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VANET applications: Past, present, and future ☆

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A B S T R A C T

Vehicular Ad-hoc Networks (VANETs) are an emerging technology that has much potential development ahead of it. VANETs seek to connect devices contained within vehicles together to create services that are particularly relevant to a vehicular environment. They attempt to do so without relying on infrastructure devices to assist in the process of network topology management. This particular nature of VANETs leads them to provide both unique challenges and opportunities to investigate. This paper will seek to address the key features that define a VANET environment, while discussing what can be done with a VANET system. This paper will then investigate many different perspectives on VANETs, including historical perspectives and ideas for uses as well as more modern perspectives, and discuss how they have changed over time. Finally, this paper will investigate the current state of VANET technologies and discuss the current progress towards the successful deployment of these technologies in the real world.

1. Introduction

As computing technology becomes more advanced, one of the biggest driving factors of its advancement is the reduction in size of computing systems. By reducing the size of computing systems, we both increase the power of the largest systems by allowing them to use more resources while also making increasingly small systems viable for use. This can be seen historically in the development of the personal computer, which fueled many advancements in networking technologies. Now, increasingly powerful tiny devices are being developed that can be embedded into larger systems and still possess network communication abilities. This onset of new devices has also lead to many innovations in network technologies, which are referred to under the general category of Internet of Things (IoT) [8].

One subcategory of IoT technologies includes Mobile Ad-hoc Network (MANET) systems. As the name suggests, MANET systems seek to connect mobile devices, typically those moved under human power, to each other to create a network. Because only devices are connected and there are no managing infrastructure devices like routers or phone towers, these networks are considered ad-hoc networks. MANET systems allow any one device in the network to exchange information with all of the devices that are currently around them at any time. MANETs lead to the development of another field of mobile networking systems that sought to connect together devices that are being moved around by vehicles. This field was originally treated as a sub-category of MANETs, but as it was investigated, it was discovered that they faced many unique challenges and could bring about many unique opportunities. As a result, the field of Vehicular Ad-hoc Networks (VANETs) was developed to help focus on some of the unique aspects of this environment. In summary, VANETs are wireless networks of vehicular devices that are spontaneously created.

This paper will perform an overview of the field of VANETs. It will focus on some of the aspects of this field that set it apart from MANETs and other networking areas, and will discuss some different perspectives of the applications of VANETs. Since the field is relatively new and has been rapidly developing, this paper will look at how perspectives have shifted over time, and will evaluate concepts that have faded into obscurity as well as concepts that have only recently been conceived. By doing so, the development of the VANET field will be shown, as well as the future direction in which it is headed. This paper will also discuss some of the research we are currently conducting in developing VANET technology, and discuss how our technology compares to previously developed ideas. Finally, this paper will look at which of the applications that have been discussed in this paper can be implemented with the assistance of our technology and what other applications that were not previously considered might now be afforded by our technology.

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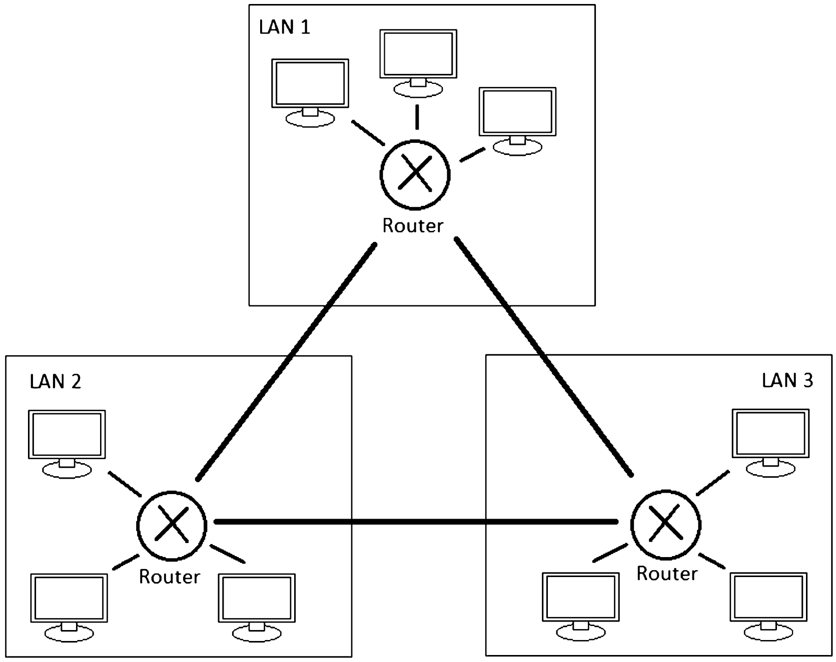

Fig. 1. Communications in LAN 1 do not disrupt those in LAN 2, and communications between LAN 1 and LAN 2 do not disrupt those in LAN 3.

This paper provides the field a longitudinal discussion of VANET applications. This new focus grants the opportunity to see how VANET applications have developed over time, granting insight both into the origins and future of VANET applications.

2. VANET and MANET

We will begin by investigating some of the key characteristics of VANETs, then look at what set these systems apart from their MANET brethren and caused them to be treated as a separate form of study. One of these key characteristics of VANETs is the high number of nodes in a VANET environment. Traditional network methods seek to manage the number of nodes on any section of the network by adding in hardware devices that assist with the management of nodes by dividing them into sectors. For instance, a group of computers are connected to a local router, which may be in turn connected to a higher router in the chain that manages a group of local routers. This sort of relationship continues until it reaches the Internet at large [71]. This structure is integral in keeping the number of nodes connected to any one router at a reasonable level.

By reducing the number of nodes connected to the router, a sub-group of computers is able to communicate with each other without impeding computers outside of their group. These sub-groups can then also communicate with the group above them without impeding other nearby sub-groups or larger groups beyond the second group, as shown in Fig. 1 [46]. However, in an ad-hoc network environment, physical infrastructure devices like routers are not available [22]. Additionally, there can be a very large number of vehicles within an area, and each vehicle is not necessarily constrained to have only one device connected to the network [40]. In fact, many applications discussed in this effort rely on having different output forms that are currently relegated to distinct devices. For example, a system that is designed to control braking for the car may be able to assist the driver in braking when it receives messages that suggest that beginning to brake may be a good idea, but may not have a consumer interface with which to display non-distracting messages to the driver to notify them of local shopping opportunities. Likewise, a cellphone being used by the navigator of the car to identify local shopping opportunities may not be able to directly assist the driver in braking to avoid an imminent collision. As a result, VANETs contain a very large number of nodes connected to them. This leads to one of the key focuses of VANET systems: network scalability. Only a system that can properly handle a large number of connected, communicating devices without physical installments will be able to properly handle a VANET environment [24].

Vehicles move quickly [37]. As a result, a VANET system needs to be able to handle an environment where the nodes within the network are moving around at high speeds, potentially entering and exiting the network very quickly. This is one of the most distinct characteristics of VANETs, since vehicles are one of the fastest-moving environments where modern technologies are currently employing computer devices [24], [13]. Therefore, identifying how long a vehicle is expected to stay within a network is very important. If a vehicle is going the opposite direction, the connection will be very brief. In such a circumstance, the network would want to transfer only the most essential information to reduce the risk of the data not being successfully received. On the other hand, if a group of vehicles are all moving together the network will have a very long amount of time to transfer any information that is received [24], [98]. This length of time can become extremely long in cases like parades or vehicle escorts. The high mobility also makes multi-hop communication more challenging, as it becomes necessary to identify which intermediate nodes will remain in the network long enough to perform the desired transmission [24], [98], [87].

The difficulty in identifying length of time for a transmission to occur is also particularly important in VANET applications, as the importance of data transferred across the network can vary greatly [24], [12]. For example, the transmitted data could be a notification of a crash that has closed off the highway ahead. By reducing the time it takes to relay this information, we increase the amount of cars that can reroute before getting caught in the traffic generated by the incident. This will result in a reduced amount of traffic caused by the accident. In an even more extreme example, the notification could be about a crash occurring directly in front of the driver, and could allow the car to successfully navigate the situation before the driver even has a chance to react to it. In such situations, delay in the transmission of the information could result in a loss of life. As a result, successfully transmitting high-priority data as quickly as possible is an incredibly important feature of a VANET system [24], [12], [63].

Another difficulty of VANETs is user privacy due to the spreading of information about any given driver across the system [24], [84]. Information that identifies the location and path of the user is very important to network clustering protocols, since the heading of a vehicle can greatly impact how long it will spend with a particular group of vehicles [24], [13]. However, this information gives the network some information about where a particular vehicle is and where it is going. If proper privacy protection measures are not put into place, a malicious user could use VANET vehicular metadata to track a particular car, which can be a huge risk to privacy. As a result, VANETs need to provide a large amount of anonymity to the users of the network to prevent information on their past, current, and future location from being leaked [24], [43], [7]. This will increase some of the security concerns around VANETs as well [24], [84].

Another challenge VANET systems have to overcome involves the availability of multi-hop routing. In normal network systems, long distance routing is achieved by determining a chain of nodes that can form a connection all the way from the sending node to the receiving node. Since VANET systems have additional difficulties involving the mobility of nodes and high movement speeds, it becomes more difficult to identify an effective chain of nodes that can pass the message along. The high mobility means that partway through the process of identifying these chains, some of the nodes in the middle may move and lose connection. In such a circumstance, the routing algorithm will have to begin the process of finding an effective chain of vehicles all over again. While multi-hop routing is far from impossible in a VANET system, it is considerably more challenging than in a MANET system, and many times the desired multi-hop routing will not be able to be performed in the current environment. This can deter the development of products that rely on passing messages across long distances, since they can't rely on long distance packet forwarding always being available in a VANET environment [24], [87], [13].

While VANET systems face challenges, they have many advantages over traditional MANET systems that can be employed to achieve a better performance. One of these advantages is that VANETs tend to have a much more dense distribution of nodes across the network than a standard MANET environment [24], [49], [94]. This means that vehicles within the network are more likely to form close together clumps than a MANET, which will have a more evenly distributed pattern of nodes across the network. This can ease the difficulty of creating local connections, since there are more likely to be nearby nodes with which a system can communicate. This will allow a larger rate of data exchange across the systems, allowing VANETs to contain a larger number of information exchange systems than a similar MANET [24], [51], [13]. On top of this, VANET systems include more heavy-duty devices built into vehicles. These devices may have a higher bandwidth than a typical node in a MANET, which is most likely to be a modern cellphone. Since these built-in computers can have a higher bandwidth, this can further facilitate the increased amount of information spread in a VANET system when compared to a MANET system. This allows VANETs to support a greater range of applications while also transporting more detailed information. Since the system can include heavier duty computers built in to the vehicles, those nodes will also have a greater broadcast range and a greater reliability in messages passed, which can further facilitate the improved passing of information in VANET systems [24], [52].

Another key advantage VANET systems have over MANET systems is the lack of reliance on a battery for many devices connected to the network [24]. Since vehicles generate electricity as they run, systems connected directly to the vehicle do not need to rely on a battery to keep themselves running, but instead can tap into the vehicle's generated energy [1]. Independent systems, like GPS units and cellphones within a vehicle, can also be plugged into the vehicle to maintain their supply of energy. As a result, VANET systems don't have to worry about nodes disconnecting suddenly due to consumed batteries [1]. Furthermore, VANET systems can consume more processing power on the connected devices since they will not be depleting the devices' power reserves as they perform computations related to their system [48]. This allows a large expansion in system up-time, allowing more information to be actively passed and more computations to be performed on the connected devices without causing customer dissatisfaction from overdrawn batteries [24], [48].

VANET systems can also obtain more accurate location data from other nodes on the network due to the ability of the nodes to create GPS and RADAR data, as well as the decreased concern about consuming battery resources by requesting more detailed data [24]. While cellphones connected in a MANET will likely have access to GPS data, accessing the GPS constantly will consume a large amount of the phone's battery resource [80]. This is less than desirable when a phone may be running on its limited battery resource and it is unknown how long that it will be required to spend connected to the network without being able to recharge. This causes MANET systems to have access to less accurate location data than a VANET system. As a result of VANET's easier access to location data, they can use location-based addressing schemes for node names, while MANET systems traditionally use attribute-based addressing schemes [24], [56], [86]. This use of location-based addressing schemes makes performing location-bounded tasks more straightforward in VANET systems [24], [86].

MANET systems, by definition, do not use infrastructure to assist in the transmission of information [24], [79]. Originally, VANET systems also rejected the idea of using infrastructure devices to assist with the transmission of data across the network [87]. However, more modern concepts have been increasingly accepting of the use of roadside infrastructure devices to assist with the transmissions [24], [62], [28]. This mode of operations is called Vehicle to Everything (V2X), while systems that only allow communications between vehicles are call Vehicle to Vehicle (V2V) systems. In Fig. 2, we can see an example of a group of vehicles communicating at an intersection using a V2V system. Since this system only supports V2V communication, this network cannot use any of the capabilities of the infrastructure devices within its range. In Fig. 3, we can see an example of a V2X system in action. Since this is a V2X system, the vehicles can now also use the nearby cellphone tower to send and receive long distance packages. Additionally, they can communicate with infrastructure devices installed in the traffic lights, which may contain detailed information about this intersection. Both these modes of operations are subsets of VANETs, with more modern works focusing on development for V2X capabilities.

One of the biggest factors behind why V2X systems came into vogue is due to the difficulty of making consistent multi-hop routing algorithms [49]. With the assistance of roadside devices, it becomes considerably more straightforward to store local data or send transmissions across long distances. While this does mean that deploying a VANET will require a greater financial investment, it will also give a lot more power to the VANET systems. As a result, many of the disadvantages of VANET systems can be greatly reduced, but the development cost will be higher than it is for a MANET system [24], [62]. As a result, we will look at applications in this paper that use both V2V and V2X modes of operation.

VANET systems enjoy a much more predictable set of movement patterns for nodes than a MANET system [24]. Since VANET systems are designed for vehicles, they can expect the nodes in the system to behave as the vehicular traffic laws specify they should.

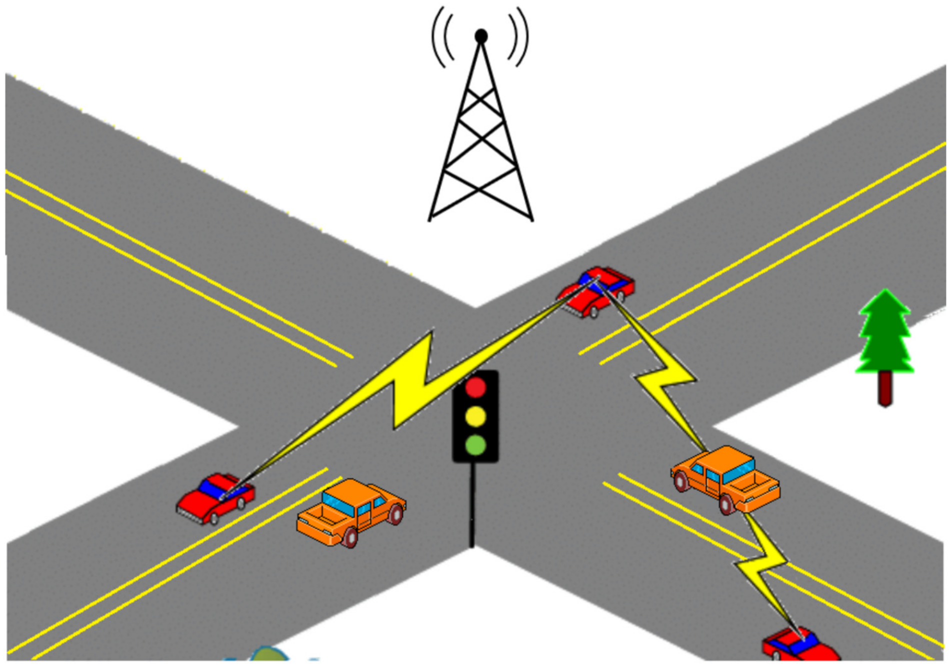

Fig. 2. An example of a VANET with V2V communications only.

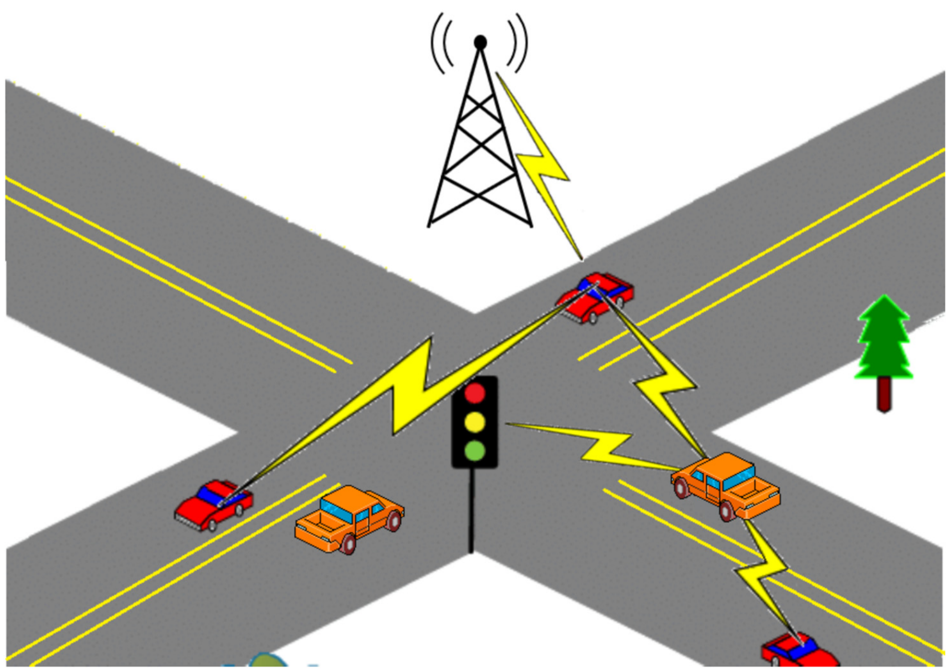

Fig. 3. An example of a VANET with V2X communications.

This will greatly reduce the number of possible turns a node is expected to make, as well as allowing systems to more easily predict where a node will be moving next based on where it currently is [59]. This is especially the case since nodes are considered to move primarily randomly in a MANET system, as pedestrians have far less strict rules governing their movement and can perform much faster turns and maneuvers than modern vehicles can [24]. This brings about a stark difference between the ability of the two environments to determine the patterns through which a node will move. This difference in mobility patterns gives VANET systems some methodologies to compensate for the much higher node speeds in their environments [24], [70]. If a system can successfully predict the movements of a vehicle, then even though it is moving at a high rate, the system can still adequately provide for them since they are moving considerably slower than the transmission rate of a network. However, this means that VANET systems have a far greater focus on developing algorithms to accurately predict the movements of vehicles, while MANET systems largely ignore this aspect of the field [51], [59], [70]. This can lead to entirely different research directions in a VANET environment that would not be expected for MANET systems.

Broadcast systems are also more important in VANET environments than in MANET environments [24], [87], [63], [51], [54]. Due to frequent changes in road conditions and issues that may cause different vehicular behavior, including accidents and accident response vehicles, it often becomes very important in VANET

Table 1
Applications discussed in this paper.

Application	Classification
Ad-Hoc Enabled Car Communities	General Purpose
Platooning	Driver Assistance
Connected Autonomous Vehicles	Driver Assistance
Emergency Response Community	Safety
Ad-Hoc Enabled ITS Car Navigation	Safety
Lane Change Assistance	Safety
Forward Collision Warning	Safety
Electronic Emergency Brake Light	Safety
Traffic Notification System	Driver Assistance
Automatic Accident Notification	Safety
Ad-Hoc Service Architecture	Advertisement
Tracking of Stolen Vehicles	Safety
Tracking of Known Criminals	Safety
Remote Vehicle Diagnostics	Driver Assistance
Internet Connection	Entertainment
Distribution of Geographical Data	Advertisement
Road Topology Predictor	Driver Assistance
Environment Evaluator	Driver Assistance
Automatic Toll Collection	Driver Assistance
Parking Spot Locator	Driver Assistance

environments to broadcast safety-related information to vehicles connected to the network. In addition, this safety information will generally be relevant to all the vehicles in a given road system, which leads to a focus on broadcasting techniques that send information to all nodes connected to a network within a region [24], [4]. These systems are expected to be employed far more frequently within a VANET environment when compared to a MANET environment, meaning that a greater focus needs to be put on effective multi-hop broadcast systems when developing VANET systems [24], [51], [85], [6].

3. Applications

Since these key differences have emerged between the two environments, the development path for VANETs has become quite distinct from the research needed to be done for MANETs. While VANET was originally considered a subset of MANET, it is now seen as an entirely separate field and development of VANET-specific applications has grown greatly [87]. These applications have been seeking to find some particular feature that can be provided by a VANET system that has not yet been explored and provide a framework for how to properly support them. This paper will discuss some of the many different concepts that were developed for VANET and how views of them have shifted over time.

In Table 1, we list and loosely classify all the applications this paper will discuss. We define general purpose applications as those that assist with the deployment of VANET, driver assistance applications as those that reduce the difficulty of the task of driving, safety applications as those that reduce the number of casualties related to driving and accidents, advertisement applications as those that advise the driver to local stores and entertainment options, and entertainment applications as those that provide some sort of entertainment to the occupants of the vehicle. There is some overlap in driver assistance applications and safety applications, as most applications that make driving easier will also reduce the risk of driving, but we differentiate them by whether their primary purpose is preventing collisions/saving lives or merely making some aspect of driving and navigating easier.

3.1. Ad-hoc enabled car communities

One of the earliest applications put forward for VANET systems was ad-hoc enabled car communities [87]. This application would identify a group of vehicles or have a group of vehicles self identify themselves as a community. This community would represent a subset of vehicles on the road that have the same goal. For example, this goal could be a group of people all traveling to the same party or a group of emergency responders all rushing to the same location. Since they are all trying to reach the same goal location, once the vehicles meet on the road, they are more likely to avoid being separated as they travel. This allows the creation of a more stable multi-hop routing scheme, which under normal circumstances is very challenging for VANETs, as discussed earlier in this paper. This more stable multi-hop environment can be used to pass around a larger amount of information relevant to this car community, such as more detailed information on traffic ahead and proper avoidance methods [87], [38], [82]. As time has passed, this idea of a car community has been developed to include many other potential features. One of these features was envisioned thanks to the onset of self-driving car technologies. As the world begins to move toward larger amounts of automatic piloting in vehicles on the market, it becomes increasingly feasible to upgrade these car communities to a new entity referred to as a platoon. A platoon shares many of the characteristics of a car community, but adds in the functionality of having a lead car in the community that collects information on the road ahead and tells the vehicles behind it how to navigate the road. This can be used to greatly reduce the amount of computation needed for the vehicles behind the lead car to perform their self-driving behaviors. It can even be relied on as a way to allow vehicles that have the ability to control braking and steering, but do not have any self-driving algorithms or road observance tools, to perform as if they were a self-driving car while belonging to the platoon [54], [9]. This type of car, while it may sound unusual, is actually commonly available, since they represent vehicles that have minor autonomous functions like auto-braking or self-parking, but do not have a comprehensive enough suite to perform fully autonomous driving [87], [9]. By granting this commonly seen subset of vehicles the ability to perform as self-driving vehicles, these technologies can greatly reduce the strain on human users driving their vehicles, and subsequently reduce the amount of collisions that occur on the roadways.

This direction of development has been extended even further to now include connected autonomous vehicles. As the name implies, connected autonomous vehicles are autonomous or self-driving vehicles connected together in a network. Having autonomous vehicles connected allows them to exchange detailed information on the roadway and traffic ahead, allowing the autonomous vehicles to make better informed decisions about how to best navigate the area. This will allow more efficient routing than an isolated autonomous vehicle could provide while also granting the vehicle access to the many services VANET can provide [72], [5].

These ad-hoc enabled car communities have sparked more developments since they were first conceived, due to their simple nature and how frequently we might expect to see this sort of event occur. The next development surrounding ad-hoc enabled car communities is intended to be used for car communities that are formed from emergency response teams [63]. When a car community is formed from an emergency response team, the car community gains the additional characteristics of having a higher speed than the legal limit on the roadway it is driving on as well as having the right of way in all scenarios. As a result, they can create a broadcast message scheme that originates from these car communities and tells the vehicles ahead of the community to yield to the group of emergency response vehicles. It can also be broadcast to the side roads that will intersect with the car community's path to warn those drivers as well. This could act like a siren that can be heard around corners and at a longer range despite road noise and would give more precise information to the drivers about where the emergency response vehicles are than a typical siren. This system could even possibly have the vehicles automatically pull over and wait for the emergency response team to pull through. This application could help speed up the response time of emergency vehicles, which could very easily reduce the number of deaths that occur in the time between when an emergency occurs and when the response vehicles first get to the location [63], [81].

3.2. Ad-hoc enabled ITS car navigation

The ad-hoc enabled localized Intelligent Transportation System (ITS) car navigation is another application that was suggested for VANET systems. ITS car navigation is an attempt to optimize a very small subset of driving that occurs frequently and can often lead to crashes, such as changing lanes and exiting a road. This application was originally imagined as a way for vehicles to identify the problem of exiting a road by evaluating a number of metrics, including vehicular speed, distance until the exit location, number of lanes between the car's current position and the exit, and density of neighboring vehicles and their speed. The vehicle would listen to determine the relative positions of vehicles around it, then attempt a merge only when there are no vehicles reporting their location that are determined to be in the way. Additionally, the car could locally broadcast its intention to merge, which other vehicles could respond to by making room for the broadcasting car to perform its merge [87], [18]. This could help improve the safety of performing merges with the purpose of exiting the highway and reduce the number of car crashes that occur as a result of this. This was also originally envisioned as the first step to adding a secondary layer of car signals that allows a car to signal its intent to merge via a wireless signal instead of only a visual cue on the car. The information could be transmitted more efficiently and lead to fewer scenarios where the signals cannot be adequately seen [87].

This application has undergone a large amount of re-evaluation since it was first proposed. While the concept of facilitating a safer exit from a highway is appealing, the limited scope of this scenario has caused it to be greatly re-evaluated. This application has been developed and split into three separate categories for more modern applications. These are separated into Forward Collision Warning, Lane Change Assistance, and Electronic Emergency Brake Light systems [63]. Of these, Lane Change Assistance is the most similar to the original application, as it is similarly focused on providing detection and avoidance systems when a vehicle is attempting to relocate from one lane to another. However, it does not have the same limited scope of the original version of only being intended for use when performing an exit from a highway. It is now intended to be used in any scenario where the user is changing lanes [63], [67]. Forward Collision Warning attempts to use short range information from the vehicle ahead of it to help avoid a collision with that vehicle. If that vehicle were to suddenly come to a stop, the Forward Collision Warning would be expected to notice it and perform braking to assist the driver in avoiding that collision [63], [17]. The Electronic Emergency Brake Light uses messages from vehicles further ahead in the same lane to determine whether or not they are braking. This was developed to alleviate the problem of brake lights ahead of your vehicle not being visible due to obscurement. Across these three technologies, vehicles are provided with warnings about vehicles to their left and right when merging, warnings about the car immediately in front of them, and warnings about vehicles further ahead, providing a much more comprehensive suite of detection and avoidance technologies [63]. This suite of technologies has been expanded further from when they were first proposed to also include warning systems that will provide information on the vehicles ahead in other lanes [54], [5]. These systems intend to identify situations where the vehicles in nearby lanes ahead lose control or begin performing some dangerous behaviors. Then, it would notify the trailing vehicles to provide adequate time to brake or avoid the car after it begins behaving abnormally [95]. Across all these methods, the risks and dangers of driving in congested situations can be reduced, thus, lessening the amount of accidents that occur on roadways.

3.3. Congestion control

The next application this paper will investigate for VANET systems attempts to deal with car traffic flow and control congestion as it develops [87], [23]. Modern vehicle-to-server systems, like Google Maps, collect traffic data from the road, update it in their systems, and attempt to choose the most optimal path given the current traffic situation when creating a navigational route [88]. This application would perform a much similar role, but would have some key differences when compared to technologies like Google Maps. This application would broadcast a message to all vehicles behind an observed congestion spot so that they can be warned of its existence and take steps to avoid entering into the congestion as well. This would differ from what other technologies might know about the situation in that it would have a much faster response time, with the ability to begin notifying vehicles behind the incident almost immediately after it occurs. This could allow drivers to be better informed and able to respond faster to avoid certain sections of the road, thus, reducing the number of vehicles stuck behind backups [87]. This would provide a number of potential benefits, including reducing the amount of energy consumed by vehicles that are left running behind backups, decreasing the average time it takes for vehicles to reach their intended destination, and making it easier for emergency responders to reach the scene of the accident [63], [54]. Future versions of this application have looked at extending it by connecting it to a central database system in an attempt to capture information on the traffic of the entire transportation network in near-real time, providing improved large scale traffic routing protocols [54], [10].

Unlike some of the previous applications discussed earlier which have been directly extended to have more uses in future versions, this application has been extended in a more parallel direction to the original concept. Future versions of this application do not only seek to notify drivers approaching the scene of an accident that they would be better off taking an alternative route, but also seeks to fully autonomously notify emergency responders immediately that an accident has occurred. Adding this layer to this application can help reduce the amount of time between when an accident occurs and when emergency responders first receive notification of it, which can be critical when it comes to the ability of the emergency responders to reach the scene of the accident in time to rescue the individuals involved. Under normal circumstances, there is an approximate delay of five minutes between when an incident occurs and when it is first reported to emergency response crews. Since it takes on average about 15 minutes for an emergency response team to arrive at the scene of an accident, this difference in time can be critical [63]. Furthermore, automatic reporting systems integrated into the car that crashed can help identify the type of incident that occurred, and give authorities more information on the types of tools they will need to adequately respond to the incident. This system could, for example, tell the authorities that the car had rolled during the accident and is now on its side, thus indicating to the authorities that they should expect heavy injuries and be prepared to have to force the door open or otherwise cut the vehicle to save the users inside the vehicle. If extended, this could even tell the authorities how many people were in each of the vehicles, allowing them to prepare an adequate number of ambulances for the incident. Furthermore, vehicle manufactures create manuals that specify the best way to interact with their vehicle to extract the passenger in case of an accident. The best method for this can vary from vehicle to vehicle. However, the optimal methodology and tools for every vehicle on the road is too much information to expect an emergency responder to recall in the limited time-frame they have to respond to an accident; therefore, they have to use general best practices instead of vehicle-specific ones. With the addition of notifications from the vehicles, an integrated technology can be created that specifies some of the best tools to take automatically and briefs the responder on some of the best practices for the particular types of vehicles impacted on route to the scene of the accident. Using these technologies, VANET systems can use the information sent by the vehicle to better inform the responders to help save the lives of the victims involved in the accident [63]. As a result, the ability for an accident to be automatically detected and reported to the appropriate authorities, as well as drivers on the road affected by the accident, is a commonly discussed field of VANET systems [63], [87], [57].

3.4. Ad-hoc service architecture

When compared to previous applications, the next application is less likely to save the lives of drivers. However, it does provide new services to the driver and is helpful for small business owners. This application is an ITS ad-hoc service architecture that provides information about local stores and services using VANET systems as an interface. In this application, store owners can install an infrastructure device that passes information about their store into the VANET system [87], [50], [91]. This information could then be relayed short distances to notify vehicles passing through about the existence of stores that they might not have otherwise been able to see. This application would provide a unique service because, unlike traditional signboards and notices, it can provide more precise information on the location of the business and can be more easily updated to represent the addition of new small businesses [87], [32], [41]. Additionally, when compared to a service such as Google Maps, it is better targeted to a vehicle environment and can provide quicker access, as the user's vehicular systems could passively collect information on local shops. Then, when the user desires to stop for food, gas, or some other commodity, they could simply apply a filter to the information already collected about local stores to see if any of them are of particular interest to them. This reduces some of the overhead of systems like Google Maps, which contains information on stores across the country and will provide information on stores within a much larger range than the user can quickly drive to [87], [66], [97]. This could help small business owners advertise their store and help users access the stores they desire more easily [54], [60].

3.5. Tracking of stolen vehicles

Another important issue in modern society that can be addressed by VANET systems involves the tracking of stolen vehicles [87]. This application would use the identification information that a vehicle provides when connecting to VANET to attempt to track where a stolen vehicle has been taken. This is envisioned being done using infrastructure components that can relay information on a vehicle's location back to local law enforcement officers. Using this system, when a vehicle is stolen, law enforcement officers can easily determine its current location. This can help reduce the time it takes to locate stolen vehicles using GPS-based tracking systems, as they can easily be updated as the vehicle is on the move. Reducing the response time is critical, since vehicles will very quickly be stripped apart for their components to be sold individually after the theft is performed. The proposed metric to be used to identify the stolen vehicle is the Vehicle Identification Number (VIN), since this system already exists and can be used to uniquely identify every vehicle on the road. Additionally, the police already have access to VIN databases, reducing the amount of additional information that needs to be collected to make this system work as envisioned. This system could greatly reduce the cost of insurance for drivers, as a large portion of insurance rates are used to pay compensation for vehicles that have been stolen. Additionally, the fast response time could provide a deterrent to potential car thieves, since they know that it has become more difficult for them to make a profit from this form of criminal activity [87], [27].

This potential application has a further variant that includes the tracking of vehicles owned by known criminals. By providing a new way to locate particular vehicles quickly, the police can use this information to locate vehicles owned by criminals with the hope that the criminals are using the vehicle and can be found in or near them. This search can be further narrowed down by only considering vehicles that are on the move or recently have been moving, suggesting that the criminals are still using the vehicle. This can help police catch criminals that are currently on the run before they have a chance to cross jurisdictional boundaries, such as the borders of a state. Providing a faster apprehension time for known or suspected criminals could help reduce the amount of crime that occurs across the country [54]. However, the ability to track all vehicles at any time provides a large amount of questions when it comes to personal privacy. This could allow the police or a hacker to have access to an excessive amount of information about the travel patterns and daily life of any user that has a car connected to a VANET system or with this feature embedded in it. This can be greatly detrimental to the average user, and in the case of a user being targeted by someone who wishes them harm for any reason, could even become very dangerous. As such, there is much debate surrounding the implementation of this system and many other systems like it [25]. These concerns could impede the implementation of this application or even stop it from occurring entirely. Even if this application is implemented, special considerations will have to be taken to protect the privacy of its users and protect against malicious hackers or the abuse of the police's authority.

3.6. Convenience and entertainment applications

A more modern application is the development of remote vehicle personalization and diagnostic technologies [54]. These technologies will allow a user to set particular characteristics of their vehicles or view diagnostic information from a remote location. This means that a user could set some features such as maximum speed or requirement of safety features, such as safety belts, when someone they do not fully trust is operating their vehicle. The most likely case for this occurring would be a parent letting their newly licensed child to drive the vehicle on their own. These features could be used to help ensure that their child is practicing best safety practices to reduce the risk of an accident. The diagnostics tools could be helpful for all users that share a vehicle. Being able to observe some key features of the vehicle, such as gas remaining, miles on the odometer, and battery level, could help a remote user remind the current user of the vehicle to perform routine maintenance activities to ensure that the vehicle runs as smoothly as possible [54], [42], [14]. This application is focused on providing convenience for the user rather than being a critically important application to safety, like many of the previously discussed ones in this paper. Applications that provide conveniences to the user are very important to help make a product sell; therefore, implementing this could make it easier for a business that is creating VANET applications and systems to turn a profit from them. As it becomes increasingly viable to profit from VANET technologies, VANET technologies will become more prolific and provide all the important life-saving measures that were previously discussed. As a result, even though this technology and some future user-focused technologies that this paper will discuss may seem frivolous, they are still vital to the development of proper VANET systems.

Another user-focused application is the connection of VANET systems to the Internet at large using infrastructure devices or by routing packets through nearby devices with alternative ways to access the Internet [54], [33], [47]. By integrating this technology into VANET systems, connecting to the VANET can help provide a more reliable access to the Internet in remote locations that might otherwise have spotty or non-existent technologies. Additionally, these technologies can help ensure that all devices connected to a VANET environment have some measure of access to the Internet, which can help a large number of new features to become available to the systems. In particular, any system connected to the Internet through the infrastructure or alternative means could use that connection as an alternative to multi-hop connections that only connect from vehicle to vehicle, which can help avoid the issue of long distance transmissions being very difficult in VANET environments. This connection to the Internet or additional infrastructure devices can be used by enterprising video streaming services such as Netflix to provide real-time video relay to vehicles as they travel [33], [42]. This could allow the user to watch videos as they travel across long distances, as previous services did using disk players. By performing this interaction over a network instead of a physical medium such as a disk, the video streaming service would allow the customer to watch their choice of any of the movies in the service's database instead of just the ones in their physical possession [54], [83]. This would add a large amount of convenience for users and is a field that could be exploited for massive profit if handled correctly.

3.7. Distribution of geographical data

Another more modern application of VANET technologies includes using local infrastructure devices to pass vehicles a local map of the area, then having vehicles spread that information using vehicle to vehicle communications [54], [77]. This would allow the user to always have a detailed map of the local area even in the absence of a full Internet connection, and to effectively navigate the region and potentially locate goods or services within the region that they find to be of interest. This infrastructure investment could be sponsored by the local government in an attempt to increase the tax revenue of their town by providing advertising for their local goods and services. This technology can be combined with route diversion technologies, which attempt to find alternative routes or activities for the user in the case of traffic congestion [54], [57], [58]. By providing users with information on the local entertainment facilities via the area map, the service could suggest some entertainment facilities where the user could spend some time while waiting for traffic to dissipate instead of spending the entire time in traffic. This could also decrease the congestion for users that cannot stop since their trip is time sensitive, as some of the other users of the road could leave the road to pursue local entertainment options while the time-sensitive users complete their driving as quickly as possible [54], [57].

Another application that can be implemented with VANET technologies is an active prediction technology that collects and distributes information about the topology of the road to reduce fuel consumption [54], [44]. This application would work by having the lead vehicle record variations in the curvature of the roadway, and report this information to the following vehicles. The following vehicles could then regulate the amount of fuel released to the combustion chamber to more efficiently navigate around the turns and over the bumps. By having this technology integrated into the acceleration system, it can reduce the amount of fuel consumed by the vehicle as it navigates across the roadway [44], [78]. Additionally, this technology can be integrated into the steering system to help compensate for some of the shifts that may be caused by road conditions, as well as preparing them adequately for upcoming turns that may potentially be hazardous [54]. While this may sound similar to a platooning system, it differs in that the movement commands passed to the following vehicles are not based off the movement commands the first car inputs, but rather are based on the road conditions observed by the first car. This could provide better optimized signals than a platooning system, but would be less well suited to being solely relied on as a means of navigating the roadway. Instead, it is best suited to use as an assistant system.

This application can be extended yet further to include scanning the environment around vehicles in addition to the roadways themselves. This would allow vehicles to share information about the conditions surrounding the roadway rather than just the topology of the roadway itself. This could be used to detect hazardous conditions, such as snow and where it is starting to accumulate. This could also be used to detect resources around roadways of interest to drivers, such as available parking spots [5].

3.8. Infrastructure enhancement

As modern technologies become more advanced, the classic systems for collecting tolls from drivers on toll roads seems increasingly outdated. These systems can be modernized by integrating them with VANET technologies [54], [76]. VANET applications could alleviate the need for queuing up to pay for the toll individually by creating an integrated system where the toll collection point detects a vehicle passing through and records the identification number being emitted by the vehicle. This identification number would be linked back to a database that correlates the identification number to an associated account that contains payment information, allowing the system to collect money from them. This can also be used with GPS-based technologies that collect information on where the vehicle is traveling and how long it spends on the road. This could allow the implementation of tolling policies that vary the amount paid by the vehicle based on the distance traveled on the road, making the payments more directly proportional to the amount of wear they add to the road. This could represent a more fair system of payment, since the wear each vehicle adds is proportional to the amount a vehicle contributes to increasing the maintenance costs of the road [54], [76]. This system also has the advantage of being more easily utilized as a universal standard than traditional toll collection technologies. It can create a centralized system that can work for all toll booths across the nation or even multiple nations. Current toll payment systems can often vary based on the current location. On top of this, this system would only require the usage of the VANET devices already installed in the vehicle. In this way, they could avoid requiring the installation of separate hardware in the vehicles as modern implementations often do. This would reduce the overhead cost of creating an account with the toll payment system, which would increase the ease of joining for new customers. This is turn would increase the audience that this system would reach. It could also decrease the need for employees to work the toll booths. This could greatly decrease the amount of overhead for toll collecting technologies, as it would reduce the number of employees they need to hire, as well as the need for employee-managing systems and employees hired to manage other employees [54].

VANET systems also provide a convenient platform for creating new parking technologies [54], [7]. Devices can use the communication from VANET systems to monitor the number of vehicles within a parking lot area [54], [64]. This could allow passing vehicles to be notified as to whether or not the parking lot they were driving past was full, and could reduce the likelihood of users wasting time entering a lot that is already full. Additionally, this can be used to create a comprehensive list of nearby parking areas that still contain parking spots, allowing the users to easily navigate to the nearest available spot [54], [55]. This creates no small amount of convenience for users in urban areas, particularly in an area where parking lots tend to fill up quickly and navigating to alternative parking lots is troublesome or time consuming. Additionally, by better utilizing the parking spaces in the area, the amount of customers that can reach a given business might increase, increasing the revenue for the local businesses. This can lead to increased prosperity for small businesses in urban areas that do not have sufficient parking spaces to support their full customer base [55].

3.9. Secondary benefits and trends

As these applications are added to VANET systems for the convenience of users or the general improvement of traffic systems, there are some secondary benefits that also occur. Some of these secondary benefits are being researched in their own rights to determine how applications can help achieve them while fulfilling their intended goal. One such benefit is the benefit to the environment by implementing many of these applications. Many of these systems attempt to improve the user experience of driving by improving aspects such as the amount of time spent on the road, as well as automatic steering adjustments such as those that predict brakes ahead. These systems can each lead to a reduced amount of fuel consumed by better optimizing how a car performs tasks or navigates through an area. By reducing the fuel consumption of the vehicles, they also reduce the emissions of the vehicles, which is beneficial to the environment [54]. Another such secondary effect is the ability of the users of the systems to better optimize their usage of time. This is often achieved by reducing the amount of time they spend on the road, but can also be achieved by allowing the users to perform some sort of beneficial task while they are not navigating the car due to being stuck in a traffic jam or something similar. A straightforward example of this would be if the user used the provided Internet connection to perform simple tasks for their work, such as replying to e-mails. When platooning technologies no longer require user supervision, the user could also take advantage of the time afforded to them by not having to navigate their vehicle en route to perform productive tasks [54]. As such, it can be seen how many of these application will provide secondary benefits that are still of great interest to the users of the systems.

By looking at how proposed applications have shifted over time, two major trends have become clear. The first of these trends is a more traditional pattern of adding in additional complexity to a previously imagined application to make it applicable to a broader range of situations or to make it more optimal for a specific situation where a VANET environment is particularly well suited to handle it efficiently. This is the subset of applications that are, in general, providing some service that is only achievable through a VANET system or at the very least considerably more feasible in such a system. The second trend involves moving traditionally provided applications from another implementation to a VANET environment to either widen the scope that the application can reach or slightly improve the convenience of the application. This sort of application becoming increasingly common as time passes is indicative of the increasing feasibility of VANET systems, since they show that traditionally usable applications have taken note of the development of VANET technologies and are interested in also taking advantage of the environment they provide.

4. Scalability

When attempting to implement these proposed applications for a VANET system, there are a number of challenges that the designer has to overcome. One of the most important of these is creating a system that can scale to handle a very large number of nodes, since VANETs run in an environment where having an extremely large number of vehicles in a very small area is a common occurrence. On top of that, delay in broadcasting messages can lead to potential life-threatening issues for certain applications that want to be run within a VANET. As a result, there is a large focus on creating a network system that can handle a large number of nodes being connected to the network without experiencing any major slowdown of the network connection. This becomes more difficult due to the limited bandwidth of VANETs, which is caused by the difficulty of establishing and maintaining a network connection in a mobile VANET environment [51], [96]. Another important aspect of this network is that it must be able to handle broadcast messages efficiently. Since many of the VANET applications give safety or warning data to all vehicles around them, there will be numerous packets flowing across the network that are intended to reach all local nodes on the network. If too many of these messages are allowed to be broadcast freely, it can create a broadcast storm on the network, greatly consuming the network's capacity. Furthermore, these messages are often very important and should be distributed across the network as quickly as possible. As a result, VANET technologies need to ensure that their network has an efficient and fast broadcast handling system if they want to be able to perform all the applications people might expect from a VANET [51].

VANETs can have very different situations in which they are being run. Sometimes they will be expected to handle the information from all the vehicles stuck behind a backup on a major highway, while others will be expected to handle a loosely tied community of two to three vehicles traveling together along the road. When the demand is low and establishing a network connection is difficult to maintain, the network must use store-and-forward algorithms to ensure that the packet reaches its intended destination. However, when the node population is dense, the necessary characteristics change entirely [51], [29]. If a densely populated network continued using a store-and-forward system, it could greatly limit its already low bandwidth, causing it to scale very poorly with larger populations. When safety alerts are passed to the system, the safety broadcast information may have to be repeatedly rebroadcast as new vehicles enter the affected area. This stored geocast will lead to an increase in the number of packets being sent on the network [51]. Historically, VANETs have employed flooding as their broadcast dissemination scheme, in which each node in the network rebroadcasts each broadcast message they receive to all nearby nodes. However, this creates a large amount of redundant transmissions being performed across the network, causing the number of transmissions performed to be proportional to the square of the number of nodes on the network, rather than the minimal necessary number, which is only one for each node on the network. In a very densely populated area, this transmission scheme can consume an absurd amount of the network's resources. When creating a better algorithm to handle network transmissions, researchers cannot directly use the methods employed in MANET systems, as VANET messages have some messages that are very high priority and must be transmitted immediately [51], [19]. As a result, some algorithms for VANET were created that seek to address this broadcast problem and implement a relevance-sensitive approach [51], [11], [15].

In order to implement such an algorithm, there are a number of parameters that the application needs to be able to evaluate. The most basic of these required for a relevance-based algorithm is some sort of numerical way to quantify the relevance of any particular message being sent across the network. This has been performed by looking at three different aspects of the message to be broadcast: the time passed since the message was created, the current situation of the VANET environment the message is being passed into, and the importance of the contained information to the nearby vehicles [51], [11]. The time passed is clearly of importance, as a very old message may no longer contain meaningful information, or the information it contains could have already been noticed by the user via more traditional means. Messages that are more recent would be given priority, since they contain the most interesting information and are most likely to be of potential impact to the user's safety. The information on the VANET environment is considered in order to factor in concerns like the amount of connectivity the VANET currently has. If the VANET environment has a large amount of connectivity, then it would not want to delay any incoming messages, regardless of how important they may otherwise be. However, when the VANET has a very small amount of connectivity, it has to be more choosy about which messages it allows through. This parameter can allow the system to perform more appropriately based on its current characteristics [51]. The last variable would be generated by the application as a tag to label the importance of the passed message. If the message contains immediate safety information, such as "the vehicle in front of you just slammed on the brakes", then the application should flag that message as being important; however, if the message contains very low priority information, it should be flagged as being non-critical information. This allows the system to pass the most important messages more quickly than it would otherwise be able to.

When attempting to moderate which messages are passed along the limited network resources, there are two locations that must be cognizant of which messages they pass: the vehicle itself and the network connection manager. The first location is within a vehicle. When a vehicle has a number of packets queued up to pass into the network, it should order its queue based on the relevance of the packets to the other vehicles around it to avoid passing low priority messages. This means that high priority messages, like a warning that this vehicle is suddenly braking, should be able to skip the queue and be sent immediately. This reduces delay in high-priority messages caused by increased network traffic. However, only having each vehicle individually select which packet to send is not sufficient to solve all network utilization issues. This is the case since some vehicles may only have low-priority packets remaining in their queues while others are attempting to send important safety information. As a result, the network connection must have the messages being passed across vehicles moderated by some sort of system to ensure that important messages are delivered quickly and less important ones do not block them from being sent. This moderation is generally performed by having the messages modify their backoff and defer times based on their relevance to the network. As a result, when two messages of varying importance are broadcast simultaneously and interfere with each other, the less important one will wait for longer before attempting to rebroadcast, giving the important message more time to begin sending its message and claim the network connection. This will increase the odds of the important messages being sent in favor of the less important ones [51].

This approach causes a few different characteristics of the network to manifest. The first of these is the altruism of the nodes connected to the network. Nodes on the network must be willing to back off when their messages are not as important and allow nodes with more important messages to use the network. Nodes do not act solely in their own benefit by sending their messages as quickly as possible, since doing so could interfere with important safety information. Additionally, this approach creates a network where the network resources are always being utilized, unlike other approaches that instead attempt to minimize the amount of traffic sent across the network in all situations. This allows the network to perform as many tasks as possible while still ensuring that the most important tasks get performed. Instead of seeking a fair allocation of network resources that makes everyone happy, this approach creates a controlled amount of unfairness that makes everyone equally unhappy. Some low-priority messages will be delayed for long periods of time and possibly be dropped, but this will allow more high-priority messages to be sent across the network successfully. This approach also allows for more optimal behavior based on the context of the network than a purely packet-based approach would, allowing some of the challenges of VANET environments to be better handled [51].

This method of reducing the network load to levels that can be handled with the current system can be combined with other systems to have a more optimal broadcasting behavior. Since one of the biggest challenges with broadcast messages is the large number of data packets they generate, we can help moderate the number of packages by introducing a new layer to the network architecture called "clusters" [53]. These clusters represent a group of vehicles that are all located near each other and are capable of communicating. After separating vehicles into clusters, the algorithm nominates a cluster head that manages the communications of the vehicles connected within the cluster. By doing this, when a vehicle wants to broadcast a message, it can notify the cluster head and either have the cluster head broadcast the message or simply broadcast the message itself. Since the vehicles within the cluster can communicate with each other, a single broadcast is enough to reach them. The cluster head would then send a message to nearby cluster heads to notify them of the contents of the broadcast message and have them distribute it to their clusters. This allows a broadcast message to reach all the vehicles in the network with a far smaller number of packets being sent across the network. Additionally, as the cluster represents a local group of vehicles, some broadcasts could be limited to the vehicle's current cluster as those vehicles are the only ones to which the message is relevant [53], [34]. This addition of clustering algorithms to the network can help add a more controlled environment to the otherwise chaotic connections inherent to VANETs.

In Fig. 4, we can see an example of how a clustering algorithm might divide up a group of vehicles. In the top left of the picture, we can see a group of vehicles stopped at a traffic light. Since these vehicles are all stationary, it makes sense for a clustering algorithm to group them together. Additionally, they can pass some of their data to vehicles passing them going the other direction. In the bottom right we see another cluster of vehicles. This cluster represents a group of vehicles that have just left a traffic light. After leaving a traffic light, vehicles tend to stay grouped together for a considerable period of time, making this another ideal set of vehicles to group together in a cluster.

As of the time of writing this paper, no method for determining clusters and their cluster heads had been determined to be an optimal solution [68]. As a result, there are many different competing algorithms for cluster selection, each with their own trade offs. Some algorithms actively poll the entire network region to collect information on all of the nodes. Then, they perform calculations to determine the ideal cluster head, which cluster each node should affiliate with, and then tell that node to be a cluster head [21]. Others perform the calculation only for themselves, then wait inversely proportionally to how suitable they are to be the next cluster head before declaring themselves cluster head if no one else did first [2]. Yet others seek to reduce the network consumption from polling and use embedded messages in network traffic to gather information on the network around them [45]. We are currently working on a system for intersections that assists with this

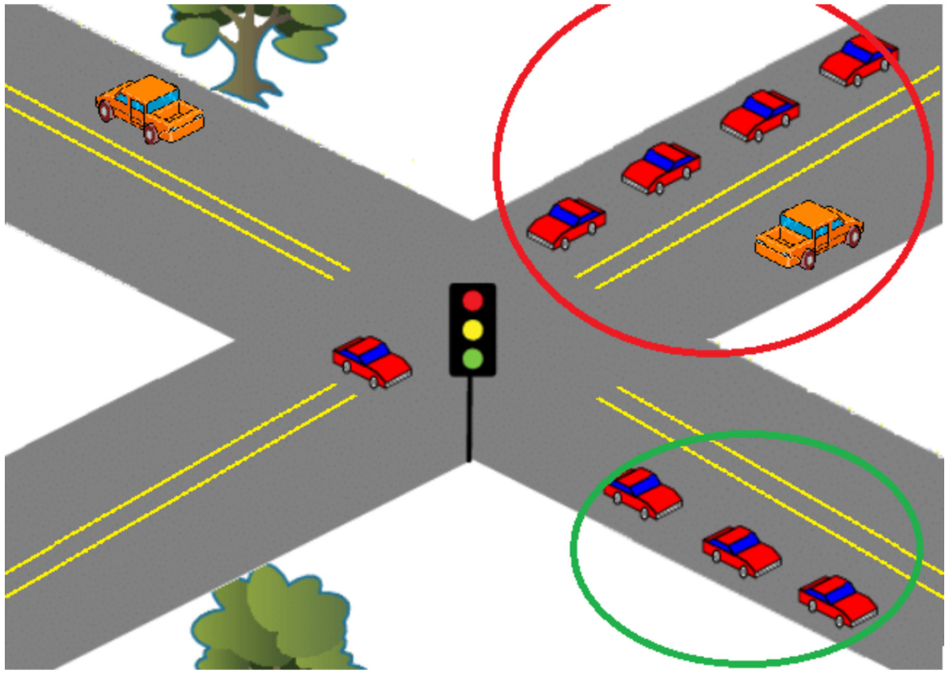

Fig. 4. An example of vehicles cluster by ability to communicate with each other.

sort of passive scheme by helping them approximate the current network status from only the packages they've seen nodes send.

Clustering algorithms require two fundamental algorithms to identify their clusters: an algorithm for identifying a group of nearby vehicles and an algorithm for nominating a cluster head [53]. Since VANET environments have more predictable node travel patterns than MANET environments, these technologies can use characteristics of roadways to identify a group of vehicles that will travel together for some period of time [24], [20]. The clustering algorithm must also be capable of noticing nodes exiting from the cluster and new nodes moving into range of the cluster. Similarly, if the old cluster head leaves, it must be capable of electing a new cluster head to manage the cluster very quickly [53].

5. Current state

VANETs have some challenges ahead of them still, but much work has been done in resolving them, and there are many applications lined up that could draw in consumers. Additionally, many automotive companies are interested in adding VANET-enabled systems to their vehicles and have provided funding to efforts to improve VANET technologies. However, VANET technologies have not actually been employed yet. What is hindering the deployment of VANET technologies? The reasons for this are two-fold. First, within the United States, Vehicle to Vehicle communications have not yet been approved by the House of Representatives. The utility of vehicle communications has been noticed and supported by the US Department of Transportation, but since legislation allowing them has yet to be passed, vehicles are not yet allowed to use VANET-enabled devices [35]. This problem is not universal to all countries. Within the European Union, regulation preventing the usage of Vehicle to Vehicle communication does not exist [75]. As a result, many projects are being developed for VANET technologies in Europe, and recently, large-scale deployment in Europe has begun.

The other hindrance to the deployment of VANET technologies is that the benefits of such systems only become fully apparent when all vehicles on the road have adopted them. As a result, there are very few perceived benefits for early adopters of the system. This can demotivate automotive manufacturers from installing these devices in their vehicles as well as discouraging customers from paying the additional cost for these systems when they do not yet provide any useful services. As a result, the United States is attempting to pass legislation that will require mandatory installment of Vehicle to Vehicle communication devices in all vehicles [73].

While V2V technologies have not yet been made legal in the United States, Ford plans on rolling out vehicles capable of communicating with any other device in the area, while Applied Information plans to deploy traffic infrastructure products within the U.S. so that vehicles with these capabilities will be able to get the benefits of VANET services [69], [93], [16]. Ford is not alone in these aspirations, as General Motors has already installed some V2V devices on their Cadillac's, and Toyota has plans to do the same for all their vehicles in 2024 [90], [61]. However, this does not mean that the move to VANET-enabled vehicles is homogeneous. General Motors and Toyota are deploying devices equipped for communication using Dedicated Short-Range Communications (DSRC), while Ford is using Cellular V2X (C-V2X) [65]. These are two different implementations of VANET. DSRC is based on Wi-Fi communications, while C-V2X uses cellular communications. This means that DSRC is shorter range than C-V2X, and C-V2X will be able to upgrade in capabilities as new cellular communications technologies are developed, including 5G. 5G alone will provide C-V2X with a considerable boost in network speed and a reduction in latency, while also greatly increasing the total available bandwidth of the network.

However, DSRC was developed earlier, which enabled these companies to start deploying it sooner without having to wait for C-V2X [65]. Since these standards operate very differently on a physical level, devices made for one of the standards will not work for the other. This challenge and many others will have to be resolved as VANET develops.

As the European Union has been able to authorize projects that allow for VANET technologies to be realized and deployed on roadways, we will look at the current state of VANET projects in Europe. One of the earliest projects deployed and tested was the Testfeld Telematik, a project that tested VANET services that focused on transmitting information about the road network, including information such as public transit connections and information on traffic lights. The testers sought to achieve the coordination of up to 64 parties connected to the network and display collected information to the user of the vehicle [26], [39]. This test proved the feasibility of such cooperative services and lead to the development of the Cooperative ITS Corridor, a joint project between the Netherlands, Germany, and Austria [26], [39], [36]. The Cooperative ITS Corridor seeks to create a corridor that connects the three countries that will provide VANET-based services to vehicles on the roadway to increase the convenience of their drive. Some of the services that this project will provide include early warnings about daily construction sites and improved vehicle traffic management. These technologies are planned to be employed in such a way that they will primarily not rely on vehicle-based data transmitted by a vehicular network, as most vehicles currently on the road are not capable of interacting with such technologies. However, the service will be compatible with VANETs, encouraging users of the corridor to purchase VANET-capable vehicles when available as there will be some perceived benefit. This corridor has been successfully created in the planned areas, and testing has shown positive results. The system looks to move towards full deployment in the future [36], [89].

A similar collaboration called NordicWay 2 is being developed in Finland, Norway, and Sweden. This project differs in that it focuses on providing test zones where various VANET services will be provided within the region. Some of these tests have already been run, while many more are going to begin within a year. This project will show the utility and feasibility of VANET technologies, and hopes to lead to the deployment of VANET-based services throughout the entirety of the countries involved [74]. Another project called SCOOP@F connects the countries of France, Spain, Portugal, and Austria. This project seeks to provide large-scale VANET services that will cooperate with the other ongoing pilot programs and provide enough VANET-enabled vehicles to allow a representative evaluation of the European Union's VANET platform, called C-ITS [30], [31]. This C-ITS system was developed by the C-Roads initiative, a project that collaborates with 16 of the states of the European Union. This project continues to test the effectiveness and security of the C-ITS system and provides updates to the software [31].

Compass4D was a project that was run earlier than the Testfeld Telematik and ran tests in areas in France, Denmark, the Netherlands, UK, Greece, Italy, and Spain. This project also collaborated with the US Department of Transportation as well as the Japanese Ministry of Land, Infrastructure, Transport and Tourism in an effort to create a globally available standard for VANET systems. This program ran a number of VANET services within the bounds of seven different cities to evaluate the effectiveness of VANET technologies and found positive results [92].

More modern efforts are also being headed up, including efforts by the CAR 2 CAR Communication Consortium. Members of this group have made much progress towards the deployment of VANET technologies, including NXP Semiconductors N.V., which worked with Volkswagen to have their RoadLINK V2X communication solution included in the new Volkswagen Golf. This marks the first European car model that is equipped with a V2X device, as well as the largest scale deployment of V2X technologies to date. The release of these vehicles should greatly assist future efforts to develop and deploy VANET technologies [3].

With the current status of the European Union projects we can see the strides that the EU has taken towards employing VANET technologies, and real world deployment has begun, with other projects soon to follow. As a result, interest in VANET-enabled vehicles should increase, allowing the EU to begin providing fully functional VANETs in the not too distant future. This will lead to even more innovations in the field, and hopefully will also spark the United States deployment of VANET technologies. The future for VANET systems is bright.

6. Conclusion

As this paper has discussed, there are many things that set VANETs apart from other fields of study. Whether it be their unique characteristics, the unique services they can provide, or the challenges that are faced by this sort of system, there are many facets of this field that cause it to be worth investigating in its own right. By investigating these, this paper brings to the front the advantages of research in VANET systems, and motivates future study in the field. This paper then goes on to discuss the current development being conducted towards employing VANET technologies, and how these developments could help to promote interest in this field. This results in this paper evaluate many of the current and future aspects of VANET technologies and serves as a guide to other researchers who may be interested in investigating this field.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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