vehicles

Article
A Survey on Mobile Road Side Units in VANETs

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Abstract: The number of vehicles on the road increases daily, causing many fatal accidents and wasting much time for the average commuter every day due to congestion. Vehicular ad hoc networks (VANETs) were introduced to overcome these issues by enabling vehicle-to-vehicle communication and vehicle-to-infrastructure communication. The prime challenge in VANETs is the necessity of very low communication delays, especially for safety-related applications due to the high mobility nature of vehicles. The VANET architecture introduces a network component, the Road Side Unit (RSU), to meet the required delay limitations. Even though the RSU is a critical component in VANETs, as expected, the RSUs were not deployed throughout the world because of their high investment cost. As a solution, the idea of mobile RSU (mRSU) was introduced, and, ever since, several techniques of mRSU deployment strategies have been proposed. In this survey, we first analyze the importance of the RSU to the VANET architecture with real-world data incorporating the new 5G standard. Then, we investigate the research done in the areas of mRSU and exploit the pros and cons of each mRSU deployment strategy. Finally, we also discuss the future research directions of mRSU, and we explain the challenges connected to these future trends.

Keywords: mobile road side units; vehicular networks; unmanned aerial vehicles

1. Introduction

VANETs were proposed in the early 2000s by introducing concepts of Mobile ad hoc Networks (MANETs) to vehicles. Today, VANETs have become a significant research field and play the main core role in intelligent transportation systems (ITS). The main applications of VANETs are exchanging safety messages, disseminating and informing passengers about real-time traffic details and many more roadside services. Among these applications, exchanging safety-related messages has become a prime and most essential application due to many fatal accidents caused by the increasing number of vehicles. According to [1], the number of vehicles was calculated at 1.2 billion globally in 2014 and predicted to reach 2.0 billion in 2035. Furthermore, 90% of the worldwide crashes are caused by human error [2]. The majority of the accidents happened in urban environments and were caused by improper traffic coordination. The vehicle drivers not being aware of other drivers' intentions was the reason for many accidents. Therefore, as a solution, the idea of VANETs can be used by allowing vehicles to form networks and communicate with other vehicles with the help of vehicle-to-vehicle (V2V) communication and vehicle to infrastructure (V2I) communication. At the same time, VANETs can reduce traffic congestion by managing and routing traffic to avoid already congested roads and intersections [3–5]. According to [2], each year, the United States wastes 3.3 billion gallons of fuel and 8.8 billion hours because of traffic congestion. The VANETs are expected to save 50 minutes from the average commuter every day [6].

The main challenge in exchanging safety-critical messages is that the required latency is less than 100 ms [7–9] because of the high driving speeds of vehicles. Therefore, the safety messages have to be disseminated with minimum delay. Otherwise, the importance of these messages is no longer valid. In order to minimize the involved latency, a new network

component called RSU is proposed for VANETs. The RSU is a fixed device similar to a small base station but with smaller coverage. The RSU can communicate with vehicles with V2I communication, and at the same time, the RSU can communicate with the core network with a high-speed back-haul link. The optimum solution will be to install RSUs to cover the whole road network infrastructure. However, the expected level of deployment was not achieved due to several issues. First, deploying RSU needs substantial investment costs. According to a study, which was sponsored by U.S. Department of Traffic, the average cost of a RSU is $17,600 [10]. Hence, covering the entire road network with RSUs will be impossible to achieve financially. Second, the RSU must be electrically powered, and the equipment's safety should also be considered. As a solution, many researchers are working on deployment strategies to use the minimum number of RSUs and cover as many vehicles as possible.

Another problem with the static RSU is that it cannot adapt to the daily traffic patterns due to its static nature. Many vehicles may be on the road during peak hours, and RSU will run at maximum capacity. However, in the off-peak hours, the traffic conditions will drop significantly, and the resources in the RSU will be not fully utilized. Additionally, static RSU is prone to sudden changes in road infrastructure. Routine maintenance can lead to road closures and cause the traffic to be routed away from the static RSU. In these instances, it is difficult to serve the vehicles with the expected level of VANET service quality.

The idea of mobile RSU (mRSU) was introduced to overcome the issues in static RSU, and mRSU is expected to deliver VANET services while moving on the road network. Since its introduction, the research community has proposed several mRSU strategies. First, existing vehicles on the road, such as public transport buses and taxis, can be used as mRSUs, requiring no additional deployment cost. Second, additional vehicles can be deployed to become dedicated mRSUs. These dedicated mRSUs can be on-road vehicles or unmanned aerial vehicles flying above. The routes of these vehicles are fully controllable and can be predefined to meet the current traffic demand. In future VANET architecture, mRSU will become a key component due to its benefits over traditional static RSU.

Many aspects of VANETs have been studied thoroughly and comprehensively reviewed. These surveys cover routing protocols, clustering techniques, security and a wider range of VANETs related aspects. However, to the best of our knowledge, there is no survey done previously explicitly on mRSUs. Therefore, in this survey, we extensively explore and investigate prior research work done in the area of mRSU. Additionally, we analyze and compare different mRSU deployment strategies while discussing the advantages and drawbacks of each strategy. Furthermore, we systematically derive the need for RSU in general, which was not conducted so far to the best of our knowledge, especially not under 5G requirements. Our main contributions are:

- We analyze the importance of a RSU for the VANET with real-world data analytics incorporating new 5G standards.
- We exploit the research done in the area of mRSU.
- Finally, we discuss future research areas of mRSU and their challenges.

The rest of the paper is arranged as follows. In Section 2, we summarize some prior survey work carried out in the VANET domain, and, in Section 3, we discuss the VANET architecture, describing main network components including RSU. The importance of the RSU is investigated in Section 4 and the different mRSU strategies are explored in Section 5 while indicating their pros and cons. In Section 6, future applications of mRSU are identified and in Section 7 we conclude our work.

2. Related Work

VANETs require reliable low latency communication among vehicles as described in Section 1. To achieve this, VANETs rely on infrastructure support with V2I communications. Therefore, the infrastructure is a critical component in successful VANET applications. The authors of [11] present detailed information about research on VANET's infrastructure.

The work discusses different classes of RSU deployment strategies and current state of the art of communication technologies for infrastructure-based VANETs.

Data routing is a major challenge in VANETs because of the highly dynamic nature of vehicles. The high velocity causes the network topology to change often by breaking and creating new routes among the vehicles. Therefore, traditional routing protocols designed for MANETs suffer from a significant reduction in performance when applied to VANETs. The authors of [12] summarized position-based routing used in VANETs. The position-based routing protocols are often based on greedy routing, considered most suitable for highly dynamic mobile networks. The authors categorize all the discussed protocols into two branches depending on their communication mode, V2V and V2I. In V2I communication, protocols designed for both static RSU and mRSU are exploited. Furthermore, the authors discuss the pros and cons of routing protocols in each branch and the associated challenges. Similarly, the authors of [13–15] have done extensive survey studies on many aspects of routing protocols in VANETs and the authors of [16,17] have mainly focused on routing for unmanned aerial vehicles.

The technical improvements in communication technologies and advancements in edge computing techniques have enabled many new VANET applications to emerge during the past decade. The authors of [18] have reviewed the state of the art of VANET applications. The safety-related applications (Collision warnings, Emergency braking and Lane change assistance) are most proliferating due to the upcoming autonomous vehicles. Besides that, driver assistance applications such as platooning, parking slot locating and real-time traffic notifications can also be identified as several useful applications. In the meantime, some infotainment based applications, namely internet connection and geographical data distribution, are developing gradually and are soon expected in future VANETs.

Emergency message dissemination can be considered one of the most important among safety-related applications. Timely delivering these messages can be critical to saving human lives. In an urban environment, exchanging these messages is quite challenging due to several problems (broadcast storm problem, interference and hidden node problem). The authors of [19] summarized the contributions toward emergency message dissemination techniques proposed for VANETs. The discussed methods were categorized into several main groups: intelligent traffic lights, internet of things, priority messaging, clustering techniques, software-defined networks, fog based techniques and 5G network techniques. Clustering-based techniques are found to be suitable for message dissemination in VANETs due to scalability, security, efficiency, and reliability.

3. Vehicular Networks Architecture

According to [20], the current VANET architecture consists of several main components, including base station, RSU, and the vehicles, as shown in Figure 1. These components can communicate with each other through V2V and V2I communications. Furthermore, using infrastructure-to-infrastructure (I2I) communications, the messages can be exchanged among RSUs and between RSU and the base station.
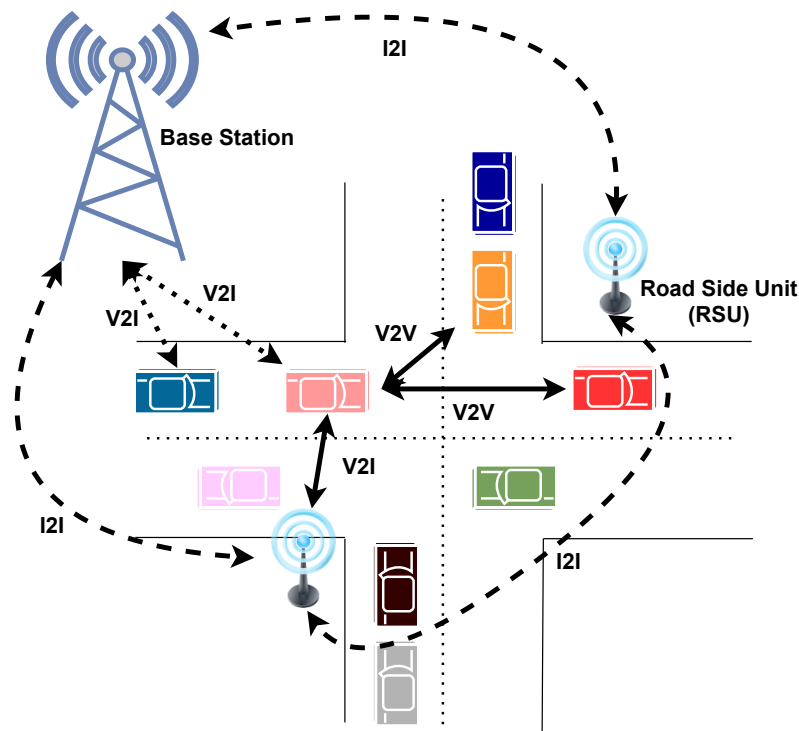
Figure 1. VANET architecture.

A simple road intersection is depicted in Figure 1, and it contains several vehicles, two RSUs, and a base station. The RSUs and the base station are connected via fast wired connections to each other. There are three possibilities when a vehicle needs to exchange information between vehicles. First, the vehicles can use the V2V communication directly to communicate with any vehicle within the transmission range. If a vehicle wants to transmit a message to a vehicle outside the transmission range with V2V communication, it is only possible to use multi-hop data dissemination. However, the latency involved may be unacceptable in most safety-critical applications.

Second, vehicles can use the cellular transmission directly to the base station, and the base station can forward the packet to the intended receiver. This forwarding process might reduce the latency compared to multi-hop forwarding. However, an extra burden will be added to the already congested terrestrial network, especially in urban environments with a high density of mobile nodes. In the upcoming sections, we will show that the base station alone cannot cater to the needs of all the vehicles on the road because of the limited bandwidth available at the base station.

The third possibility is to use the RSU in the data forwarding process. The vehicles can transmit the packets to the nearest RSU. The RSU will find the destination node or intended receiver's current responsible RSU and use the fast wired connection between the RSUs to transmit the packet in the lowest possible latency. Therefore, RSU is an essential network component in future VANET architecture, and up to now, several RSU deployment strategies have been proposed.

3.1. RSU Deployment Strategies

As explained in Section 1, RSU deployment requires high investments; therefore, a significant amount of planning is necessary before deployment to cover as many vehicles as possible. The primary deployment strategies are listed in Figure 2, and the main two strategies are static RSU and mRSU. Next, we subdivide mRSU strategy into using existing vehicles as mRSUs and using additional vehicles as mRSUs. Furthermore, the latter can be split into specially built on-road vehicles and using unmanned aerial vehicles. In the following subsections, we describe each of these branches in detail.
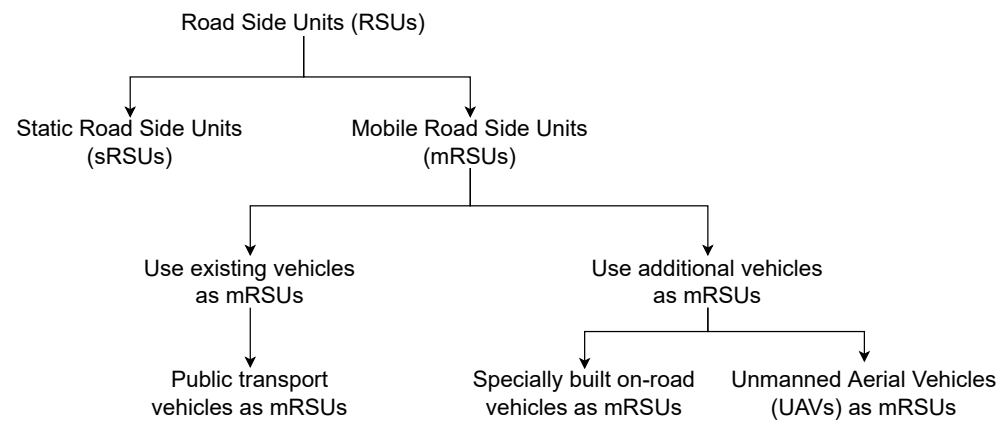
Figure 2. RSU taxonomy.

3.1.1. Static RSU

The most common strategy is to use static RSU [21,22]. Due to high investment costs, the static RSUs will be deployed only in the most demanding intersections or in the most popular areas of the road infrastructure. Daily human behaviour causes the traffic condition to change from time to time in peak and off-peak hours. Therefore, in static RSU, there may be excess resources available during off-peak hours without being fully utilized. Another drawback of static RSU is its fixed location. For example, if there is maintenance or an accident on the road, all the traffic is rerouted through another intersection that is not busy normally and therefore not equipped with a RSU. Due to the incident, traffic flowing through this intersection will increase suddenly and cause the network to fail.

3.1.2. Mobile RSU

To overcome the issues with static RSU, researchers have exploited the idea of having mRSU. The mRSU is not fixed to one location and can move throughout the road infrastructure while handling the communications. Additionally, mRSU can be deployed according to the demand of the current traffic condition. If not required, mRSU can be removed from the network (off-peak hours), or if more are needed, the number of mRSUs can be increased (peak hours). However, during mRSU deployment, the mobility routes must be arranged efficiently to meet as many vehicles as possible. The relatively low cost and traffic adaptability have made mRSU a worthy candidate. In Section 5, we investigate the proposed mRSU deployment strategies in detail.

4. The Role of the Road Side Unit

We discussed a typical VANET architecture in the previous section, where RSU is often used. In this section, we would like to analyze how important the RSU is to the VANET architecture. Is the RSU really needed? Can the traditional base station alone cater to the needs of all the vehicles on the road? In the following, we tried to answer these questions by analyzing the data rates in the 5G base station and also calculating per vehicle required data rates for different VANET applications.

The newly deployed 5G network architecture [23] contains mmWave technology [24,25] and, therefore, the operating frequencies will be high due to shorter wavelengths. The major drawback of high frequencies is the tendency to get attenuated very easily. Hence, the coverage area of the 5G base station will be small, and to cover a certain area, more base stations will be required. According to [26], mmWave 5G base station density will be around 40–50 per km^2 and each base station can handle data speeds up to 25 Gbit/s.

Even though the maximum data rate appears to be high, when catering for multiple devices simultaneously, the critical factor is how much data rate can be allocated for each individual device. To answer this question, we exploit the resulting data rates, with an increasing number of users connected to one single 5G base station. We divide the

maximum data rate of 25 Gbit/s by the number of users, and the results are depicted in Figure 3.

As expected, the resulting data rates drop with increasing users. For better understanding, we have included the required data rates for different VANET applications such as exchanging safety messages, web browsing and video streaming according to [27–29]. The problem with insufficient data rates starts with just above 100 users for 4K video streaming. For the current environment, there can be an argument about whether is it required to stream 4K videos. However, we believe that these high data rate applications will be widely deployed in the future. Regardless of these high data rate applications, in Figure 3, when the number of users (vehicles and mobile users) exceeds 500 per 5G base station, the resulting data rate is not enough to handle even critical safety messages for VANETs. We have to remember that the main application of VANETs is the exchanging of safety-critical messages within the required latency to avoid fatal accidents and to save human lives.
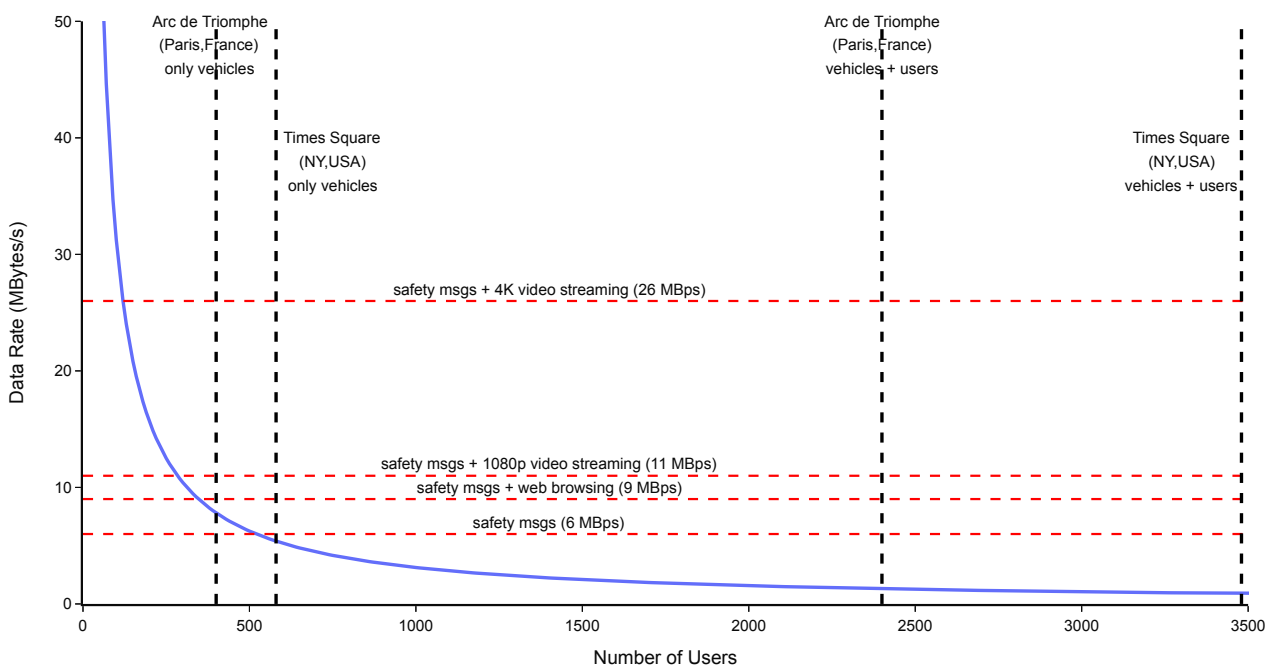

Figure 3. 5G data rates vs. number of vehicles inside the base station.

Next, there might be a doubt in real life about how many users have to be served by the base station simultaneously. To answer this, we have calculated the approximate vehicular density of several popular intersections (Arc de Triomphe in Paris and Times Square in New York) and indicated the values in Figure 3. The vertical black lines illustrate the calculated vehicular densities (mobile users are not included). For calculations, we have gathered the total road area around these intersections from Google Maps and divided the total road area by the average size of a vehicle taken from [30] to mimic a high traffic scenario around the intersections. The calculated values show that the base station has to serve around 500 vehicles in highly congested situations.

However, this is only a part of the problem because, in these calculations, we have only considered the number of vehicles, but not the mobile users. Unfortunately, there is no possibility for us to calculate the number of mobile users per base station. Therefore, we make a simple assumption that the number of mobile users is five times higher than that of vehicles. We believe this assumption is realistic because, even inside one vehicle, there can be multiple passengers connected to the same base station. With this assumption, we indicated the resulting data rates in red vertical lines for the two selected intersections. This drastically reduces the resulting data rates and is well below expected levels for VANET applications. This implies, in reality, that the base station cannot serve all the users alone

while adhering to the latency limitations of VANETs and emphasizes the necessity of the RSU for the future VANETs. The coexistence of both the base station and RSU will aid in reducing the traffic load on the base station, and operating collaboratively will support meeting the expected latencies.

5. Mobile RSU Deployment Strategies

As discussed in Section 3, the mRSU has several key benefits over traditional static RSU. This section discusses the research work conducted with mRSUs in detail. Mainly, we categorize mRSU deployment strategy into two main branches as shown in Figure 2:

- Use existing vehicles as mRSUs;
- Use additional vehicles as mRSUs.

5.1. Using Existing Vehicles as mRSUs

The most cost-effective method to extend the coverage area of RSUs is to use existing vehicles as mRSUs because additional deployment costs are not required. Public vehicles like buses and taxis are ideal vehicles to become mRSUs (Figure 4) since they are readily available in many urban cities. Additional communication and computational devices can be installed into these public transportation vehicles and afterwards, they can be used as mRSUs while travelling to serve other neighbouring vehicles.

The public buses are scheduled to match people's daily routines (more buses are scheduled during rush hours). Therefore, buses automatically contain traffic adaptability. The routes of the buses are also designed to cover the most demanding road sections with shopping malls, office buildings, etc., where generally a high density of vehicles is expected. Following, we discuss some of the main contribution ideas using public vehicles to disseminate messages in VANETS.
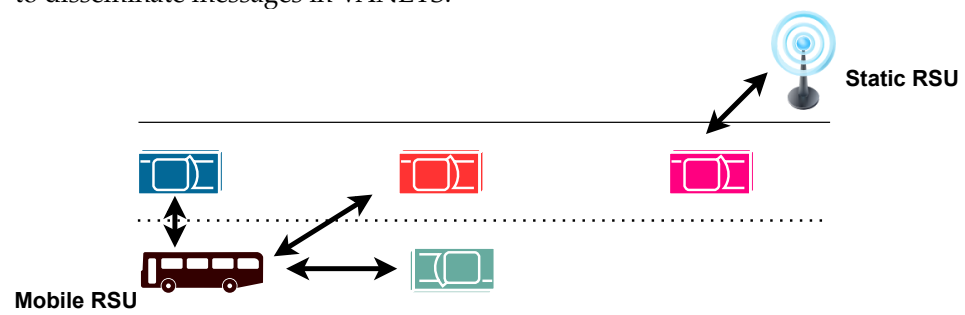

Figure 4. Public transportation as mRSU.

Public transportation buses are used to disseminate data between vehicles in [31]. The authors proposed a novel routing protocol, Mobile Infrastructure based VANET Routing Protocol (MIBR), by considering several key characteristics in urban environments involving buses and ordinary cars. First, they consider that vehicle movements are constrained to the roads, and buses are dispatched periodically running on fixed lines. Second, vehicles move like clusters in an urban scenario due to traffic lights. At red lights, all the vehicles are stopped, and when the green light appears, vehicles moving in the same direction will be close to each other like a cluster. In the proposed protocol, during message forwarding, nearby buses are chosen to be the forwarders over other ordinary vehicles assuming that buses carry better equipment, enabling a longer transmission range than cars. The simulated results depict significant performance improvement in delivery ratio and throughput with the proposed system. The authors of [32] proposed a new routing method called BRT (Bus based Routing Technique), which exploit the regular mobility pattern of buses. The vehicles can use the bus-based backbone to transmit data to the RSUs with a minimum end-to-end delay because of the buses' pre-determined schedule rather than using a high latency store and carry forward method. In the initial learning phase, routing entries are built to determine the time needed to transmit data packets from buses to RSUs. The data routing can switch between two modes—first mode, only with bus-based

backbone network, and, second mode, other types of vehicles participate in the routing process to accelerate the data forwarding. The proposed protocol was evaluated in terms of delivery ratio and end-to-end delay with simulations. Similar work was conducted by the authors of [33] and the proposed novel routing protocol called Taxi and Public transport based heterogeneous vehicular network Fuzzy Routing (TPFR). In the considered scenario, vehicles are equipped with conventional DSRC devices with a smaller communication range. The buses, bus stations and taxis are equipped with both DSRC and LTE D2D devices. Compared to DSRC, LTE D2D devices have a longer communication range. Vehicles select the best next candidate for data routing based on the candidate's vehicle type, distance to the destination, current traffic condition and location (in a crossroad, T junction, straight road or dead-end). The simulated results depict better delivery ratios and improved delivery delays obtained by the proposed TPFR protocol against other reviewed protocols.

A set of public transport buses were deployed as mobile gateways for a traffic monitoring application in [34]. The architecture assumed that all buses, bus stops, and traffic lights were equipped with wireless devices to communicate with other in-range buses. Only a small number of buses are considered mobile gateways, and all traffic lights are considered static gateways. Traffic sensors are installed on all urban roads for vehicle counting. Traffic sensor data are collected by public buses and uploaded to a central traffic management system via a static or mobile gateway. The feasibility of such an architecture was tested with simulations with realistic movement patterns. The results suggest that radio technology (DSRC) was feasible for such traffic monitoring applications.

The authors of [35] proposed a novel message dissemination scheme to use public transport buses to assist message exchanging among taxis. This scheme takes advantage of the high regularity of bus routes and schedules and wide coverage of taxis. There are two options for taxis to deliver messages to other taxis: first forwarding to other surrounding taxis and, second, forwarding to a bus, and the bus helps to relay towards a destination taxi. With trace-driven simulations, two options were compared. Simulation results show that the end-to-end delay and delivery ratio improves significantly when accommodating buses (second option) in the message dissemination process.

The infrastructure coverage area can be extended by deploying many mRSUs. However, if an unnecessary amount of mRSUs are placed to create the mRSU backbone network, many control messages have to be exchanged, increasing network overhead. To overcome this issue, the authors of [36] proposed a system where each mRSU decided to be active or inactive by considering its' neighbouring mRSUs' states. The authors have considered city environments with mRSUs in high density and discussed the issues with having many active mRSUs. This method adaptively changes the active number of mRSUs in the network and effectively reduces network overhead.

The replacement ratio is another critical factor to consider when deploying mRSUs. The replacement ratio indicates how many mRSUs are required to replace one static RSU to reach the same level of network performance. The authors of [37] analyzed mathematically, with simulations and also with real-world experiments, the effect of replacement ratio on contact time and network throughput when a certain number of static RSUs are replaced with public transport buses as mRSUs. The results were compared with two schemes (only static RSUs and static RSUs + mRSUs). The simulated and real-world experiment results depict that a higher number of packets were received by vehicles when both types of RSUs are used than using only static RSUs. However, the variation in inter-contact time is significantly higher when using mRSUs due to the change in relative velocity between vehicle and mRSU that depends on the travelling direction of the mRSU.

The idea of using public transport vehicles as mRSUs is a feasible and cost-effective solution, but some challenges need to be solved before actual deployment. One such challenge is determining which public bus routes to be selected to cover a larger area. Some analysis should be done to choose the most suitable bus lines because deploying more than needed is a waste of resources and, on the other hand, will increase the cost of deployment.

Another challenge with public transport is the inability to control the route because these vehicles follow regular daily routines while acting as a mRSU. In the case of an unexpected event like road maintenance, the road traffic will be shifted to another road, and the bus acting as the mRSU might select another more convenient route for the passengers.

Additionally, the public transport will not provide adequate coverage during off-peak hours. The buses are scheduled to cater regular life patterns of people, and, therefore, during night time, the number of buses on the road will be drastically reduced or sometimes there may be no buses on the road. Typically, since the number of vehicles on the road during nighttime is also reduced, this will not cause an issue. However, during a special event like a concert or carnival, many people will be active at nighttime. The expected coverage will not be covered by public transport vehicles. Furthermore, most of the bus routes are designed to cover only the city's main streets; therefore, the total geographical area of a city cannot be covered. The following strategy, using additional vehicles as mRSUs can be used to solve these issues.

5.2. Using Additional Vehicles as mRSUs

Some researchers have focused on deploying additional vehicles to become dedicated mRSUs. These vehicles are built explicitly to be a mRSU and can be added to the network by considering current traffic conditions. Therefore, this strategy holds scalability and adaptability toward present traffic demand. Additionally, the routes of these mRSUs can be fully controlled and can be scheduled to cover the most demanding road sections. Several specific intersections might be busy during morning rush hours in some cities, but traffic can be shifted to a completely different set of intersections in evening rush hours. In such a scenario, route controllability is a significant benefit. Following this, we discuss some research work that uses additional vehicles as mRSUs. We divide these research into two main branches, as shown in Figure 2:

- Dedicated on-road vehicles as mRSUs;
- Unmanned Aerial Vehicles (UAVs) as mRSUs.

5.2.1. Dedicated on-Road Vehicles as mRSUs

The first idea was to deploy additional on-road vehicles to serve as mRSUs. These vehicles can roam through the city, and the routes can be selected to serve as many vehicles as possible. The travelling speed of these mRSUs is similar to other surrounding vehicles. Therefore, higher contact duration can be expected between vehicles and the mRSU if the travelling directions are the same, which improves the possibility of creating a cluster to exchange messages. Several prior works were done by deploying dedicated on-road vehicles as mRSUs, and, following this, we discuss them in detail.

The authors of [38] used a set of vehicles as mobile gateways to extend the coverage of fixed RSUs. The onboard unit (OBU) of mobile gateways are equipped with IEEE 802.11 and 3G interface, and other vehicles are only equipped with IEEE 802.11 interface. They proposed a novel routing protocol based on positions, called mobile-gateway routing protocol (MGRP). In MGRP, once a packet is received from a vehicle, the mobile gateways transmit the packet to a gateway controller via the base station by using the 3G interface and depending on the location information of the intended receiver, the gateway controller transmits the packet to a set of nearby gateway vehicles in the destination area. Then, the selected gateway vehicles transmit the packet to the destination vehicle by using IEEE 802.11 link. The simulations show that the proposed routing protocol with mobile gateways improved the delivery ratio and significantly dropped the hop count.

The authors of [39] considered a particular vehicle that is carrying the RSU equipment around the city as a mRSU. The work proposes to offload and cache data in RSU to minimize the packet requests forwarded to the backbone network to ease the burden on network operators. The vehicles can download data primarily from the local RSU in its transmission range, and if not available, the file can be downloaded from the base station. Therefore, the authors discussed content placement in RSU and proposed using a mRSU with cached

content to maximize the cache hit ratio. The mRSU is moved through each sector of the map, complementing fixed RSUs in the sector to satisfy a significant amount of vehicle's content requests and reducing the number of requests sent to the backbone network. The simulated results illustrate the improvement in network throughput compared to other tested approaches.

Even though using dedicated on-road vehicles as mRSUs is a practical solution to extend the coverage of RSUs with flexibility towards traffic status, there are still some disadvantages. The main drawback of this architecture is the additional cost of building these dedicated vehicles. Additionally, the route selection must be continuously adjusted to cater to as many vehicles as possible. Therefore, centralized traffic monitoring systems and additional drivers are also required. Furthermore, adding additional vehicles can increase traffic congestion, a major concern in many urban cities. To overcome these issues, some research work was focused on using unmanned aerial vehicles as mRSUs.

5.2.2. Unmanned Aerial Vehicles (UAVs) as mRSUs

The most recent category to join mRSU strategies was to use Unmanned Aerial Vehicles (UAVs) as depicted in Figure 5. There are several key advantages when UAVs are used as mRSUs over previously described strategies. First, the movement of UAVs is not limited and not affected by the existing road infrastructure and traffic condition because the deployed UAVs are flown above the road network. Therefore, direct line of sight communication to the vehicles is guaranteed, increasing network throughput and reducing traditional channel quality issues. Second, the UAVs are capable of highly dynamic movement patterns due to their flexible manoeuvrability and faster speeds than average urban vehicles. Due to these advantages, using UAVs as mSRUs is applied to many VANET applications. According to the research work published during the past couple of years, it is clear that, out of all strategies, using UAVs as mRSUs for VANETs is the most popular approach among researchers. We next discuss some of the proposed methods. In some of the discussed approaches, authors have considered UAVs as basic relays, data forwarders or caching enabled edge devices without indicating the concept as mRSU. However, we categorize them into using UAVs as mRSU strategy in this work.
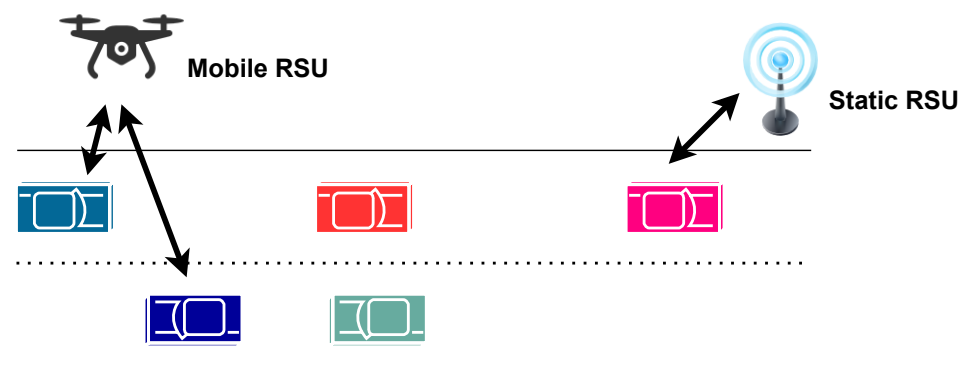

Figure 5. UAV as mRSU.

A routing scheme was proposed in [40] with the help of UAVs to reduce the communication delay between connected automated electric vehicles in densely crowded environments. A massive amount of sensory data are required by each autonomous vehicle with minimum possible delay to make crucial driving decisions in crowded cities because of high-density obstacles. Therefore, the authors proposed accommodating a swarm of UAVs in message dissemination. The vehicles can use the UAVs to forward the messages to intended receivers. During the route selection, the authors tried to minimize the number of UAVs involved in the message exchange process to increase the lifetime of the UAV network because UAVs are battery-powered, and available battery life should be optimized. Therefore, the proposed architecture selects the routing path that consists of the shortest

communication delay and involves a minimum number of UAVs. The authors simulated an urban scenario, first accommodating only with V2V communication, second accommodating cellular infrastructure and finally accommodating UAVs. The results show better communication delays with the proposed system and significantly outperformed other simulated methods. Similarly, the authors of [41] proposed a novel routing protocol named VRU (VANET Routing protocol with UAV assisted) for VANETs using UAVs. The proposed VRU protocol has several purposes: reduce delay, improve packet delivery ratio, reduce routing overhead and detect malicious nodes in the network. A cluster-based method is used to improve the network performance, and UAVs are used to deliver packets and to re-link communication links when disconnections take place. The simulated results show notable network performance improvement compared to other reviewed routing protocols.

Deploying a sufficient number of UAVs is expected to enhance the overall network delay. Therefore, finding out the required number of UAVs is essential for achieving adequate performance without wasting resources. The authors of [42] propose a mathematical framework to determine the UAV density (maximum separation distance between two neighbouring UAVs) that fulfils the delivery delay requirement. The UAVs are considered as gateways to the internet and ITS infrastructure. The authors consider a two-way highway segment, and moving vehicles generate packets that are destined to UAVs. The proposed method can be used to determine the required number of UAVs given the current vehicular density. Depending on the demand, UAVs can be switched off or on and then remaining active UAVs change the location based on the newly calculated distance between them. The achieved analytical results and simulated results are closely aligned with each other, indicating the systems' accuracy in terms of delivery delay. The authors of [43] focused on position planning for UAVs to maximize the data rate of the network. UAV is used to relay the information between a RSU (source) and a vehicle (sink). First, the authors aim to determine the optimal position for the single UAV relay case. Later, they extend their work to obtain optimal transmit powers and positions when using multiple UAV relays between the source and the sink. Normally, multiple UAVs must be deployed to assist VANETs. However, when deploying a sufficient number of UAVs to cover all the areas, there might be collisions among UAVs. Therefore, each UAV trajectory should be properly decided in order to provide coverage for many isolated sections as possible while consuming less energy. As a solution, the authors of [44] proposed a deep reinforcement learning framework to optimize the UAV trajectories. The proposed method outperformed other commonly available methods regarding coverage, power consumption and routing performance.

Maintaining communications during disaster scenarios is a well-discussed topic because the existing infrastructure can be easily damaged or destroyed after the disaster. The authors of [45] proposed to use UAVs in such disaster scenarios to create a quick, efficient and self-configuring recovery network when the normal infrastructure is temporarily unavailable. The main goal was to minimize the number of deployed UAVs by optimizing UAV trajectory and radio resource allocation. The authors consider a partly damaged highway scenario with some surviving RSUs. The UAVs are located at the RSU and deployed depending on demand. The proposed mechanism deploys just enough UAVs from the RSU to serve all vehicles before exiting the highway segment while considering vehicle mobility and data requirements. The impact of the proposed system was illustrated with mathematical modelling and simulations. The work in [45] was extended by the same authors in [46]. Two types of UAVs were considered in [46], namely fixed-wing UAV and rotary-wing UAV. The main difference was that the ability to change direction is much more flexible in rotary-wing UAV than in fixed-wing UAV. The overall aim was to guarantee a certain quality of service (average serving rate) for each vehicle by optimizing the UAV trajectory and resource allocation. The mathematical analysis and simulations show that the proposed mechanism maximized the minimum average serving rate per vehicle by changing UAV velocity in the considered highway scenario. From the considered two types of UAVs, the rotary-wing UAV depicts the better performance of average serving rate due to its manoeuvrability. For a similar disaster rescue application, a two-layer architecture

is proposed in [47]. An aerial sub-network consists of multiple UAVs that aid the ground vehicle sub-network with air-to-air and air-to-ground communications. The UAVs are carried and charged by ground rescue vehicles and deployed to obtain information about road conditions of the affected areas. The UAVs transmit image information to the ground sub-network, and ground stations extract road conditions and disseminate them into the ground network by V2V communication. Furthermore, UAVs are used to relay information between ground vehicles when direct V2V communication is not available. The authors evaluated the performance of the proposed system in terms of power consumption and communication delay in a prototype with three ground vehicles and two UAVs. A similar concept was used by the authors of [48] to use UAVs as intermediate relays to reinforce the weak links and to connect disconnected vehicles or clusters. In [49], the authors used a highway scenario to evaluate the performance in delivering emergency messages in a case of a collision to other vehicles. The UAVs are used to relay the information to guarantee the timely delivery of the safety messages so other drivers can take that safe action to avoid further collisions. The obtained simulation results show UAVs' ability to disseminate messages quickly to the surrounding vehicles. The authors of [50] proposed a mechanism to select the next best candidate relay in UAV assisted VANETs. Highly dynamic network topology and faster moving speeds of nodes in VANETs cause frequent handovers, increasing delay and communication overhead. The work aims to reduce the communication handovers and guarantee transmission reliability. The effectiveness of the proposed relay selection method was verified with simulations with improved data delivery ratio, throughput and end-to-end delay. The UAVs can be used as relays effectively to improve the connectivity in VANETs because the UAVs have the line of sight communication with the vehicles. Therefore, UAVs are the best candidate to play the role of relays to improve the coverage and the capacity. However, the limited battery power heavily restrict the performance. The authors of [51] proposed a transmission power optimization method to minimize the power consumption. The simulated results outperformed other conventional methods significantly in terms of power consumption.

Serving the increasing demand for high bandwidth content in highly dynamic VANETs is quite challenging while guaranteeing service quality, especially on high-density urban roads because terrestrial network resources are fixed (4G/5G). Caching content in UAVs is becoming an exciting paradigm to assist current infrastructure in such situations. The UAVs can cache popular and most requested content to significantly ease the burden on the terrestrial network. Since UAVs are considered to have line-of-sight communication with vehicles, cached content can be disseminated to vehicles, and delays can be significantly reduced. The authors of [52] proposed a mechanism for jointly optimizing the content placement and UAV trajectory to maximize the overall network throughput while considering UAV power consumption. The simulated results significantly improved network throughput with the proposed UAV trajectory than UAV hovering in the same static location. The authors of [53] uses a similar approach to use UAVs for content distribution with the aim of reducing the transmission delay. In the proposed method, once the resources at RSUs are fully occupied, the UAVs are deployed for the content distribution and to improve the vehicle user's quality of experience. The simulated results illustrate the significant improvement of the proposed content distribution and improved quality of experience compared to other conventional mechanisms.

Using UAVs as mRSUs seems to be a more viable solution than other strategies. However, using UAVs also come with several challenges. The main issue with the UAV is the battery consumption, and because of the limited battery capacity, UAVs can only be in the air for several minutes. In the case of using it as a mRSU, the battery consumption will increase because of all the communications involving VANET applications. In the future, if the UAVs are to be used as mRSUs, the battery technology should be more advanced by increasing the active flight time of the UAVs. Another challenge will be the route management of the UAVs. The routes of the UAVs must be decided beforehand to cater for as many vehicles as possible. At the same time, all the UAVs on the air should

communicate with each other to optimally distribute to extend the coverage area while serving as a mRSUs. Additionally, there may be some privacy issues involved with UAVs because someone can fly a UAV and pretend to act as mRSU while conducting illegal activities like spying on others. The idea of using UAVs as mRSU is an exciting topic, but these challenges have to be solved before we can use UAVs in future VANETs.

The discussed two main strategies (using existing vehicles and using additional vehicles) are summarized in Table 1. The cost of vehicles and the deployment costs are relatively low with existing vehicles because they are readily available and only need to be equipped with communication devices to adapt them as mRSUs. These existing vehicles follow predetermined routes to cover the main parts of a city. Hence, there is no need for any route planning. However, a major drawback of these predetermined routes is that, in some cases, the expected coverage in rural areas may be cannot be achieved. In the case of using additional vehicles, the mRSUs can be deployed much faster because their route can be fully controlled. Therefore, the fastest route can be selected to reach the destination area in demand. Furthermore, these vehicles can stop at a location to serve, which is impossible with existing public vehicles due to a predetermined schedule. In special situations like concerts or carnivals, these additional vehicles can be stopped at the desired location and can be asked to serve as an mRSU to the surrounding vehicles. Another drawback of using existing vehicle strategy is that the number of mRSUs cannot be increased as desired, but, when using additional vehicles, there exists the possibility to increase the number of mRSUs as desired. However, increasing the number of mRSUs can cause several issues. First, a higher level of coordination among mRSUs is required to determine the serving neighbourhood of each deployed mRSU. Overlapping serving neighbourhoods should be avoided. Second, the deployed mRSUs can cause traffic congestion to increase. Therefore, the optimum number of required mRSUs should be calculated to avoid additional traffic burdens on the road network.

Table 1. Comparison of different mRSU strategies.

	Use Existing Vehicles as mRSU	Use Additional Vehicles as mRSU
Cost of vehicles	Low (Only communication equipment is required)	High (Vehicle and communication equipment are required)
Cost of deploying	Low	High (Additional drivers needed)
Adaptability to current traffic condition	No	Yes
Pre-determined travelling routes	Yes	No
Ability to cover both urban and rural areas	Low	High
Deployment speed in case of need	Low	High
Ability to stop at a location and serve	No	Yes
Possibility of increasing the number of mRSU as desired	No	Yes
Level of coordination among mRSUs	Low	Medium to High
Impact on traffic congestion by adding	N/A	High

The two approaches in using additional vehicles as mRSU strategy (Dedicated on-road vehicles and UAVs) are summarized in Table 2. In the case of dedicated on-road vehicles, any vehicle type can be used, but they are fixed to the road infrastructure since these are on-road vehicles. In the case of UAVs, there only exist two options (fixed-wing and

rotary-wing UAVs). Considering these options, rotary-wing UAVs are much more suitable for being a mRSUs, given their flexible manoeuvrability. The cost of a normal on-road vehicle can expect to be much more than that of a UAV, which can significantly increase the deployment cost. However, a major drawback of UAVs are the power consumption issues due to UAVs being battery-powered devices. The traffic congestion might be increased when on-road vehicles are used as mRSUs due to the added additional vehicles, but, in the case of UAVs, traffic congestion is not affected because UAVs are flying above the road network. Another benefit of UAVs is that the direct line of sight communication can be guaranteed, but, in the case of on-road vehicles, the light of sight communication is very rare due to many obstacles. UAVs' moving speed is much faster than the normal driving speed of vehicles in an urban environment. Therefore, the UAVs can be deployed faster than on-road vehicles in case of need. Moreover, the deployment height of UAVs is significant in determining the communication range. Hence, when using UAVs as mRSUs, they must be deployed in close proximity to the ground to get a longer communication range. Furthermore, in severe weather conditions like heavy rains, snowstorms, etc., it will be difficult to deploy UAVs, and, in such situations, using on-road vehicles might be a safer option. Since UAVs are power constrained, a higher level of coordination among mRSUs is required to serve many vehicles as possible while using resources efficiently.

Table 2. Comparison of using additional vehicles as mRSUs.

	Dedicated on-Road Vehicles as mRSU	UAVs as mRSU
Vehicle types	Any on-road vehicle	Fixed-wing and Rotary-wing UAVs
Cost of vehicles	High	Medium
Power consumption issues	No	Yes
Privacy concerns (etc spying)	Low	High
Fixed to road infrastructure	Yes	No
Impact on traffic congestion by adding	High	N/A (Flying above)
Line of sight communication to vehicles	Rarely	Yes
Speed of vehicles	Similar to other vehicles	Faster than on-road vehicles
Deployment speed in case of need	Medium	High
Communication range	Long	Depend on the deployed height
Prone to whether conditions	No	Yes
Level of coordination among mRSUs	Medium	High

6. Future Trends and Challenges

RSU is an essential component for VANETs, and, therefore, the deployment speed of RSU should be increased to cater for future VANET requirements. Moreover, the idea of self-driving, fully autonomous vehicles is on the near horizon. According to [54], the penetration of autonomous vehicles (AV) into the mass market is expected around 2025. The AVs are capable of automated driving without human interactions due to large numbers of built-in sensors. These sensors generate a vast amount of data, and these data have to be analyzed as soon as possible to make automated driving decisions. In such scenarios, the vehicles can use the RSU to offload computational [55] tasks when the onboard processing power is not enough because the RSU is expected to be equipped with higher computation power.

The idea of mRSU is a viable solution for the high investment costs of static RSU. By considering the research work carried out with mRSU deployment strategies, it is clear that the most popular strategy is to use UAVs. However, as we explained in Section 5, each of the mRSU deployment strategies still have many challenges such as data privacy issues,

regulatory challenges, route management concerns and power consumption issues, which have to be solved before any real-world implementations.

In the case of using existing vehicles as mRSUs, most of the research was still mainly focused only on using public transport buses. However, other public vehicles such as taxis, shared cars and electric scooters can also be used as mRSUs. The characteristic of the taxis is entirely different from the buses because taxis are not moving according to a predetermined schedule. The taxis can cover the whole area of the city, and the travelling routes depend on the passenger, but bus routes are designed to cover only the city's main streets. Additionally, taxis are idle for a considerable amount of time. During this idling period, taxis can be used as dedicated mRSUs, and appropriate incentives can be awarded to taxi drivers and taxi companies for their services. Due to their unique characteristics, considering taxis as mRSUs can be beneficial but not adequately analyzed yet in the literature.

Furthermore, the upcoming idea of air taxis is another exciting type of public transport vehicles that can be used as mRSUs. According to [56], air taxis are scheduled to begin in Dubai by 2022 and are expected to reach 430,000 units by 2040. Another study [57] forecasts that the global urban aircraft market will mature during this decade and will increase drastically to a total worth $1.5 trillion by 2040. Air taxis have the same benefits as UAVs (line of sight communication and are not affected by traffic congestion) and do not have any battery issues. However, in an urban scenario, the routes of the air taxis might be restricted due to buildings and other obstacles, but they at least will be able to fly above the road infrastructure. The air taxis combine the mobility characteristics of ordinary on-road taxis and UAVs and, therefore, can be more beneficial to use as mSRUs than other public transport vehicles.

Rental electric scooters are readily available in most cities today. Thousands of these scooters are deployed by the rental companies and scattered around the most demanding streets. Due to their lower prices and easy access, these scooters have become popular among many daily commuters. Therefore, rental scooters frequently cover most of the city area and can be ideal vehicles to serve as mRSUs. Since scooters are battery-powered, the power consumption will be a limiting factor, but, still, we believe it will be interesting to analyze the performance of rental scooters as mRSUs. To the best of our knowledge, no available study analyses the feasibility of using rental electric scooters as mRSUs.

In addition, a mix of all above mentioned public vehicles can be used as mRSUs. In such a scenario, the regular schedule of buses and broader coverage of taxis and rental scooters can jointly improve the total performance of deployed mRSUs. However, it is important to make sure not to deploy too many mRSUs, which can degrade the network performance. Additionally, clustering techniques can be used among mRSUs when there are too many mRSUs in each other's coverage to select the most suitable mRSU to serve. Others can temporarily switch off the mRSU capabilities to save resources.

Most of the challenges in each discussed deployment strategies (using existing vehicles and additional vehicles) can be mitigated by implementing a hybrid strategy that merges both strategies into one network architecture. In such a network, the low deployment cost of using existing vehicles as mRSUs and route controllability of using additional vehicles as mRSUs can be combined. Therefore, the network performance can be improved. However, in such a network, the management of the mRSUs will be challenging and has to be investigated extensively.

Moreover, the aspects of data security and privacy are major issues in VANETs [58,59]. These security concerns grow even more when considering mRSUs because mRSUs are not part of the fixed infrastructure like static RSUs. Currently, many research works are done on using advances in machine learning and blockchain technology to improve the security of VANETs. These technologies can be incorporated with the idea of mRSUs in future VANETS for proper authentication and data encryption while keeping latency at a minimum to identify malicious nodes in the network.

7. Conclusions

The number of vehicles on the road is increasing and causing many fatal accidents. Therefore, VANETs have become one of the major hot spots for research to improve vehicular safety. In this survey, we first analyzed the importance of RSU to the VANET architecture by analytically calculating per user bandwidth, incorporating mmWave 5G base station. We showed that, even with higher data rates with 5G, still, the base station cannot cater to all of the users (vehicles and mobile users). Furthermore, we discussed the idea of mRSU, which tries to overcome some limitations in static RSU. We described the main strategies of mRSU deployment currently proposed by the research community, and we also discussed the pros and cons of each strategy. We categorize the discussed related works in Table 3. It is clear that, by looking at the most recent research, using UAVs as mRSUs can be identified to be a more popular solution than other strategies. Furthermore, we also discuss the possible future research directions and associated challenges.

Table 3. References categorization for each mRSU startegy.

Reference	Public Transport Vehicles as mRSUs	Use Additional Vehicles as mRSUs	
		Specially Built on-Road Vehicles as mRSUs	Unmanned Aerial Vehicles as mRSUs
Luo et al. [31]	✓		
Chaib et al. [32]	✓		
Li et al. [33]	✓		
Lan et al. [34]	✓		
Zhang et al. [35]	✓		
Lee et al. [36]	✓		
Heo et al. [37]	✓		
Huei-Ru et al. [38]		✓	
Akhavan et al. [39]		✓	
Bouachir et al. [40]			✓
Fatemidokht et al. [41]			✓
Seliem et al. [42]			✓
Su et al. [43]			✓
Oubbati et al. [44]			✓
Samir et al. [45]			✓
Samir et al. [46]			✓
Zhou et al. [47]			✓
Khabbaz et al. [48]			✓
Raza et al. [49]			✓
Fan et al. [50]			✓
Qu et al. [51]			✓
Wu et al. [52]			✓
Su et al. [53]			✓

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