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Using Passive RFID Tags for Vehicle-Assisted Data Dissemination in Intelligent Transportation Systems

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***Abstract*—Intelligent Transportation Systems (ITS) in the form of Vehicular Adhoc NETworks (VANETs) have engaged significant interest from the academic, industry and government sectors. Data dissemination is of the utmost importance for the day-to-day operation of ITS applications. Numerous standards, architectures and communication protocols have been anticipated for data diffusion in ITS applications. However, existing schemes are based on an essential condition that the relaying vehicle has to be equipped with an active communication module – termed Intelligent Vehicle (IV). One of the major drawbacks of these schemes is that they do not exploit the potentially large number of non-intelligent vehicles (non-IVs), i.e., the vehicles without any active communication module for relaying and diffusion purposes. In this paper, we fill this gap by proposing a novel data dissemination scheme utilizing a non-IV to act as a data ferry. The non-IV is tagged with a low-cost passive RFID tag whereas the IV is equipped with an embedded RFID reader. The non-IVs ubiquitously store and carry the events in the passive tags, as recorded by the IV or by the roadside equipment, as they maneuver around the city blocks. Two system configurations, namely co-operative and stand-alone with and without vehicle-to-infrastructure (V2I) support, respectively, are also proposed. Simulation results show the proposed scheme's effectiveness and performance superiority over the existing active-based data dissemination methods.**

Keywords—RFID passive tags, Data dissemination, VANETs, Intelligent transportation systems

I. Introduction

Technology has made its way into Intelligent Transportation Systems (ITS) as the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) paradigms [1]. These paradigms rely on active communication and sensing, e.g., WiFi, WiMax, short-range radar, active RFID tags, etc. The active communication links are employed in two generally diverse, yet mutual schemes to acquire events information from outside sources. The first scheme is the vehicular ad-hoc wireless communication, i.e., the V2V model and the second scheme makes use of fixed infrastructure-based wireless communication, i.e., the V2I model. Diverse approaches have been investigated in the literature, employing these schemes for efficient data dissemination. Sophisticated routing, (e.g., location-aided routing [2], trajectory based routing[3], gossiping-based routing [4] and flooding), relaying protocols [5], [6], opportunistic and delay-tolerant approaches, (e.g., spray-and-wait[7], epidemic [8] and message ferrying methods [9]) and medium access protocols [10], [11] have been studied extensively in the context of ITS.

An approach that is based on an active communication model has the following design limitations. Firstly, the high monetary cost associated with equipping the vehicles for the V2V or the V2I communication. This confines the technology adoption rate that further affects the data dissemination rates. Data dissemination rate is defined as the rate at which an event, once generated, is diffused to other vehicles within a given time frame. The diffusion rate is significantly affected as only a small ratio of the total vehicles are Intelligent Vehicles (IVs), i.e., the vehicle with an on-board communication module and participate in the data dissemination process. Secondly, the incapability to exploit the significantly a large ratio of the non-Intelligent Vehicles (non-IVs), i.e., the vehicles without any on-board communication module, to assist in the data dissemination process.

In this paper, we propose a low-cost passive solution which exploits the non-intelligent vehicles to facilitate superior data dissemination rates hence, assisting other ITS applications. The solution employs passive RFID tags, a low-cost, paper-thin and battery-less device, for data diffusion in the *store-carry-forward* manner. The non-intelligent vehicles tagged with the passive RFID tags store and carry events as they move around the city blocks. The stored events are eventually read, and therefore forwarded, by the intelligent vehicles or the road-side equipments. The basic philosophy is to exploit the non-intelligent vehicles to act as data ferries for the event distribution. The passive RFID tag can be integrated with the annual vehicle registration process or can be affixed on the windshield by the owner. An intelligent vehicle, in addition to the conventional communication and sensing devices, is equipped with an RFID reader. The reader continuously interrogates the nearby mobile tags, i.e., the non-intelligent vehicles, for several reasons. These include classification and detection of the nearby vehicles for ITS-based safety applications, reading the stored events from the tag, writing its own accumulated events to the tag and so forth.

The proposed passive-based system has numerous advantages. Firstly, the non-intelligent vehicles can now assist, without any on-board ITS sensor or communication module, in sensing, data relaying and data diffusion. Secondly, it is an extremely low-cost solution, and hence, acts as a catalyst in facilitating high adoption rates. Thirdly, with vehicles being tagged, convenience applications, e.g., real-time traffic updates, can be articulated in a cost-effective manner. And lastly, it can support a broad-range of ITS-based applications. The potential applications include safety applications, e.g., forward collision warning, safe gap advisory, etc.; handiness and luxurious applications, e.g., adaptive cruise control, blind spot monitoring, etc.; and management applications, e.g., highway traffic conditions, congestion avoidance techniques, etc.

The remainder of the paper is organized as follows. Section II explains in detail the proposed passive-based solutions. Section III provides detailed information about the simulation environment, performance metrics and evaluation methodology. Section IV describes the related work. Finally, section V concludes this paper.

II. The Passive-based approach

Existing schemes lack the capability to exploit the non-intelligent vehicles for data dissemination. We fill this gap by proposing an innovative RFID-based passive solution which is pervasive, low-cost, facilitates high adoption rates and make use of the non-intelligent vehicles to assist in data diffusion. The motivation is to utilize the large number of the non-intelligent vehicles (anticipated to number in the thousands in a downtown area) for the pervasive relaying. The notion of pervasive relaying implies that the vehicle's owner need not to acquire any expensive communication or sensing gadgets, nor is conscious of the carrying data and his/her driving routine is not obstructed. Furthermore, privacy is not jeopardized as the tag memory contains no personal information and uses a time-driven random generator for the tag serial number.

Communication between an intelligent vehicle and non-intelligent vehicle occurs using RFID protocols [12]. An intelligent vehicle, using an on-board RFID reader, interrogates the passive tag of the non-intelligent vehicle. The event data acquired from the passive tag is then stored locally and, upon contact, is relayed to other intelligent vehicles and road-side infrastructure using V2V and V2I approaches, respectively.

The tag memory space is split into fixed and non-fixed segments. The contents of the fixed memory portion are unchangeable for the entire lifetime of the tag. This memory segment includes the tag's serial number and the vehicle's model, classification, dimensions, and other physical information. The intelligent vehicle at first, with an onboard RFID reader, singulates a tag within its proximity, i.e., obtains the tag ID. The tag ID is utilized to read and read/write to the tag's fixed and non-fixed memory segments, respectively. The non-fixed memory segment contains event data and is both readable and writeable. The event data are stored in the tag either by the close-by intelligent vehicles or the road-side equipments, e.g., sensors on the road, police or ambulance at the scene of an accident, etc. Event data may include information such as the event type, e.g., accident, congestion, traffic condition, etc., event time, event location and so on.

Lack of any on-board equipment, for the non-intelligent vehicles, demands that the intelligent vehicles and road-side infrastructure manage the tag memory for them. The tag memory management involves storing of the new events, updating the existing events and deleting of the obsolete events from the memory space. An efficient memory management scheme is required to avoid the loss of important events and to decrease redundancy. In this paper, we evaluate two basic memory management schemes, First-In-First-Out (FIFO) queue and no queue. In the FIFO-based approach, on full memory space, the least recent event is dropped and is replaced by the most recent one. In the case of the no queue approach, on full memory space, any new available event is rejected. Other management schemes, e.g., random, priority-based, application specific, time-driven, etc. may also be used.

The proposed passive-based system, based on the application requirements, can be configured as stand-alone or as a co-operative system.

A. Stand-alone system

In the stand-alone configuration, the intelligent vehicle relies only on its on-board sensing or communication devices and hence, does not receive any external information feeds. In such a configuration, illustrated in Fig. 1, the intelligent vehicle is equipped with an RFID reader which constantly interrogates its proximity to determine the presence of passive tags, i.e., other tagged vehicles. Possible four directional antennas mounted at the front and rear corners of the vehicle assist in detecting the presence of other vehicles. By varying the radiated power level for the directional antennas the vehicle determines the front moving vehicle position, its speed, its acceleration and its bearing, all at low communication latencies [13]. Such information assists in the implementation of Adaptive Cruise Control (ACC), headway advisory, forward collision warning, platoon and lane change support.

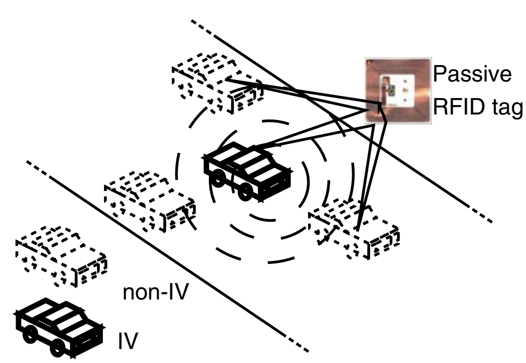


Fig. 1. Stand-alone passive-based system

B. Co-operative system

In the co-operative system, the intelligent vehicles are assisted by the road-side equipment. The road-side equipment includes wireless sensors, WiFi enabled RFID readers and wired RFID readers. Such roadside infrastructure assists the intelligent vehicle in interrogating and managing the events stored within the passive tags of the non-intelligent vehicles. Furthermore, they also collect the event data stored in the tags, using RFID readers, and route the aggregated data to both the base-station and passing-by intelligent vehicles. The co-operative system is conceptualized in Fig. 2. In the case of an event, the road-side sensors are utilized to obtain the type of event, e.g., traffic congestion. The newly generated event, along with time and location, is then periodically stored onto the passing non-intelligent vehicles, i.e., vehicles traveling on the opposite direction lanes. The in-coming intelligent vehicles interrogate the *event-carrying non-IVs* for the latest events and hence, facilitating them to adjusts their route. The proposed passive-based co-operative system is effective in data diffusion as it successfully exploits the on-coming non-intelligent vehicles.

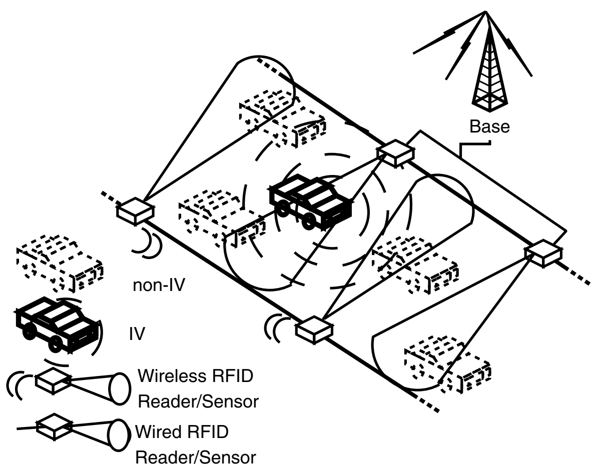


Fig. 2. Co-operative passive-based system

III. Performance evaluation

In this section, we evaluate the performance of the conventional active-based system and the proposed passive-based system. We use data dissemination ratio, number of events relayed and missed relaying opportunity as performance metrics. Furthermore, we also study the impact of the ratio of intelligent and non-intelligent vehicles along with traffic density on the data dissemination rates.

A. Simulation setup

We have extended the ns-2 network simulator [14] to support the RFID standard. Major extensions involve modification of the simulator architecture to support basic RFID operation, EPC class1-gen2 MAC protocol [12], multi-channel interfaces (RFID and WiFi) and a non-EPC singulation protocol [15], [16]. Minor changes include nodal extension to act as an RFID tag, RFID reader, and events generator, backscattering communication between the tag and the reader and so forth. The Manhattan grid-based model, from Bonnmotion [17] is used to generate mobility traces for the various scenarios that were run. Unless otherwise mentioned, simulations are performed using the following parameters. In the setup, vehicles are uniformly distributed in a simulated city grid of 200x200 blocks. The RFID reader, on both IVs and periodic event generators, has an interrogation range of $15m$. The event generator, in the single event scenario, is located at the center of the simulated city. However, for the multiple events scenario, the locations are picked randomly. Simulations are made to run for a period of 3600 seconds. The performance metrics are averaged over ten different topology runs generated using distinct random seeds.

B. Dissemination rate

The data dissemination rate is defined as the rate at which an event, once generated, is diffused to other vehicles within a given time frame. In other words, it is an assessment of how well an event infiltrates any given vehicle's distribution. We compare the data dissemination rates of the conventional active-based system with our proposed passive-based system. This comparison is depicted in Fig. 3 for a distribution of 250 vehicles, of which 5% are IVs. The active-based system and the passive-based system are labeled as 'IVs only' and 'IVs with non-IVs', respectively.

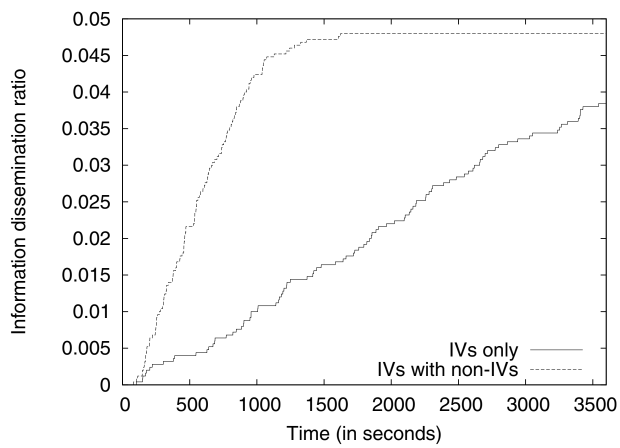


Fig. 3. Data dissemination rate when using a set of 250 vehicles of which 5% are intelligent vehicles

The passive-based system attains the saturation point significantly earlier than the active-based system. The saturation point is defined as a point in time when the maximum data dissemination rate is achieved, for a particular ratio of intelligent vehicles. After the saturation point, the dissemination rate of the system remains unchanged. There are two reasons behind the low dissemination rate for the active-based system. Firstly, the events are inter-exchanged only between the intelligent vehicles. These limited exchanges constrain the data routing opportunities and hence, lower data diffusion rates. On the other hand, the intelligent vehicles in the passive-based system can relay data from both intelligent and non-intelligent vehicles. Secondly, the low ratio of the intelligent vehicles compared to the total number of vehicles. Increasing the ratio of the intelligent vehicles will certainly increase the relaying probability however, has associated monetary costs and communication overheads.

C. Ratio of Intelligent Vehicles

As is mentioned earlier, the ratio of the intelligent vehicles impacts the data dissemination rates of the active-based system. The impact of varying this ratio between 5% and 70% for a set of 100 vehicles is illustrated in Fig. 4. The large number of intelligent vehicles has two major effects on data diffusion. Firstly, the saturation point, for both active-based and passive-based schemes, emerges earlier in time. For instance, the saturation point decreases linearly with an increase in the intelligent vehicle ratio. This translates into scalable and efficient data dissemination as the events data can readily be available for everyone. Secondly, the diffusion rate gap between the active-based and passive-based system diminishes. The rate gap eventually fades away as 100% of the vehicles become intelligent, i.e., employs active-based system.

D. Traffic density

Traffic density, i.e., number of vehicles in a given city block, dramatically affects the data dissemination rates for the passive-based and the active-based systems. Having more vehicles, in a given area, implies high probability and greater opportunity to interrogate the non-IVs' passive tags and hence, bartering of events betweens IV-IV and IV-nonIV. This translates into elevated diffusion rates. Data dissemination rates for various traffic density, i.e., low (50 vehicles), medium (150 vehicles) and high (300 vehicles), using 10% and 30% IVs ratio are shown in Fig. 5 and Fig. 6, respectively.

The passive-based solution is effective under both sparse and dense distribution for various ratios of the intelligent vehicles. However, most enhancements are observed in a likely scenario of either the dense ratio and the low ratio of intelligent vehicles, as is depicted in Fig. 5. The low ratio of intelligent vehicles provides an opportunity for the non-intelligent vehicles to carry a higher volume of events data, hence acting as data ferries. Furthermore, at low ratio, the probability of the intelligent vehicle to encounter a non-intelligent vehicle is significantly higher than of an intelligent vehicle. Consequently, the passive-based system relays many times more events than the active-based system.

The probability of the intelligent vehicle to encounter another intelligent vehicle increases with an increase in their ratio. This effect is illustrated in Fig. 6. From the results it is conclusive that the existing active-based solution may achieve similar performance to the passive-based solution under specific scenarios such as dense traffic and higher ratios of the intelligent vehicles. In all other likely cases, the passive-based system outperforms the active-based system.

E. Multiple events

To disperse multiple events requires efficient management of the tag memory space. In the remainder of this section we evaluate the two simple schemes namely FIFO-queue and no-queue, for the passive-based system. For our comparative analysis, we use metrics such as event deliverables, events dropped or rejected and the number of missed relay-able opportunities.

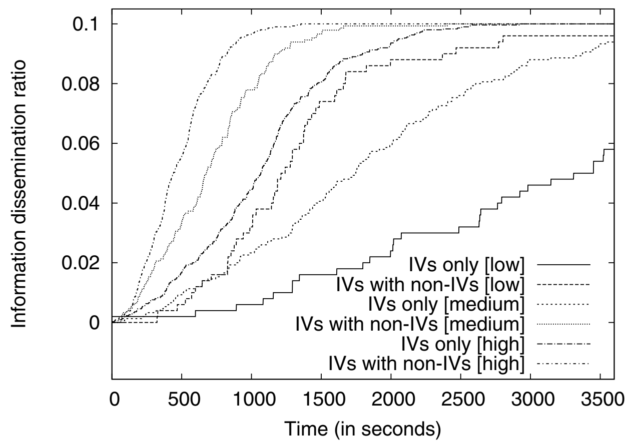


Fig. 5. Data diffusion rates using various traffic levels (low, medium and high) with 10% intelligent vehicles ratio

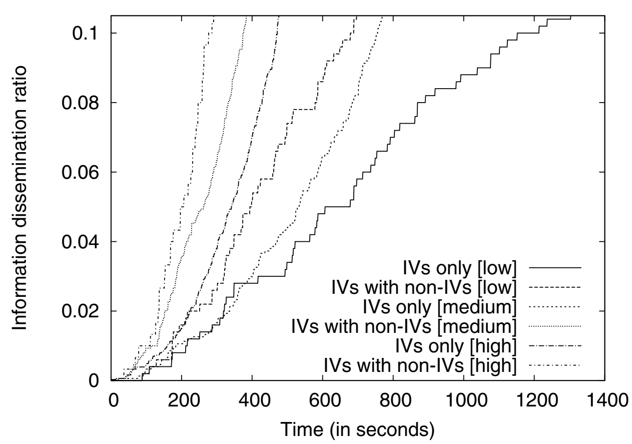


Fig. 6. Data dissemination rates at various traffic levels (low, medium and high) with 30% intelligent vehicles ratio

1) Events relayed: An RFID tag, due to its limited memory, can only store a certain number of events. The average number of events relayed, using the memory size of 5 and 10 events, for a ratio of 10% and 40% intelligence vehicles are illustrated in Fig. 7-a and Fig. 7-b, respectively. Neither of the management approaches, i.e., FIFO-queue and no-queue, yields any comparative diffusion rate improvements. An interesting observation, however, is the dramatic increase in the average number of events relayed as the ratio of the intelligent vehicles increase from 10% to 40%. The improvement becomes more obvious as the number of events exceeds the tag cache size. The reason lies within the extremely large memory, compared to a passive tag, of the intelligent vehicles, allowing them to store a larger number of events. Upon interaction with other intelligent vehicles, an intelligent vehicle utilizes its higher available bandwidth and large memory to exchange and store multiple events at any time. However, with increase in the number of event generators the number of events successfully relayed eventually levels out, evident from the right-sides of

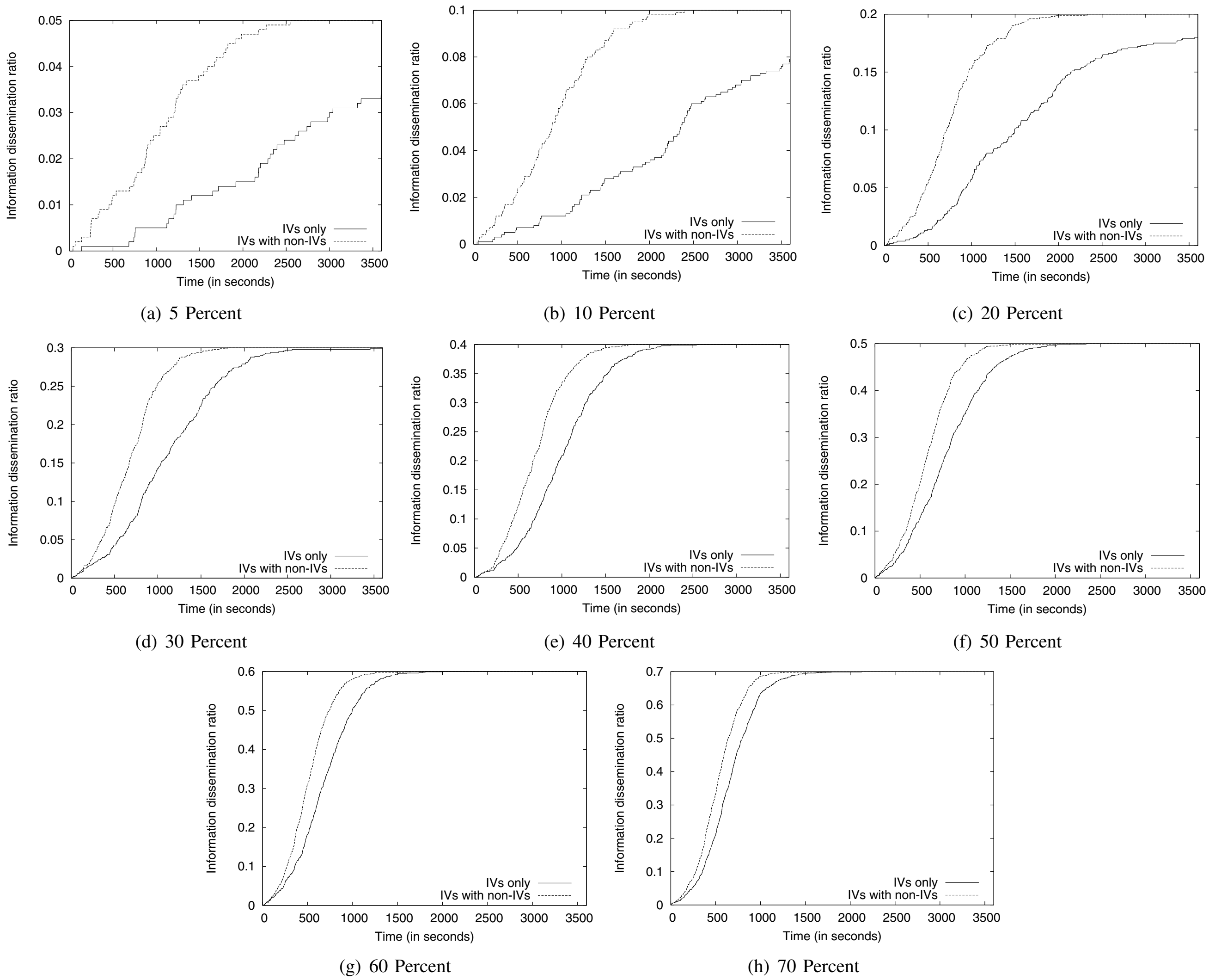


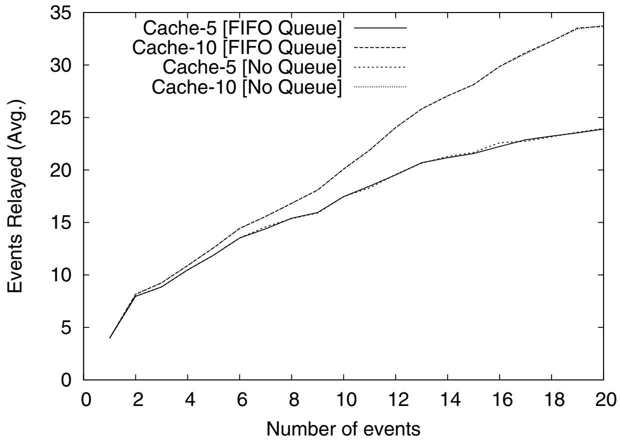
Fig. 4. Effect of the ratio of intelligent vehicle, as it varies between 5% and 70%, on the data dissemination rate when using a set of 100 vehicles

Fig. 7-a and Fig. 7-b. This is due to the limited storage capacity of the passive tags. Regardless of the intelligent vehicles' memory or communication capabilities, it is the non-intelligent vehicles indirectly, or the event generators directly, that are responsible for the events broadcast to the intelligent vehicles. The non-intelligent vehicles, with their limited memory, can only disperse a certain number of distinct events. To conclude, having sophisticated storage management schemes, for the passive-based system, is very important, as their performance directly impacts the data dissemination rate.

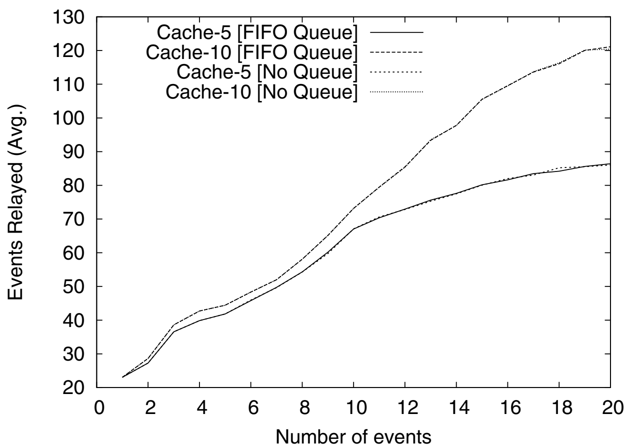
2) Events dropped or rejected: As mentioned, in this paper, we use two storage management schemes, namely, FIFO-queue and no-queue. Once the memory is filled and a new event is available, the FIFO-queue replaces the oldest entry with the newly available event, whereas, the no-queue scheme rejects the new event.

The average number of events dropped or rejected, depending on the queuing approach, for the 10% intelligent vehicle ratio and using memory of 5 and 10 events are depicted in Fig. 8. As anticipated the no-queue model with minimal cache memory discards most events, i.e., almost 30% of the total events. This translates into the significantly higher *missed relay-able* opportunities. On the other hand, the FIFO-queue approach, even with minimal cache memory, shows stability.

3) Missed relay-able opportunities: Miss relay-able opportunity is defined as, for a non-intelligent vehicle, the likelihood of forwarding an event had it not been dropped or rejected. Examining this metric assists in fine tuning the trade offs between the memory size and the data dissemination rate. The missed relay-able opportunity for various cache sizes is depicted in Fig. 9. The no-queue approach with minimal memory cache missed most of the relaying opportunities and is amplified radically with the increase of the intelligent vehicles ratio. Theses results dictate that there is a trade off between



(a) 10 Percent



(b) 40 Percent

Fig. 7. Average number of events relayed by the non-intelligent vehicles, for distinct intelligent vehicle ratios, using the caching size of 5 and 10 events

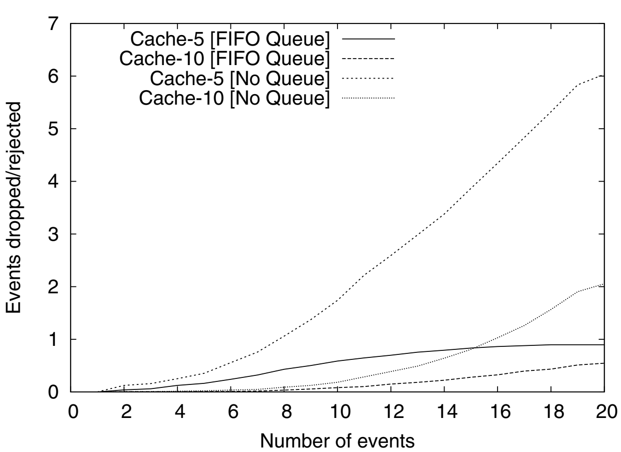


Fig. 8. Average number of events dropped/rejected at the non-intelligent vehicles. Intelligent vehicle density is 10% of the total vehicles

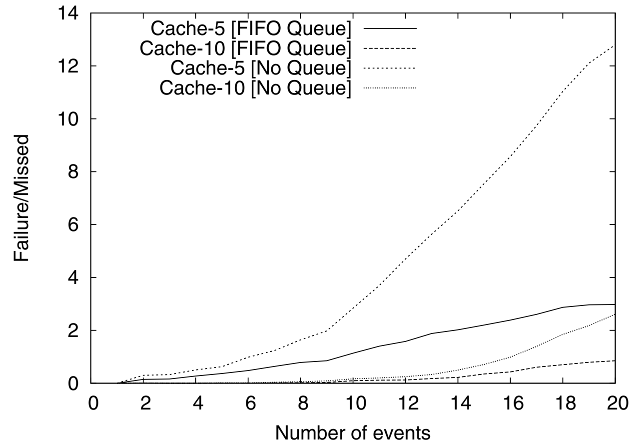


Fig. 9. Relay-able opportunity missed due to events discarding

the tag cache memory and the data dissemination rate of the passive-based scheme. Having bigger memory space results in higher data dissemination rates however, requires sophisticated storage management techniques and maybe higher monetary costs. On the contrary, low memory yields simple or even no storage management overheads but may affect the diffusion rates.

IV. Related work

Various data dissemination schemes have been proposed in the literature. These schemes engage a broad range of diverse approaches such as the use of sophisticated routing [2], [3], [4] and vehicle-assisted relaying protocols [5], [6], opportunistic and delay-tolerant techniques [7], [8], [9] and medium access control [10], [11] tailored for efficient data dissemination.

Vehicle-assisted data relaying schemes based-on the carry and forward have been proposed in [5], [6]. Similar to our approach, a mobile vehicle carries the packet until it encounters another vehicle and forwards the packet. However, these schemes are different from our proposed schemes in multiple ways. Firstly, unlike our approach, the mobile vehicle is to be only an intelligent vehicle. Secondly, it works under a specialized case (e.g., availability of a stationary vehicle at an intersection [6]) or ability to predict vehicle mobility [5]. On the other hand, our proposed scheme disseminates data autonomously under any traffic pattern, road layout and mobility, without any special requirements. Thirdly, these schemes, unlike ours, do not exploit the non-intelligent vehicles in the data dissemination process, and therefore result in lower diffusion rates.

Many routing protocols have been proposed, e.g., location-aided routing [2], trajectory based routing [3]and gossiping based routing [4]. In the location-aided routing [2], the node location information, for instance, obtained using global positioning service, is utilized to route the packets and to reduce the routing overheads. The packet routing is confined to a *request zone* or a given area of interest [18], which is determined based on the expected location of the destination of the node at a given time. The trajectory-based approach [3], on the other hand, routes the packets along a predefined curve. The curve, as is defined by the source node, assumes the availability of a sophisticated sensing unit, e.g., angle of arrival, range estimations, compasses and accelerometers, therefore, it is applicable to limited vehicles. Gossiping-based protocols [4] provide an effective approach to reliable data diffusion however, they require location-aware, active communication and active sensing capability be embedded into every vehicle, a likely scenario only possible in the decades to follow.

Vehicular ad hoc networks, largely depending on the traffic flow and vehicular mobility, may experience intermittent communication links. To overcome the sporadic connectivity Delay Tolerant Network (DTN) approaches [7], [8], [9] have been proposed. DTN-based data delivery is made possible by exploiting the store-and-forward mechanism [9] such as those employed by vehicle-assisted data relaying schemes [5], [6]. Simple routing mechanisms such as an epidemic-based scheme [8] and spray and wait [7] (*spray* a number of copies of data into the network and *wait* until one meets the required destination), have been proposed. A DTN-based approach is a reliable data delivery method, however, only for sparse environments, e.g., rural areas, where car densities are low. On the contrary, our proposed passive-based solution is effective for both sparse (rural) and dense (urban) environments.

As existing schemes do not exploit the potentially large number of non-intelligent vehicles (non-IVs), i.e., the vehicles without any active communication module, they have confined the data diffusion rate. Furthermore, these schemes have high monetary associated costs, limited operation lifetime, require regular device maintenance and hence, obstruct world-wide technology adoption by vehicle owners.

V. Conclusion

In this paper, we presented a novel data dissemination approach which exploits the non-intelligent vehicles, i.e., the vehicles without any on-board active sensing or communication modules, tagged with the passive RFID tags to act as data ferries. The non-intelligent vehicles ubiquitously store-carry-forward the events cached in the passive tag. The passive-based scheme is more cost-effective to deploy since the passive RFID tags are much cheaper than installing active sensing equipment onto the intelligent vehicles. Consequently, drivers will be less reluctant to adopt this new technology. As the roadside readers pick up the events from the passive tags and wirelessly communicate the events to a radio station for broadcasting, the non-intelligent vehicles can benefit as well.

The passive-based approach opens the door to new applications and facilitates cost-effective solutions for existing applications in intelligent transportation systems. As future work, we plan to investigate more sophisticated storage management schemes and study their effects on the data diffusion rates. Furthermore, we will investigate applications of the passive-based system in other areas of intelligent transportation.

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