE-COOP.

desired total strain B_0 is $1500Kbytes$ and $450Kbytes$ for the GREEDY-COOP and the PRESERVE-COOP respectively. Notice that both algorithms perform $40\% - 50\%$ better than the stand-alone scheme. The clients generally retrieve useful information half a minute earlier, raising their chances of early notification (and e.g. avoiding traffic).

It is worth of notice that although GREEDY-COOP and PRESERVE-COOP have just $5 - 7secs$ difference in the achieved mean waiting times, the strain that they impose on the hovering sub-system is unbalanced. As shown in Fig. 3 GREEDY-COOP causes $2.5 - 3$ times more strain than the PRESERVE-COOP. Notice that for the chosen desired strain B_0 values, both algorithms assign approximately the same number of events to the hovering subsystem (40-41 events). PRESERVE-COOP however asks (by choice) only a 30% of the clients in any hovering area to contribute to the hovering process. It is evident that this portion is sufficient for the client (vehicle) density of the employed data set.

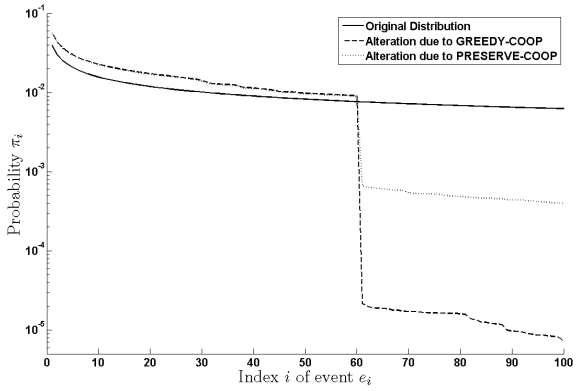


Fig. 4. Alterations on the central authority's perception of the clients' preferences, due to the intervention of the hovering. Notice that the events are shown sorted by descending altered popularity.

The difference in the degree of strain (which can also serve as a metric of the required bandwidth) can also be explained with the help of Fig. 4. When hovering is present, a certain number of clients is informed by the hovering system instead of the wireless data broadcasting. Naturally, these clients do not provide feedback to the central scheduling authority. Thus, the authority obtains an altered form of the events' popularity. The effects of both GREEDY-COOP and PRESERVE-COOP are shown in Fig. 4 alongside the original event popularity distribution. Both algorithms offload the least popular (and more sizeable) events to the hovering sub-system, with different strain degrees. Notice however that optimal broadcast scheduling algorithms [9] define a low occurrence ratio in the schedule for these pages anyway. Thus, even though GREEDY-COOP causes deeper reduction in the perceived popularity of the events, the scheduling authority cannot reduce the occurrence ratio much further. This inevitably results into a waste of local bandwidth.

V. Conclusion and Future Work

In the context of the present work, a cooperation scheme between wireless broadcasts systems and information hovering for MANETs was proposed. Bandwidth allocation limitations-especially in wide areas-hinder stand-alone wireless broadcast systems from achieving minimal serving times. Through the proposed merging of technologies, the broadcast system offloads some of the data to a local hovering scheme for further dissemination. The broadcast system thus handles dissemination of data with high general popularity, while the hovering scheme undertakes the distribution of data with high locality of demand. Simulations in a realistic VANET environment yielded better mean serving times than the stand-alone broadcast solution in any case. Furthermore, an algorithm for reducing the strain on the hovering system while still achieving better waiting times was proposed.

Future work is directed towards more realistic simulations of the physical and network layers, as well as the implementation of cooperation schemes that target environments where the

preferences of the clients change rapidly, accenting adaptivity issues.

APPENDIX

Explanation of Rule 1: The rule is empirical. Assume that the hovering area of event e_i covers a percentage s_i of the total area. Assuming spatially uniform distribution of clients, the following portion of the total clients will be served by the wireless broadcast system:

$$\pi_i - \pi_i \cdot s_i \cdot b_i = \pi_i \cdot (1 - s_i \cdot b_i) \tag{4}$$

i.e. the total number of clients, minus the ones that are in the hovering area *and* informed successfully via the hovering. Only these clients will give feedback to the wireless push system, resulting in an alteration of the scheduling authority's perception of the popularity of event e_i, by a multiplicative factor of $(1 - s_i \cdot b_i)$. Assuming that $s_i = constant$, the factor that defines the alteration is simply the b_i. Multiplication with l_i connects this quantity with the size of the conveyed message. Thus the aggregate strain on the hovering system is $B = \sum_{i=1}^{N_H} b_i \cdot l_i$. If $b_i = b_{max}, \forall i$, the strain is maximized. This can be used for defining a normalized expression of the strain:

$$B_u = \frac{\sum_{j=1}^{N_H} b_j \cdot l_j}{\sum_{j=1}^{N_H} b_{\max} \cdot l_j} \tag{5}$$

■

Explanation of Rule 2: The rule follows the *golden ratio* conclusion of [2]. According to it, in order to produce an optimal broadcast schedule that minimizes the mean waiting time (no hovering present), one must create a periodic broadcast schedule containing u_i occurrences of each data item:

$$u_i \sim \sqrt{\frac{\pi_i}{l_i}} \tag{6}$$

The u_i quantity measures the share of each event e_i in the total mean waiting time: lower u_i means higher share, in accordance with [2]. Rule 2 simply offloads the events with the highest share to the hovering subsystem, until the strain B_o is reached. Finally, notice that sorting the events by u_i or by $\frac{\pi_i}{l_i}$ produces the same result. ■

REFERENCES

[1] D. Konstantas and A. Villalba, "Hovering information: A paradigm for sharing location-bound information," in *Proc. of the European Conf. on Smart Sensing and Context*, 2006.

[2] S. Hameed and N. Vaidya, "Efficient algorithms for scheduling data broadcast," *ACM/Baltzer Wireless Networks*, vol. 5, no. 3, pp. 183–193, 1999.

[3] N. Schabanel, "The data broadcast problem with preemption," in *Proc. of the 17th International Symp. Theoretical Computer Science (STACS)*, 2000.

[4] S. Acharya, R. Alonso, M. Franklin, and S. Zdonik, "Broadcast disks: data management for asymmetric communication environments," in *Proc. of the ACM SIGMOD International Conf. on Management of data*, 1995.

[5] J. Xu, D. L. Lee, Q. Hu, and W. C. Lee, "Data broadcast," in *John Wiley and Sons: Handbook of Wireless Networks and Mobile Computing, Chapter 11*, 2002, pp. 243–265.

[6] S. H. Kang, S. Choi, S. J. Choi, G. Lee, J. Lew, and J. Lee, "Scheduling data broadcast based on multi-frequency in mobile interactive broadcasting," *IEEE Trans. on Broadcasting*, vol. 53, no. 1, pp. 405–411, 2007.

[7] P. Nicopolitidis, G. Papadimitriou, and A. Pomportsis, "Exploiting locality of demand to improve the performance of wireless data broadcasting," *IEEE Trans. on Vehicular Technology*, vol. 55, pp. 1347 – 1361, 2006.

[8] C. Liaskos and G. Papadimitriou, "Ultra lightweight adaptation processes for scheduling servers in push-based systems," in *Proc. of the 17th Annual Symposium of the IEEE/CVT*, 2010.

[9] C. Liaskos, S. Petridou, and G. Papadimitriou, "Towards realizable, low cost broadcast systems for dynamic environments," *IEEE Trans. on Networking, to appear*, 2011.

[10] C. K. Liaskos, S. G. Petridou, and G. I. Papadimitriou, "Cost-aware wireless data broadcasting," *IEEE Trans. on Broadcasting*, vol. 56, pp. 66–76, 2010.

[11] A. Villalba and D. Konstantas, "Towards hovering information," in *Proc. the First European Conf. on Smart Sensing and Context (EuroSSC)*, 2006.

[12] G. Villalba, A. Di Marzo Serugendo and D. Konstantas, "Hovering information - self-organising information that finds its own storage," in *Proc. of International IEEE Conf. on Sensor Networks, Ubiquitous and Trustworthy Computing*, 2008.

[13] G. Di Marzo Serugendo, A. Villalba Castro, and D. Konstantas, "Dependable requirements for hovering information," in *Supplementary Proc. of the 37th Annual IEEE/IFIP International Conf. on Dependable Systems and Networks (DSN)*, 2007.

[14] A. Vahdat and D. Becker, "Epidemic routing for partially connected ad hoc networks," Duke University, Tech. Rep., 2000.

[15] S. Hermann, C. Michl, and A. Wolisz, "Time-stable geocast in intermittently connected ieee 802.11 manets," in *Proc. of the IEEE Vehicular Technology Conf.*, 2007.

[16] A. Xeros, M. Andreou, A. Pitsillides, and M. Lestas, "Information hovering in vehicular adhoc networks," in *Proc. of the IEEE Workshop on Networking Intelligent Vehicles and Infrastructures (NiVi)*, 2009.

[17] A. Xeros, M. Andreou, A. Pitsillidis, and M. Lestas, "Adaptive probabilistic flooding for information hovering in vanets," in *Proc. of the 2nd IEEE Vehicular Networking Conf.*, 2010.

[18] "Vissim traffic simulator," http://www.vissim.de, 2011.

[19] L. Pietronero, E. Tosatti, V. Tosatti, and A. Vespignani, "Explaining the uneven distribution of numbers in nature: The laws of benford and zipf," *Physica A*, pp. 297–304, 2001.