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Towards Opportunistic Sensed Data Dissemination in Vehicular Environments

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***Abstract*—This paper proposes guidelines for the design of dissemination protocols for data sensed in vehicular environments in view of a number of potential applications. We organize the data dissemination process in three main tasks: *discovery, assessment*, and *seizing* of data exchange opportunities. One major problem is the limitation in bandwidth due to large amounts of data and short communication time slots. We elaborate on this problem by presenting preliminary results which favor an approach which disseminate date fairly over the nodes in the network.**

***Keywords*-Vehicular Sensor Networks (VSN), Vehicular Networks, Wireless Sensor Networks, Opportunistic Networks**

I. INTRODUCTION

Vehicular Ad-hoc Networks (VANETs) have caught the attention of both academia and industry due to their promising applications in the areas of vehicle safety, transport efficiency, and entertainment. Vehicular networks have emerged as means to disseminate data captured by sensors, such as GPS, chemical spill detectors, still/video cameras, vibration sensors, acoustic detectors, to name a few [1]. Possible applications benefiting from such data range from traffic flow and pollution monitoring to safety warning systems.

In order to disseminate data in such networks, referred to as Vehicular Sensor Networks (VSNs), new dissemination protocols are required to cope and exploit the specific characteristics present in road environments. Existing solutions designed for Wireless Sensor Networks (WSNs) mainly focus on tiny, battery-limited devices equipped with sensors and wireless communication, whereas protocols and algorithms designed for Mobile and Ad Hoc Networks (MANETs) assume stable end-to-end path connectivity and a limited number of nodes. In contrast, modern vehicles do not suffer much from battery or storage constraints. However, vehicular networks consist of fast moving nodes, with constantly changing vehicle distributions, which yield intermittent connectivity with sudden variations from sparse to dense networks. Due to the relative high speed of vehicles, the connectivity duration time can be seriously limited, e.g., when vehicles move in opposite directions. Therefore, the available bandwidth must be utilized in such a way that it is fairly shared among vehicles.

In such a dynamic picture, a new network paradigm referred to as opportunistic networks emerges as a suitable solution. In opportunistic networks, stable paths are never assumed to exist and nodes take decisions opportunistically solely based on current and anticipated circumstances. Intermittent connectivity is resolved by adopting a *store-carry-forward* communication model in which nodes hold pieces of data which is forwarded to other nodes when expedient. The assessment of opportunities to actually forward data is adaptive to the inferred knowledge about the current context. Data priority, the vehicle's direction or its complete route inferred from its navigation system adhere to this context.

In this paper we focus on maximizing the benefit of disseminating sensed data to mobile and static sinks given the limited shared bandwidth of the system. Our contribution lies in identifying potential applications (Section II) and challenges (Section III). In Section IV, we propose guidelines for the design of dissemination protocols in VSNs, which we divide in: *discovery*, *assessment*, and *seizing* of opportunities. In Section V, we focus on the assessment task and fair data distribution. Section VI concludes the paper.

II. POTENTIAL APPLICATIONS

Traffic Monitoring and Control: opportunistic vehicular communication can be used to gather near instantaneous (order of milliseconds) information such as the speed and position of vehicles to build a speed profile of the upcoming traffic [2]. In addition, traffic engineers can benefit from accurate live traffic information to enhance the so-called intelligent traffic light control.

Environment Monitoring: data from chemical sensors installed both in vehicles and in road-side units can be disseminated to provide a global estimate of the level of pollution in different regions of the city. Furthermore, sensors which are able to detect vibrations during the ride can generate estimates about the conditions of the road [3].

Safety Warnings: vehicle communication has the potential to complement internal on-board sensors (cameras or radars) to detect and warn drivers about hazardous situations when a vision beyond what sensors can provide is required [4].

III. CHARACTERISTICS AND CHALLENGES

Resource Efficiency: in contrast to traditional wireless sensor networks, energy is not of primary concern, since vehicles can be used as a source of electric power recharged by fuel. However, the bandwidth is limited. Thoughtless use of transmission energy may cause heavy interference in communication and thus congestion bandwidth. Storage, although abundantly available, must be managed as well.

Scalability: vehicular environments are in a constant state of flux. The network varies in density and connectedness. In order not to compromise scalability, the amount of exchanged data must be managed so as to effectively utilise the limited bandwidth.

Security/Privacy: in a pervasive system the data must be shared and exchanged with guaranteed privacy. This goes beyond secure and encrypted exchange of data.

User Penetration Rate: most of the applications suggested in this paper require a minimum density of vehicles equipped with wireless communication. Careful study is needed to determine the minimum market penetration rate for each application to function properly.

Data locality: in a VSN there are multiple data sources as well as data sinks, points where the data is used. Examples include data that belongs to the vehicle, that belongs to the spot, to the roadside, etc. Therefore, methods for correlating data and location, specially when the latter is not known (e.g., not equipped with GPS), are required.

Predictable Pattern: vehicles move along known paths, often in a predictable manner. Therefore, applications can leverage context and history information such as the current and previous routes set in navigation systems as well as the vehicle's direction, speed, etc.

The above characterization has implications for applications and solutions: while being "predictable" generates *opportunities* for the data to be disseminated, "data locality" establishes the scope, *conditions*, for effective dissemination.

IV. DESIGN GUIDELINES

Given the characteristics of vehicular environments, we propose an opportunistic dissemination process of sensed data that consists of three alternating tasks (Figure 1): *discovery*, *assessment*, and *seizing*. Opportunities for data exchange are constantly discovered, assessed, and chosen (seized), where *opportunity* is defined as the possible benefit from either sending or receiving data. In the following, for each task we derive requirements and design directions.

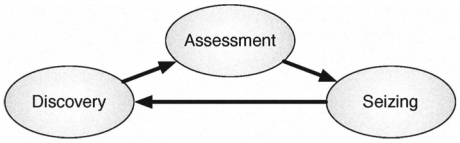

Figure 1. Cycle of tasks performed by vehicles

A. Discovery

Discovery deals with searching and detecting available opportunities of vehicle connectivity and consequent potentially beneficial data in the immediate environment. The typical approach in vehicular networks is to rely on safety beaconing; periodically sent messages that broadcast the geographical position and speed of a vehicle. Beaconing creates awareness among vehicles, but on the downside it congests shared bandwidth in high density vehicular networks, which might create unfairness among vehicles. Beacons may even hinder the propagation of safety message, such as crash warnings, the Dedicated Short Range Communications (DSRC) spectrum.

Therefore, new mechanisms to prevent the misuse of the safety channel capacity are required. As described in [5], three aspects must be considered: the power level employed in the transmission, beaconing rate, and message size. All these aspects influence directly the number of vehicles that can share the radio channel.

B. Assessment

In a highly dense network, several opportunities of connectivity will coexist. The assessment task must decide on which opportunity to take in order to effectively disseminate the data, by receiving, storing and forwarding. The ultimate decision is based on the current level of context knowledge the vehicle has about the data being available in its vicinity. For instance, when a vehicle intends to send data to a specific destination, it must leverage the mobility of other vehicles to store, carry, and forward the data to its final destination. Similarly, when a vehicle becomes aware of the data being carried by other vehicles it evaluates the amount of interest it has in that data, e.g., whether it regards traffic information of a geographical region the vehicle is heading to. This process can repeat and involve several intermediate vehicles. We classify such context knowledge into the following categories:

Mobility context: which can range from the complete route of a vehicle (e.g., a bus with fixed schedule or a vehicle with its route set in a navigation system) to only the vehicle direction (e.g., a vehicle is traveling in the direction of the data message's destination), speed, mobility history, etc.

Data context: including the priority of the data, data size, age, target region, and so forth. Both types of context information can be acquired by simply individually inferring about the environment (e.g., other vehicles' direction) and/or by exchanging *context profiles* with other vehicles in the vicinity which contain a list of data items and mobility predictions/information.

The evaluation can be generalized in a so-called *utility* function that attributes a value for every data message, m_j, being carried by vehicle v_i and by others before the actual dissemination of information. The normalized utility function $u_{i,j}$ of vehicle v_i for message m_j is given by:

$$u_{i,j} = \alpha_1 f_1(m_j) + \alpha_k f_k(m_j) +, ..., \alpha_{h_i} f_{h_i}(m_j). \quad (1)$$

where f_k $(0 < k \leq h_i)$ are the functions concerning each type of context information weighed by their respective parameters α_k. Functions f_k may differ between vehicles and refer to the mobility and data context information.

From a system perspective, vehicles build a list of selected pieces of data and rank them according to their individual utility. However, the amount of data that is to be transmitted in the time slot exceeds by far the available bandwidth. Moreover, a simple ordering scheme of all utility values would create unfair dissemination of data over all vehicles in the network. The unfairness problem can be mitigated by deploying incentive mechanisms for vehicles to refrain from immediate sending or collecting all data.

The main challenge is to choose which piece of data to send and at what time (opportunity). In [6], a relevance-based altruistic communication scheme is used to help achieve scalability by optimizing the application benefit and the bandwidth usage. Game theory proves to be a powerful tool to evaluate the overall performance of incentive solutions in [7]. The overall delivery ratio is shown to improve by discouraging selfishness and employing a simple mechanism based on the principles of barter trade. Interestingly, excessive altruistic behaviour yields non-optimal performance, which indicates that a simple flooding of information not only misuses bandwidth but also decrease the overall delivery ratio. The impact and application of the level of selfishness/altruism in opportunistic networks requires further study.

C. Seizing

Seizing comprises two actions: *communication* and *data processing*. The communication deals with the actual data transfer. Although the amount of data has been limited in the assessment task, vehicles still have to compete for the medium to send their selected data. Therefore, it is paramount that scheduling mechanisms relate partial assessment of all vehicles involved to prioritize higher relevant data for the use of the medium. Another issue is the contact duration time between peers. Due to the high speed of vehicles this time can be particularly limited. To mitigate this problem, higher power levels and thus higher transmission ranges and/or increasing the transmission rate can be employed to increase the connectivity duration time. The 802.11p standard defines transmission ranges up to 1 km and transmission rates that vary from 3 to 27 Mbps.

Data processing is an ongoing optimisation action which can help considerably reduce the amount of data in the system. In addition, it adheres to the scalability of the system. Data aggregation is an important process which involves summarization, reduction of redundancy, and compression, and can be executed before and/or after the communication. Another process involves network coding in order to increase robustness and overall delivery.

V. PRELIMINARY EVALUATION

In this section we evaluate two different approaches for assessment of opportunities: the *Total Sum Optimization* and the *Fair Sum Optimization*. The Total Sum Optimization follows the principle applied in [6], which seeks the optimum data exchange that maximizes the total sum of utilities gained by all vehicles in the system. Differently, the Fair Sum Optimization constraints the Total Sum Optimization to a *fair* distribution of utility over all vehicles. It relies on the Nash Bargaining [8] solution from game theory which has been widely used in fields such as fair network bandwidth allocation and fair resource allocation to multiple parties. The use of Nash Bargaining has been proposed in vehicular networks for data exchange in [9]. However, no comparison has been made with other approaches.

Let U be the utility matrix for m vehicles and n messages,

$$U = \begin{array}{c} \\ v_1 \\ v_2 \\ \vdots \\ v_m \end{array} \begin{array}{c} \begin{array}{cccc} m_1 & m_2 & \dots & m_n \end{array} \\ \begin{pmatrix} u_{1,1} & u_{1,2} & \dots & u_{1,n} \\ u_{2,1} & u_{2,2} & \dots & u_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{m,1} & u_{m,2} & \dots & u_{m,n} \end{pmatrix} \end{array}. \qquad (2)$$

where $u_{i,j}$ is given by (1). The Total Sum Optimization and Fair Sum Optimization approaches are defined respectively by (3) and (4). The binary vector $x = x_1, ...x_n$ selects the messages m_j which will be transmitted. k_{max} denotes the maximum number of messages which can be transmitted in each communication time slot considered.

$$\max \sum_{i=1}^{m} \sum_{j=1}^{n} [u_{ij} \times x_j] \quad (3) \qquad \max \prod_{i=1}^{m} \sum_{j=1}^{n} [u_{ij} \times x_j] \quad (4)$$

$$\text{with} \quad x_j \in 0, 1 \quad \text{s.t.} \quad \sum_{j=1}^{n} x_j \leq k_{max}.$$

The *Nash Bargaining* solution is employed in (4). In [8] it is proved that in a convex, closed and bounded set the solution is unique when considering the axioms: Pareto optimality, symmetry, scale covariance, and independence of irrelevant alternatives. The solution lies in maximizing the product of the utility functions of each player.

Our evaluation consists in comparing both approaches with regard to: (i) the fairness when distributing the utility among the two vehicles during the data exchange; and (ii) the sum of utilities gained by all vehicles in total. We consider a configuration with two vehicles, each with 10 messages ($(n, m) = (2, 20)$ in (2)). Let $u_{1,j} = 0.10$ and $u_{2,j+10} = (0.02j - 0.01)$ for $0 < j < 10$ and $u_{i,j} = 0$ elsewhere. The total gain for each vehicle is normalized such that $\sum_{j=1}^{n} u_{i,j} = 1$. The two patterns provoke disparity between each vehicle's utility. The utility values for vehicle 1 follow a uniform pattern whereas the values for vehicle 2 follow an increasing linear pattern.

In our evaluation we vary the length of the communication slot (k_{max}). We deploy Jain's Fairness Index [10] as the indicator of the level of fairness. Jain's index varies between zero and one, where one represents the optimal balance of utilities between entities. As shown in Figure 2, the Fair Sum Optimization approach seeks symmetry in the distribution and therefore Jain's index is above 0.9; for $k_{max} = 1$ fairness is undefined. On the other hand, when k_{max} is low the Total Sum Optimization approach tends to increase the utility of only one vehicle. The high level of fairness achieved with the Fair Sum Optimization approach comes at the price of a lower performance in terms of the total utility sum distributed in the data exchange. However, as shown in Figure 3 the difference is almost negligible for low values of k_{max} and reaches zero after $k_{max} = 10$. In both results, the two approaches present more similar values with a higher amount of time available. This is expected since with more time, most messages will be sent. Thus, fewer differences are present. Overall, Fair Sum Optimization presents more advantageous results when compared with Total Sum Optimization, since it provides a fairer distribution of utility among the vehicles while not compromising the overall performance achieved by all vehicle together.

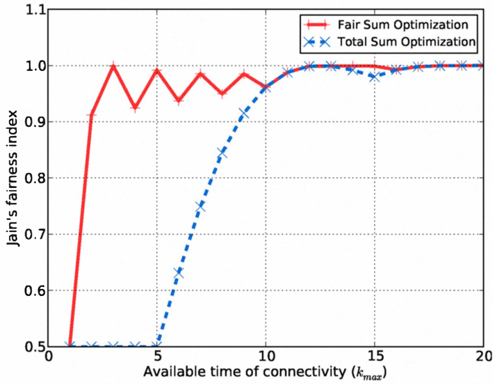

Figure 2. Jain's Fairness Index

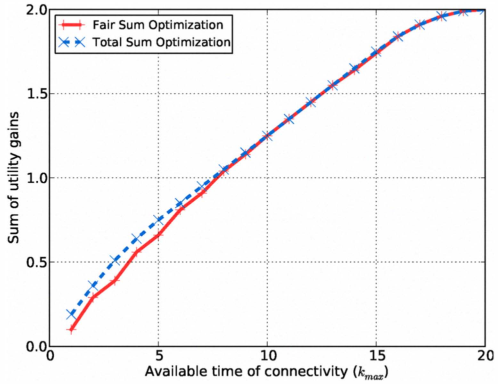

Figure 3. Sum of utilities gained by all vehicles in total

VI. CONCLUSION

In this paper we set the scope for opportunistically disseminating data in vehicular sensor networks. We identified the main characteristics and applications in this type of networks. The opportunistic dissemination involves three tasks: *discovery*, *assessment*, and *seizing*. We have outlined guidelines to address existing challenges in each of these tasks. Vehicles in the assessment task leverage both present and previous context information in order to choose the best opportunity available. In our preliminary evaluation, a proposed fair approach outperforms an approach which simply optimizes the total gain for all vehicles together. As future work, we plan to work on a fair and light mechanism following the guidelines described in this paper.

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