Abstract—In a wireless ad hoc network, an opportunistic routing strategy is a strategy where there is no predefined rule for choosing the next node to destination (as it is the case in conventional schemes such as OLSR, DSR or even Geo-Routing). Rather, an intermediate node en route acts in an impromptu fashion and takes a decision that is based solely on current circumstances. A popular example of opportunistic routing is the “delay tolerant” forwarding to “data mules” when a direct path to destination does not exist. Conventional routing in this case would just “drop” the packet. With opportunistic routing, a node acts upon the available information: it seeks the neighbor best qualified to “carry” the packet to destination. If none is available, it will await the right opportunity. This procedure is also known as “data muling” or Delay Tolerant Network (DTN) routing.

The Vehicular Ad Hoc Networks (VANET), because of its intrinsic intermittent connectivity (during off peak hours and at night) is an ideal “playground” for opportunistic routing/multicast. In this paper we will examine two examples of VANET opportunistic routing: Delay Tolerant geo-inspired routing and real time video stream multicast of emergency/accident multimedia reports to vehicles in disconnected platoons using network coding.

I. INTRODUCTION

With the sharp increase of vehicles on roads in the recent years, driving has become more challenging and dangerous. Without a clear signal of improvement in the near future, leading car manufacturers have decided to jointly work with national government agencies to develop solutions to help drivers anticipate hazardous events and avoid bad traffic areas. One of the outcomes has been a novel wireless architecture called Wireless Access for Vehicular Environment (WA Ve), dedicated to vehicle-to-vehicle and vehicle-to-roadside communications. While the major objective has clearly been to improve the overall safety of vehicular traffic, promising traffic management solutions and on-board entertainment applications are also expected by the different bodies (C2CCC, VII, CALM) and projects (VICS [1], CarTALK 2000 [2], NOW, CarNet [3], FleetNet [4]) involved in this field. When equipped with WA Ve communication devices, cars and roadside units form a highly dynamic network called a Vehicular Ad Hoc Network (VANET), a special kind of Mobile Ad-Hoc Networks (MANETs).

While safety applications mostly need local, single hop broadcast connectivity, emerging intelligent transport systems (ITS) scenarios will use multi-hop routing. Moreover, applications that deliver contents and disseminate useful information will eventually follow and will require multi-hop connectivity support. Although countless versions of routing protocols [5], [6] have been developed for MANETs, they do not all apply to VANETs. Indeed, VANETs present a new challenge. They are extremely large (hundreds of thousands of nodes). Yet, most vehicular applications require only “local” broadcast or dissemination. Moreover, the infrastructure is generally reachable within one or two hops (contrary to the absence of infrastructure in traditional MANETs). VANETs are supposed to support an extremely broad range of applications, from safety to urban sensing, dissemination and games. MANETs in contrast, are application agnostic, and are designed to carry unicast or multicast traffic from source to destination(s). Finally, VANETs have a density that can vary very rapidly (from traffic jam scenario to intermittent connectivity situations). When the VANET is intermittently connected, some communication applications (called Delay Tolerant applications) can still be deployed, using a combination of radio forwarding and “mechanical” forwarding (ie data muling). This type of hybrid forwarding is called Delay Tolerant Networking.

To set the stage, we show in Figure 1 a possible taxonomy of vehicular routing schemes. There are two main categories of routing protocols: topology-based and geographic routing. Topology-based routing learns about links that exist in the network and creates a local “map” (the routing table) that is used to perform packet forwarding. Geographic routing uses only instantaneous neighboring location information to perform packet forwarding. Since link information changes on a regular basis, topology-based, table driven routing suffers from route breaks.

A thorough review of VANET routing schemes is beyond the scope of this paper. For a survey on VANET routing we direct the interested reader to Li et al. [7]. We focus here on a
II. OPPORTUNISTIC ROUTING IN DTN URBAN SCENARIOS

Position-based routing has proven to be well suited for highly dynamic environments such as Vehicular Ad Hoc Networks (VANET) due to its simplicity. Leading Position-based routing schemes such as Greedy Perimeter Stateless Routing (GPSR) and Greedy Perimeter Coordinator Routing (GPCR) use greedy algorithms to forward packets by selecting relays with the best progress towards the destination or use a recovery mode in case such solutions fail. These protocols are very efficient if the node population is dense and thus the underlying topology is well connected. However, the dynamic nature of vehicular network, such as vehicle density, traffic pattern, and radio obstacles tends to introduce partitions and disconnections.

To protect routing from such perils we have designed GeoDTN+Nav, a hybrid geographic routing solution that exploits the vehicular mobility and on-board vehicular navigation systems to deliver packets more reliably even in a partitioned network. GeoDTN+Nav outperforms standard geographic routing protocols such as GPSR and GPCR because it can estimate network partitions and can thus improve delivery to partitioned components using a store-carry-forward procedure.

In the sequel we first introduce the concept of virtual navigation interface (VNI) to provide generalized route information that supports forwarding. The goal of the VNI is to discover vehicles that can deliver packets in partitioned networks. Without any prior information, random choice of a neighbor might not be appropriate because this neighbor might move even farther away from destination. The knowledge of a neighbors’ future trajectory helps make a better decision.

We assume cars are navigation-system-equipped. This is a valid assumption since navigators are becoming increasingly popular. Moreover, driver assistance features such as route hints will promote the deployment of navigators. However, while the GPS data has been standardized, the content and transmission format of navigation information is not a standard, and may differ significantly between different classes of vehicles. Some vehicles may not even be equipped with navigators.

GeoDTN+Nav offers a unified framework for the different navigator formats and styles. We will assume that every car is equipped with a Virtual Navigation Interface (VNI), a lightweight wrapper interface that interacts with underlying vehicular components. VNI provides two kinds of information:

1) Route info that includes detailed path, the destination, or simply the direction of the vehicle, depending on the types of underlying data sources.
2) Confidence that indicates the probability that the vehicle’s movement would abide by the given route information. More specifically, confidence = 0% means that the vehicle moves completely randomly; confidence = 100% means that the vehicle moves strictly according to advertised route information. This confidence information can be preconfigured or can be derived from vehicles’ movement history. The VNI information is periodically broadcast, allowing each vehicle to make “opportunistic” routing decisions accordingly.

Geo-routing forwards packets in two modes: greedy mode and perimeter mode. In greedy mode, a packet is forwarded

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class of protocols called “opportunistic” forwarding protocols. The definition of “opportunistic forwarding” is fuzzy and varies from author to author. All definitions and applications however agree on one point: a node forwards a packet in “opportunistic” mode if it does not have a predefined strategy to choose the next node for guaranteed delivery to destination (as it would be in the case of OLSR, for example, or DSR or even Geo-Routing). Rather, it acts “on the spur of the moment” and takes a decision that is justified by the current circumstances. Or, if the node does have a predefined path on which to forward, it decides to use “opportunistically” another path instead.

In vehicular networks there are several examples of “opportunistic” forwarding. First, the vehicle may decide “opportunistically” to use the VANET to deliver a unicast packet even though it can access the Internet within one hop (Figure 2). The decision may be made due to delay or security considerations. Secondly, the vehicle may have collected via its sensors some information (e.g., license plates, pollution measurements, spectrum occupancy, etc) that in principle could be of interest to everyone and thus could be uploaded to an Internet server. However, if the volume of collected information is overwhelming, the vehicle may instead “opportunistically” disseminate the information in the neighborhood, in an unstructured way, in order to alleviate the load on the Access Points and at the same time assure that an eventual future search for that data can be carried out efficiently given that many copies exist.

A third model is the “opportunistic” delay tolerant forwarding when a direct path or tree to destination(s) does not exist. Conventional routing in this case would just “drop” the packet. Opportunistic routing will act upon the available information; the node will “carry” the packet in memory, awaiting the “best opportunity” to deliver the packet to a neighbor that happens to pass by and, possibly, is going in the right direction. As mentioned earlier, this procedure is also known as “data muling” or Delay Tolerant Network (DTN) routing.

The VANET, because of its intrinsic intermittent connectivity (during off peak hours and at night) is an ideal “playground” for opportunistic routing. In this paper we will examine three cases of opportunistic routing: Delay Tolerant geo inspired routing and opportunistic, real time video stream distribution of emergency/accident multimedia reports to vehicles in an intermittent connectivity setting.
to destination greedily by choosing the neighbor that promises best progress to destination. However, due to obstacles the packet can arrive at a local maximum, i.e., dead end. In this case, the perimeter mode is applied to extract a packet from a local maximum and eventually return it to greedy mode. After a planarization process, perimeter mode drives the packet around the obstacles towards its destination. Packet delivery is guaranteed as long as the destination is connected.

However, due to vehicular motion patterns, it is not uncommon that the a destination becomes disconnected, particularly in sparse traffic. The greedy plus perimeter approach does not work. We introduce a third mode: DTN (Delay Tolerate Network) mode, which can deliver packets even if the network is disconnected or partitioned by exploiting mobility. Namely, packets are forwarded in the greedy mode first, and then in perimeter mode when a packet gets stuck in a local maximum. If the perimeter mode also fails, routing switches to DTN mode and relies on carry/forward to deliver packets.

To determine when to switch to DTN mode, one must define a cost function and a threshold that are related to: network partition detection, and; quality of a nodes mobility prediction. Determining network disconnection is not an easy task; in fact, there is no way to know unless we have complete topology information. Moreover, even with complete network topology knowledge, any decision has very limited validity since VANET topology changes very rapidly. Thus, we propose to base our decision on the simplest topology related measure, the hop count. For example, an increasing hop count in the perimeter mode is a good indicator of network disconnection.

Delivery quality prediction is the second criterion to determine whether we should use DTN forwarding or not. If there is a good neighbor that has a mobility pattern that will bring the packet closer to destination, we rely on it to deliver the packet. By a good neighbor, we mean a neighbor that features a path, destination, or direction towards the destination with high confidence. For example, a bus may have paths in its VNI because its route is well-known; it may have high confidence ranking because the route seldom changes. A taxi may not transmit its path; rather, its destination because it only knows the customers destination. The confidence associated with the actual path is low as traffic conditions may alter it.

Network disconnectivity and the delivery quality only are not enough to define a good muling neighbor. We also must consider the direction. For example, a bus may have good delivery quality because its route will eventually get close to destination. But, if it is moving away from it, it becomes a less desirable relay to carry a packet.

Combining these three factors, we obtain a “score function” S as follows:

\[
S(N_i) = \alpha P(h) \times \beta Q(N_i) \times \gamma \text{Dir}(N_i)
\]

where:
- \(S(N_i)\) : Switching score of \(N_i\)
- \(P(h)\) : Probability that the network is disconnected (range from 0 to 1)
- \(Q(N_i)\) : Delivery quality of \(N_i\) in DTN mode (range from 0 to 1)
- \(\text{Dir}(N_i)\) : Direction of \(N_i\) (range from 0 to 1)
- \(\alpha, \beta, \gamma\) : System parameters
- \(N_i\) : a neighbor of current node \(i\)
- \(h\) : hop counts that the packet has traversed in the perimeter mode.

Because of space limits, we only sketch the functions \(P(h)\), \(Q(N_i)\), and \(\text{Dir}(N_i)\). Readers can refer to [8] for detail. The function \(P(h)\) represents the probability that the network is disconnected, in function of hop count. The larger the hop counts, the higher the probability that the network is disconnected. \(Q(N_i)\) depends on the distance between the destination and the location of \(N_i\) and its neighbors. The closer the distance of a neighbor to the destination, the higher its delivery quality. \(Q(N_i)\) is not sufficient to identify a “good” neighbor; we also need to consider the moving direction of nodes. \(\text{Dir}(N_i)\) outputs \(N_i\)’s directionality towards destination with respect to the current forwarding node \(C\). In brief, if \(C\) and its neighbor \(N_i\) are going toward the same direction toward the destination, \(\text{Dir}(N_i)\) would be larger than \(\text{Dir}(N_j)\) where \(C\) and \(N_j\) are going in different directions.

**GeoDTN+Nav Routing with VNI Example**

After having described the VNI and the GeoDTN+Nav routing protocol, we now demonstrate their joint functionalities in an example. We emphasize that the main purpose of switching from the perimeter mode to DTN mode is to virtually bridge network partitions and improve the delivery ratio while switching from DTN mode back to greedy speeds up delivery within a connected partition. For simplicity, we assume all packets in our example start in the perimeter mode. Moreover, each node has already collected navigation information from neighbors’ VNIs.

Assume weight parameters \(\alpha, \beta, \gamma\) are 1, and the threshold \(S_{\text{thresh}}\) is 0.25. Also suppose that a packet has traversed 8 hops in the perimeter mode up to node \(A\) in Figure 3. Node \(A\) has three neighbors, \(N1, N2,\) and \(N3\). While the packet arrives at node \(A\), node \(A\) calculates the probability of network disconnection and obtains \(P(8) = 0.4\). Note that \(P(h)\) depends only on the hop counts that has been traversed in the perimeter mode. At the same time, node \(A\) calculates the delivery quality of its neighbors, also including itself, in order to know if they can deliver the packet to the targeted network partition in DTN mode. It finally computes the “score function” \(S\) by multiplying \(P(h)\), \(Q(N_i)\), and \(\text{Dir}(N_i)\). At this time, none of its neighbors including itself has a higher score than \(S_{\text{thresh}}\), so the packet will remain in the perimeter mode until the next hop. The above process repeats in node \(B\), but now \(B\) along with two neighbors \(N5\) and \(N6\) have greater scores than \(S_{\text{thresh}}\). Node \(B\) therefore switches to DTN mode, and chooses the neighbor, \(N6\) in this case, with the greatest score to carry the packet. \(N6\) will buffer
the packet until it reaches a point where it can switch back to the greedy mode. Once it has reached that point, the packet is forwarded to destination in the greedy mode again.

**GeoDTN+Nav Performance Evaluation**

Our evaluation shows that for sparse or partitioned networks, GeoDTN+Nav significantly improves packet delivery by exploiting mobility and on-board navigation information. It outperforms non-DTN schemes such as GPCR and GPSR with respect to packet delivery ratio as it improves graph reachability. It does, however, increase delivery delay. To reduce delay, one must efficiently select the nodes that carry packets between partitions. The Virtual Navigation Interface (VNI) scheme works even for vehicles not equipped with navigation systems. As a difference from conventional DTN schemes, in dense or connected networks, GeoDTN+Nav falls back to Geo-routing and deliver packets more efficiently via radio channels.

We evaluate the performance of GeoDTN+Nav with Qualnet using a real urban map and realistic vehicular mobility. The mobility traces have been generated using the Intelligent Driver Model with Intersection Management (IDM-IM) by VanetMobiSim [9], an open source and freely available realistic vehicular traffic generator for network simulators. The mobility scheme is based on a sequence of activities (home, work, shopping, etc.) described by a relative transition probability matrix. The unified transmission range is 300m. The urban topology employed in this paper is a realistic 1500m by 4000m Oakland area from U.S. Census Bureau’s Topologically Integrated Geographic Encoding and Referencing (TIGER) database. All intersections are controlled by stop signs and all road segments contain speed limitations. Unless differently specified, all roads have a single lane and a speed limit of 15 m/s (54 km/h).

GeoDTN+Nav is compared against a randomized DTN routing scheme [10], RandDTN. RandDTN works as follows. At each beacon interval, a node forwards its packet with probability $p$. When $p = 0$, RandDTN is reduced to direct transmission where packets are delivered only when source meets destination. When $p = 1$, a node always considers its neighbors to forward the packet. To avoid the packet from being forwarded to any node, thus reducing progress towards the destination, we modify RandDTN so that the node would forward to its neighbor whose final destination is closest to the destination of the packet. If such a neighbor does not exist, the node would simply store and carry the packet until the next beacon interval. Moreover, in this paper, we set $p = 0.5$ for generality.

We generate mobility traces for 50 nodes and introduce extra ‘Bus’ nodes. We manipulate the number of bus nodes as well as their departure patterns in order to study the virtual connectivity between the two partitions. More precisely, we compare two departure patterns: a uniform pattern, in which a bus departure time is uniformly distributed throughout the whole simulation time; and the Random pattern, in which each bus node randomly departs. In each simulation, 20 random source nodes send data to a fixed destination node using constant bit rate (CBR), a UDP-based packet generation application. To emulate radio propagation in urban area, blocking radio obstacles have been placed between different road segments if they do not share the same horizontal or vertical coordinates. In each experiment, we compare GPSR, GPCR and GeoDTN+Nav for the following metrics: 1) packet delivery ratio (PDR), 2) latency, and 3) hop count. We also show in the figures the 95% confidence interval.

Initially, because the node density is low and the connectivity is limited by obstacles therefore creating a large number of network partitions, the packet delivery ratio is very low for all protocols. In Figure 4(a), as the number of buses increases, GeoDTN+Nav’s PDR increases accordingly, first because nodes have a higher probability to meet and delegate packets to ‘Bus’ nodes, but also as ‘Bus’ nodes have a higher chance to connect the corresponding partitions. However, without a DTN mode, GPCR and GPSR remain unable to efficiently transport packets in such a partitioned network. We may also see in Figure 4(a) that the uniform departure pattern also yields to a better PDR than the random one.

GPSR’s and GPCR’s PDR remain low even though the number of buses increases. For random source-destination pairs, the relatively low number of ‘Bus’ nodes is not sufficient to connect the different partitions. In fact, as it may be observed in Figure 4(c), GPSR and GPCR only successfully deliver packets when the source and destination nodes are one hop away, which also results in low latency. In Figure 4(b) and 4(c), as the number of buses increases, GeoDTN+Nav’s hop count and latency increase. This is GeoDTN+Nav’s fundamental tradeoff between packets’ forwarding latency and delivery ratio.

Last, note that RandDTN achieves slightly better PDR and lower latency than GeoDTN+Nav. This is because of the intelligent feature of GeoDTN+Nav: whenever the packet is carried across partitioned network, GeoDTN+Nav would try to switch back to geographic routing. However, in such a sparse network, GeoDTN+Nav is likely to fall back to DTN mode again, which increases the latency and might also decrease the PDR. However, owing to the dynamic and evolving nature of vehicular networks, we expect that this hybrid geo-routing and DTN forwarding nature of GeoDTN+Nav could yield better performance in general.

III. OPPORTUNISTIC MULTICAST: EMERGENCY VIDEO STREAMING

The dominant VANET application today is navigation safety. In the simplest example, vehicular communications can be used to exchange electronic tail lamp signals between
congest the lanes. Thus reliability is key for safety multimedia streaming. The application must be protected not only against the unreliable wireless channel, e.g., random obstacles on the path and packet drops, but also against variable vehicular density, frequent partitions and gaps in the column of cars.

Finally, one should note that the delivery of emergency video is most critical following major disasters that have destroyed the entire infrastructure. For example, a hurricane or earthquake that has wiped out 3G repeaters and WiFi access points. Thus, the emergency communications cannot rely on the infrastructure but must be totally contained within the vehicular network.

There is a vast literature on reliable data dissemination in vehicular networks. The main focus has been on short alert messages over a single hop. Little exists, however, about multimedia streams that must be disseminated to remote vehicles well beyond the visual range. In data dissemination over multiple vehicular hops, packets may be corrupted and lost because of many reasons. Fading, environment interference, and mobility can produce random like losses. Another cause of loss is packet collision. In particular, collisions among hidden terminals are quite frequent in broadcast where the RTS/CTS feature of the 802.11 like MAC is disabled. We assume in this study that the DSRC MAC protocol or the emerging 802.11p MAC protocol are used. Because of broadcast, packet losses tend to be random and non uniform even in the same locality. That is, each node in a neighborhood has dissimilar, rapidly varying packet reception characteristics. Therefore, upon packet loss, a “local diversity” recovery strategy, i.e., neighbors helping each other, can be very effective. To fight locally correlated losses (e.g., losses experienced by multiple receivers in the same neighborhood due to common upstream congestion, broken link, etc) multipath diversity, i.e., the use of multiple, disjoint paths paves the way to effective recovery. Path diversity is abundant in urban vehicular networks when vehicles are densely packed, say, during peak hour. The main issue is to utilize path diversity efficiently. Also, the overhead must be low, so that the scheme does not introduce extra inefficiency when the vehicle network is “sparse.” A very effective approach is to combine multipath diversity with random network coding, leading to a scheme which transparently implements both localized neighbor recovery and...
path diversity with remarkably low overhead.

We mentioned earlier that cars can become separated on the highway, forming platoons. If an accident occurs, a platoon that follows by 30 seconds, say, will automatically incur a 30 second delay. Fortunately, the emergency streams are intrinsically delay-tolerant, in the sense that reactive action to the accident alert (e.g., stopping and turning around) is generally required only when the second platoon establishes radio contact with the first one. Thus, it is important that the vehicles in the second platoon learn of the accident all at the same time (albeit with a 30 second latency).

The next question is how to propagate the stream to disconnected platoons. One approach is to exploit vehicles coming in the opposite direction, assuming that the highway has multiple lanes in both directions. The opposing traffic may actually consist of vehicles that have already turned around after the accident. These vehicles are used as “data mules.” In this study we will use network coding in conjunction with opportunistic routing to provide efficient, reliable delivery both within the platoon as well as across platoons.

Opportunistic delivery across disconnected platoons

In this section we study the model with opposite direction vehicles that act as “data mules.” We are interested in evaluating different schemes and their respective performance. Some of these results were reported in an earlier paper [PaUO08]. In a VANET, vehicles continually exchange information about speed, acceleration, braking, obstacles, and so forth. In our specific scenario, the vehicles exchange information about an accident. Namely, vehicles located just in front of the accident site multicast video streams to the platoon immediately behind.

Obviously the data cannot propagate instantly to disconnected platoons. Our freeway relay model uses platoons in the opposite direction to pick up, carry, and forward the data. For this model, we want to estimate the delay of delivering the complete data file to the platoons following behind. The delivery delay can be simply expressed as follows:

\[ Delay = \min(\text{overtake delay}, \text{relay delay}) \]

Overtake delay is defined as the time for a random platoon to catch up with (reach within its communication range) the source platoon (or other platoons that have merged into the source platoon) that is driving in the same direction. Relay delay is defined as the time for a target platoon to receive the whole data from data mule platoons driving in the opposite direction. For example, let us say that we have a target platoon \( P_{f-2} \) as shown Figure 5. Overtaking delay is the time for \( P_{f-2} \) to catch up with the source platoon \( P_{f-1} \) and relay delay is the time for \( P_{r-1} \) to encounter \( P_{f-2} \). Given the limited data transfer rate between two crossing platoons, the target platoon may have to receive different parts of the data file from different platoons, i.e. data mules.

When relaying data, we could image the following strategies:

- **Relay without coding (R-WC)** - A platoon passing by the accident site randomly picks up a number of packets and “data mules” them to the disconnected target platoon.
- **Relay with erasure coding (R-EC)** - A source encodes the data using erasure coding. Erasure coding protects from packet loss caused by relaying platoons that may exit the highway.
- **Relay with network coding (R-NC)** - The data is distributed using random linear network coding.

We compare the above alternatives using a simple example. Let us say that vehicles driving with constant speed of 110 Km/h (=30 m/s). A vehicle sends packets over a 11Mb/s radio channel with maximum throughput 7.74 Mb/s and the communication range is 250m. We assume that the highway has a single lane (10m wide) in both directions. The connection duration of two mobile vehicles in both directions is then approximately 8.3s/15 competing vehicles within the communication range, the effective capacity of the contact will be 0.5MB/contact. Assuming that \( \lambda = 1/10 \), the average delay between two vehicles is 10 seconds; thus, for every 10 seconds 512 KB of data is delivered across platoons.

\[ \begin{align*}
\text{Average delay (Seconds)} & \quad \text{Data size (MB)} \\
\text{No coding} & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \\
\text{EC, } r=0.1 & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \\
\text{EC, } r=0.5 & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \\
\text{NC, } q=16 & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \\
\text{NC, } q=256 & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \\
\end{align*} \]

**Fig. 6.** Delay for R-WC, R-EC, and R-NC strategies.

Let us then compare R-WC, R-EC, and R-NC in terms of delay. For R-EC we use redundancy factor of \( r = 0.1, 0.5 \) and for R-NC we use field sizes of \( q = 16, 256 \) (4 and 8 bits respectively). We vary the size of video data to see the impact of delay. Figure 6 shows the delay. As expected, R-NC performs best, yielding a delay 5 times lower than no coding. Surprisingly, even a small field size implementation of 16 can reap the benefits of network coding. R-EC performs almost as well as R-NC when redundancy factor is 0.5. These results confirm that “opportunistic” multicast using data mules can propagate the emergency streams to vehicles in a partitioned VANET scenario within acceptable delays, if proper encoding schemes, such as Network or Erasure coding, are used.
IV. LITERATURE REVIEW

We first start with the review of VANET broadcast and multicast streaming schemes. Urban Multi-hop Broadcast (UMB) [11] supports directional broadcast in VANET. UMB tries to improve reliability of broadcast by alleviating a hidden terminal problem through an RTS/CTS-style handshake, and broadcast storms through black-burst signals to select a forwarding node that is farthest from the sender using location information. Unlike UMB, Broadcast Medium Window (BMW) [12] and Batch Mode Multicast MAC (BMMM) [13] requires all the receiving nodes to send back ACK to the sender in order to achieve reliability. BMMM has also adapted to directional MAC in VANET [14]. However, all the previous work basically requires considerable amount of contention resolution time for each transmission, and thus, it is not suitable for real-time streaming which could potentially generate a large number of packets for a relatively short period of time.

At the applications level, several cooperative peer to peer type schemes have been proposed for vehicular environments. TrafficView [15] disseminates, or pushes (through flooding), information about the vehicles on the road, thus providing real-time road traffic information to drivers such as speed of vehicles. To alleviate broadcast storms, this work focuses on data aggregation/fusion based on distance from the source. Vehicular Information Transfer Protocol (VITP) [16] provides on-demand, location-based, traffic-oriented services to drivers using information retrieved from vehicular sensors. A user can pull information from virtual ad hoc servers (i.e., collection of private vehicles) at the target location by sending a location-aware query. Similarly, V3 [17] supports a video request query (i.e., video trigger message) to the target location. Multiple vehicles at the destination could forward the video data to the query originator, and intermittent connectivity is handled by the carry-and-forward method. Our work is different from existing approaches in the following aspects. First, our protocol “pushes” urgent video streams regarding emergency situations such as natural disaster, traffic accidents, terrorist attacks etc which cannot be “pulled” by remote customers a prior. These emergency streams must be disseminated to other surrounding vehicles in order to help drivers effectively avert the danger. Second, our protocol exploits random linear network coding to provide reliable streaming. Finally, we address the carry-and-forward approach to deliver delayed streams to disconnected platoons. In the vehicle environment, the limited bandwidth allows only piecemeal transfer between vehicles traveling at high speeds in opposite direction, thus creating the video data packets collection problem (i.e., the “coupon” collection problem). However, random linear network coding elegantly solves this problem.

In the unicast routing field, opportunistic DTN routing strategies have been well studied. Zhang et al. [18] surveyed DTN routing protocols and categorized them into deterministic and stochastic cases according to the scheduling of node movements. In deterministic cases, Jain et al. [19] proposed a framework for evaluating routing algorithms given different levels of knowledge about the network. Jones et al. [20] continued Zhang’s work and classified DTN routing protocols by DTN properties of replication (stochastic) and knowledge (deterministic). Since VANET is a non-deterministic network and node contact times are not known in advance, our literature review will only address stochastic routing protocols. Unlike GeoDTN+Nav, most VANET DTN schemes are inspired to epidemic dissemination except for FFRDV.

Probabilistic Routing Protocol using History of Encounters and Transitivity (PROPHET) [21] utilizes delivery predictability at every node for each known destination. The delivery predictability of a message at a node indicates how likely the node meets the destination. When two nodes meet, they exchange delivery predictability information which is used to update the internal delivery predictability of encountered nodes. The information is also used to determine whether a message is forwarded to the meeting node. The results show significant performance improvement over plain Epidemic routing; however, PROPHET has not yet been evaluated in vehicular ad hoc networks.

Distance-Aware Epidemic Routing (DAER) [22] is an epidemic DTN routing that addresses three problems common to epidemic routing: limited connection time, number of duplications, and limited buffer space. Since vehicles contact one another for such a short time due to high speed, prioritizing data delivery is beneficial. Data is prioritized based on the distance of a node’s neighbor to the data’s destination. The shorter the distance is, the higher is the priority for the data to be forwarded to the node’s neighbor. To limit the number of duplications, a vehicle would also keep track of distance between its current location and data destination. The data is pruned if the node moves further away from the destination. To control the buffer size, data that moves further away from its destination has a higher priority to be removed when new data comes in. The results showed performance improvement over plain Epidemic routing protocols.

Fastest-Ferry Routing in DTN-enabled Vehicular (FFRDV [23]) ad hoc networks is a unicast DTN routing protocol in which ferry selection depends on its velocity, in addition to its destination with respect to data destination. When the next ferry is selected, data is removed from the current ferry. A new ferry is selected when a node enters into a new “block”; however, there might not be nodes in the new block. Possible improvement is to eliminate block requirement for ferry selection to take place. Nodes should choose ferry every time they encounter new neighbors. Resource Allocation Protocol for Intentional DTN (RAPID) [3] routes a packet by opportunistically replicating it until a copy reaches the destination. Replication depends on the marginal utility of the underlying routing metric (average delay, missed deadlines, and maximum delay); in other words, replication only takes place if it justifies the resources used. DAER can be viewed as a resource allocation protocol in which replication depends on the routing metric of distance to data’s destination.

Similar to PROPHET, MaxProp [24] uses delivery likelihood to prioritize scheduling of transmitting and dropping packets. The delivery likelihood is different from delivery predictability in PROPHET in that nodes use the probability of meeting with another node to compute the path cost. Packet that has the least cost to the neighboring node will be delivered first. MaxProp is evaluated under a network of 30 buses. In Edge-Aware Epidemic Protocol [25], upon receiving a message a vehicle waits for a random time before making a decision whether to broadcast the message or not. The
waiting time is exponentially biased towards vehicles further away from the source node. To reduce flooding, nodes would propagate based on the number of packets they have received from their neighbors in the past. Thus, vehicles that are closer to the source would wait longer than vehicles further away. When the closer vehicles finishes waiting, because they have received many broadcasts from vehicles further away from the source, they will not broadcast, thereby reducing broadcast storm.

V. CONCLUSION AND FUTURE WORK

In this paper we have considered the problem of opportunistic routing in VANETs. We have identified three domains offering ideal applications of opportunistic routing: Delay Tolerant geo-inspired routing and real time video streaming/multicast of emergency multimedia streams. For each application area we have introduced a representative example and have offered a solution approach.

In the area of video streaming, we have gone one step further and have proposed a novel opportunistic multicast strategy that combines both diversity routing and network coding. We have evaluated its efficacy and suitability for the very challenging VANET scenario. In particular, we have shown that the delivery of the video stream to convey using vehicles in the opposite direction poses the well known “coupon collector” problem. Network coding elegantly solves the problem, outperforming the previously proposed schemes.

Future work will investigate the application of network coding for a broader range of vehicle scenarios beyond dissemination of alarms or safety related videos. On a broader scope, research is needed to trade off the delay of “opportunistic” routing with the potential traffic congestion, energy expenditure and risk of failure (under intermittent topologies) of aggressive, instantaneous routing, multicast and broadcast. Related to this research is the investigation of hybrid opportunistic and deterministic schemes which will switch from conventional broadcast flood mode, say, to opportunistic dissemination mode based on user, application and network utility functions.

REFERENCES