# Chapter Submission – Adapting Future Vehicle Technologies for Smart Traffic Control Systems

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# Adapting Future Vehicle Technologies for Smart Traffic Control Systems

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## Introduction

Traffic control systems are imperative to the everyday function and quality of life for society. The current methods, such as; SCATS [1], SCOOT [2] and InSync [3], provide this solution, but with limited flexibility. With the advances in context-aware technologies and wireless vehicular communication as discussed by Maglaras [4], and the rise of the Internet of Things allowing inexpensive networking of devices current technologies are becoming rapidly outdated. Some examples of such vehicle technologies are discussed in recent studies, namely, social internet of vehicles [5] [6], and wireless sensing technologies [7]. As the smart city landscape develops, some of these technological advances can be adapted into smart traffic control systems, improving the transport efficiency throughout the road network, while reducing levels of traffic congestion, amount of air pollution, improving quality of life. Although air pollution can be somewhat mitigated with technologies like Stop-Start, Hybrid or Electric, traffic congestion still has negative effect on the quality of life for the drivers, as well as the residence in the affected areas. As it has been outlined before by Glaesar [8], reducing traffic congestion remains a crucial goal of these future vehicle technologies.

Addressing the traffic congestion problem, this chapter reviews existing technologies and future vehicle concepts that can be a good starting point for future studies of implementing a Smart Traffic Control System (STCS), starting by looking at the importance of STCSs, reviewing

existing technologies in use with a focus on the most common, and identifying their shortcomings. Afterward, three potential vehicular technologies; V2X (Vehicle-to-X) communication [9], vehicle cloud computing (VCC) [6] and vehicle social networks (VSNs) [5], will be reviewed based on previous works [10] [11], with their applicability in STCSs based on potential efficiency, security and privacy aspects.
We decided to choose these three technologies or concepts, because they attracted great attention by both research communities and industry, for their potential role in the smart city landscape.

## Current Technology

Adaptive traffic control systems (ATCS) are designed to manage a traffic junction effectively. These systems use varied sensing equipment to determine the number of vehicles waiting at a given point and then change the lights for an appropriate length of time to allow for the most optimum number of vehicles through the junction. As a result, the vehicles waiting time is minimized and congestion is mitigated. See Table 1 in the Appendix for a comparison table of the reviewed ATCSs.

### *1.1.1 Sydney Co-ordinated Adaptive Traffic System (SCATS)*

SCATS is the most widely implemented ATCS across 25 countries, though it was originally created by the Roads and Traffic Authority (RTA) of New South Wales, Australia in 1970 [12]. It is a real time traffic control system designed to optimise the traffic flow by synchronising the signals over a whole city, region, or corridor. This is done by having a central management server that can connect to 64 regional controllers, these regional controllers can handle up to 250 intersections.
The regional controllers connect to the local intersection controllers which have access to control the lights, as well as gather vehicle presence information from the coils built into the road called “Loop Detectors”. The local controllers measure the traffic intensity using the loop detectors to determine the degree of traffic saturation over a predetermined time [13]. This data is then sent to the regional controllers which calculates the most effective cycle lengths (from 20 to 240 seconds, the time for each road to

wait), splits (changes the importance of the main road over minor ones), and offsets for the intersection lights, which the local controllers enact.
Statistics show that SCATS on average reduces the delays by 20%, reducing stops by 40% and therefore reducing fuel consumption by 12% and emissions by 7%. Also allowing emergency services on the fly control to stop traffic for their arrival [14].

### *1.1.2 Split Cycle Offset Optimisation Technique (SCOOT)*

A technology developed in the United Kingdom, SCOOT is similar to SCATS in that it uses green-split and offset calculation to manage traffic in real time. Using a centralised architecture and scheduling algorithm, the system uses the induction loop technology built into the road to detect when vehicles pass over them. The system works by having a sensor at the start of the traffic light waiting zone of an intersection then another sensor fifty to three hundred metres before this waiting point. The system then uses something called cyclic flow profiles to estimate the number of vehicles that enter the road area roughly every four seconds. To minimise stops and delays a queue model is used, this model optimises the amount of green for each approach called the “Split”, the time between adjacent signals or “offset” and time allowed for all approaches to the intersection or “cycle time”.
A hierarchical levelling is used for optimisation, using Region, Link, Node and Stage as the different levels. Region determines the cycle length optimisation, Link prevents queuing occurring, Node is for fine adjustments of all parameters and Stage sets limits for the minimum and maximum stage lengths. These optimisations can be turned off or on by the system depending on histograms of traffic saturation in the zone collected hourly, daily and weekly. These inform future flow predictions to determine how to operate the most efficient flow through the intersection. These records also include data like occupancy levels, peak flow hours, queue length, etc.
Upon introduction certain areas experienced delay reductions of up to 30% over the conventional fixed-time systems, interestingly during high peak times like sporting events delay reductions as high as 61% [14] [2].

### *1.1.3 InSync*

This system differs to the previous two as it doesn't use induction loop technology built into the road, with optimisation occurring on the split and offsets. Instead InSync uses Internet Protocol (IP) camera systems installed at the intersections to visually detect the number of vehicles approaching and waiting at given points. This is done by having detection zones with contours drawn across them, by counting how many of these contour segments have vehicles in them, the system can determine how many vehicles are waiting, as well as how long they have been waiting there. This allows the system to quantify the traffic saturation at the intersection as well as providing real time video feed monitoring of the approaches.

The system also avoids the analogue style of light control with cycle length, splits and offsets, instead using something called finite state machine. This method contains states the intersection can be in, with some states being adaptive so to account for varied scenarios and local optimisation, implementing phasing, sequencing and green time allocation to do so. The system is also much simpler in hierarchy than SCATS or SCOOT as there is only local and global optimisations, with the global able to override the local at any time.

At the global level traffic is monitored in something called "platoons" which are routed through traffic corridors by altering the green time of intersections to reduce stop times. The local optimiser handles the phasing and sequencing, leaving green time to global, this leaves the local optimiser to control the delay time and volume of vehicles. This is done by using an algorithm to award each vehicle with a weight of importance, an approach with a higher weighting will be given priority over those with a lower weight, or those with no vehicles waiting at all. This weighting can be altered as well for different vehicles, like; buses, trucks, emergency vehicles, etc. [3]

### *1.1.4 Shortcomings*

In this section, we will outline some limitations of the current technologies that future technologies will have a potential to improve.

**Emergency responder:** Not all the discussed traditional technologies have an emergency responder control function implemented, this can mean responders take longer to move through junctions. If the functionality is in place but is not used at the correct time then the timings will not be influenced ready for the responder's arrival at the junction, voiding the functionalities usefulness.

**Limited Bandwidth:** The transfer of information about the state of the traffic signals is slow, as the decision-making time of drivers slows the process of moving off from an intersection. *"When fully aware of the time and location of the brake signal, drivers can detect a signal and move the foot from accelerator to brake pedal in about 0.70 to 0.75 sec."* [15] This pause added up from numerous drivers, as well as acceleration time reduces efficiency significantly. If the state of the traffic signals could be sent directly to vehicle computers not only would there be a record but also in the case of self-drive vehicles the decision-making time would be removed. Unfortunately, there are still few vehicles able to receive this information and less able to act on it, however vehicle automation is on the rise so adding this functionality could improve future usage.

**Inability to divert:** Namely, if there was a traffic collision and traffic is building up already there is currently limited or only manually activated ways to prevent vehicles from routing the same way. To do this would require the cooperation of the vehicles as the onboard computer would need to recommend the new route to the driver for them to confirm it, of course this would not be viable in all scenarios.

**Limited sensing range**: The range at which an intersection can receive data is limited to the range of vision of the camera or induction loops installed at an approach. Having these sensors so close prevents the intersection control from pre-emptively implementing alterations to the lights to further reduce unnecessary stops of approaching vehicles.

## Potential Application of Future Technologies in STCS

### *1.1.5 V2V/V2I/V2P/P2I (V2X) communications*

**Introduction:** V2X is derived from the Internet of Things (IoT) concept where varying devices are all connected to a network, to share sensing and controlled functionality. Many vehicles are equipped with Electronic Control Units (ECU), sometimes with wireless connectivity for maintenance purposes. Also, most intersections are connected via wired connection to control infrastructure. V2X would utilize this connectivity to facilitate information sharing with all other end points on the road network, Zheng et al. [16] discuss varied methods of communication in detail. See Figure 1 in the Appendix for diagram.

**Potential Role in Traffic Control:** By adapting V2X communications in road traffic control, the goal is to facilitate sensory sharing across the road network. [7] This allows each node in the network, whether that's a vehicle, base station or pedestrian, to get more accurate picture about the traffic. Vehicles may alter their route to avoid road congestion and therefore reduce it for others. Intersection control algorithms will be able to determine the most efficient sequence to allow vehicles and pedestrian to move, and to improve safety monitoring to mitigate safety risks as they may occur. Relating to road intersections particularly, it would allow information about approaching vehicle speed, distance and route to inform more efficient sequencing of the lights to reduce unnecessary stops [17]. Current sensing range of an intersection is quite close, whereas with V2X the information could be received a few miles in advance allowing the information to be enacted at the correct time and effect other intersections in the vicinity to compensate.

**Challenges:** There are several challenges for this technology that need to be resolved; lane identification whether that's at an intersection or travelling through areas of poor GPS signal, mechanisms for incident detection to ensure appropriate response is made, route sharing in a way that ensures privacy, and integration in a way that doesn't mean old technology is obsolete and incompatible but that isn't as efficient as newer V2X hardware.

### *1.1.6 Vehicular Cloud Computing (VCC)*

**Introduction:** As said previously, many vehicles are equipped with ECUs, however, their resources (i.e. storage, processing power, etc.) go for long periods of time each day without use, i.e. when in congestion, or parked at work or home. See Figure 2 in the Appendix for diagram.

**Potential Role in Traffic Control:** VCC would make use of surplus or unused resources by creating cloud networks that allow the exchange of the resources for a reward, such as; traffic information, connectivity credit, reduced service cost from an organisation, etc. Similar to solar panels slowly pay themselves back for the household, this technology could allow vehicle owners to make use of their vehicles in a monetary way. One of the first to develop the idea was Abuelela et al. [18], defining it as *"a group of largely autonomous vehicles whose corporate communication, sensing, computing and physical resources can be organised and dynamically allocated to authorized users"*. It is likely the more usable resource available is the CPU of the ECU, due to the fact that storage will not be much larger than the operating system, space for update files, and maintenance and debugging logs. When considering this technology specifically for intersections, there will be a lot more sensory data being fed into the intersection controller; greater processing abilities would be required. To facilitate this the intersection could distribute the required processing to vehicles approaching and waiting at the intersection, in this way improving efficiency of the intersection is the reward for the small amount of CPU usage the intersection would take per vehicle.

**Challenges:** The major issue is that if there is no incentive to allowing your vehicle to become part of a cloud network then no one will want to, as if it becomes too currency orientated there may be reduced cooperation. Anytime a resource is used to benefit the cloud network there needs to be a good enough reward in return. If the correct balance is struck vehicles should mutually share information that is important to other road users such as; location, traffic information, etc. There are several other challenges for the introduction of this technology, including; how to dynamically set up an ad-hoc non-static infrastructure on the fly, ensuring the resource-to-reward system is fair and reasonable, and how to distribute processing dynamically taking into consideration end-point drop out.

### 1.1.7 *Vehicle Social Networks (VSN)*

**Introduction:** In VSNs vehicles travelling in groups can form social groups for sharing information or for the passengers to play games together during their journey. Compared to traditional social networks, VSNs maintain only short-term social connections built up on-the-fly. These ad-hoc social networks are built up based on different aspects, such as same destination, same route, interests or goals. VSNs also rely on V2X communications, however, its core concept is based on social connection among vehicles. There are several applications similar to VSNs; RoadSpeak [19], CliqueTrip [20], SocialDrive [21], Waze [22], Social on Roads (SoR) [23], with some allowing passengers to share route information, and traffic conditions (e.g., Waze, SocialDrive). See Figure 3 in the Appendix for diagram.

**Potential Role in Traffic Control:** VSNs have potential to improve traffic efficiency on the road, when vehicles travelling in a certain area form Traffic VSNs (TVSNs) to share traffic information, namely, vehicles on one road can share traffic information with vehicles on other roads. For example, Waze [22] is a GPS and community-based navigation application, where users can share traffic condition on certain road segments with each other. On the architecture level, TVSNs can be centralised, decentralised or hybrid. In centralised TVSNs, only V2I type communications take place with every communication passing through the service provider (e.g., Waze's servers), who create, manage, and maintain the TVSNs. Decentralised TVSNs is based on V2V type communications, where the TVSNs are built up and managed by the vehicles themselves on-the-fly. Finally, in hybrid TVSNs the roadside units (RSUs) are also involved in conjunction with smart traffic lights when relevant; real-time traffic information is also shared with them.

**Challenges:** VSNs opens some interesting problems due to the ad-hoc short-term nature of the social networks, such as data-forwarding incentives of non-member nodes (as vehicles outside a TVSN may not be willing to forward messages to save resources), trust problems with selfish or malicious nodes sending or forward inaccurate information to save resources. Finally, it is unavoidable to completely separate the human aspect from the applications when considering social networks.

## Discussion

A primary directive any vehicle technology should be is safety. To do this these technologies need to ensure the security of data to prevent misinformation from causing potential risks, and the privacy of users to protect them from attackers. Using wireless communications means the attack vector can be from external sources, as well as internal ones. Therefore, security measures need to ensure the protection of all data in the network so that only correct information is sent between vehicles, roadside units and control systems. Also, only allowing those authorized to access sensitive data. This information could include details about vehicle speed and route, vehicle owner payment methods, passenger-specific details, etc; all of which require different levels of protection based on the scenario of requirement. To this effect, permission levels should be implemented so that only certain information is available to different groups of network users. For example; traffic control systems require vehicle specific details but don't require passenger or payment details, toll roads would require payment details but don't require route or passenger information.

Each scenario differs so it may be difficult to strike a balance. In cases where further information is needed, a request process should be implemented to vet the user. Getting this sharing of information right may improve efficiency network-wide and could reduce unnecessary stops at varied places. Pseudonyms have been discussed before [24] to obscure the user from their data, allowing only authorized users to be aware of which vehicle it belonged to, maintaining the anonymity of data. Another potential option for obfuscation of sensitive data is implementing varying levels of encryption on the data that a vehicle stores, this way only those with the correct key can decrypt that data.

Tampering with devices connecting to the network will be the first potential threat as attackers attempt to reverse engineer hardware and communication protocols to determine vulnerabilities. Two researchers were able to gain control of critical vehicle systems (like; brakes, steering, accelerator, etc.) and control them from ten miles away, connecting via 3G using vulnerabilities in Uconnect software the vehicle used [25]. Anti-tampering techniques (e.g. inductive switches, hall effect sensors, etc.) can prevent or detect physical tampering, however, attackers may still find ways to circumvent them. Therefore, reactionary methods should be used to inform of a rogue node as information from it is likely incorrect. This is a persistent issue of all technologies discussed as developing trust between network nodes' is tricky [26]. Especially true in the case of technologies like VCC where resources are of monetary value. Implementing the vehicle profile aspect of VSNs into all handshake protocols to determine the other node's trustworthiness, could be a potential solution based on previous communications to ensure they are tamper free. Current methods of authentication could be used with some alterations, perhaps a twin authentication where each node communicates with an infrastructure node to validate authenticity, or within the firmware to flag whether the system has been tampered with based on sensors in the casing.

Of course, breaches will occur, in these scenarios fail safes should be implemented to ensure public safety and avoid misinformation manipulating traffic control systems into causing serious damage. Applying anywhere on the road network where a set of rules operate (i.e. route 1 stops before route 2 can move). Physical redundancies also ensure any service drops are for as minimal time as possible, if a roadside unit or intersection controller goes down there should be another on standby ready to come online until repairs are made. Considering the security implications of a downed station, all vehicles in the vicinity will be looking to connect to a station, which leaves a hole in the network that an attacker could fill with a rogue station.

Unfortunately, even fail-safes and redundancies will sometimes not be enough to avoid incidents, such as when traffic lights have been misled by fake or incorrect information coming from vehicles or roadside units. In these scenarios, there should be procedures in place to ensure that any incident is reported and investigated correctly. Though it is heavily reliant on the scenario, each vehicle will likely be logging a lot of information, like a black box in an airplane. This information should contain a histography of speed, intended route, steering wheel angle, etc. This information could then be used to determine all actions from involved vehicles up to the point of the incident to allow an investigator to understand how and why an incident occurred, as well as who is at fault. This also relates to physical infrastructure nodes, as if there is a service drop, the risk of an incident occurring may increase. In these cases, an investigation would need to be conducted to find whether it was lack of maintenance, energy brownouts or surges, incorrect manipulation by the regulator, etc. One of the most important things to ensure investigations can be conducted correctly is the existence of extensive logs storing as much data as possible on all actions taken by road users, system checks and network traffic.

To ensure that all manufacturers integrating these technologies into their products are compatible with each other a set of standards would need to be adhered to. Within the IEEE, there is a technical sub-committee that regularly review Vehicular Network & Telematics Applications (VNTA). Since VCC and VSNs are in their infancy, mainly research stage, no standardization can be found in these areas, there are however several international standards relating to the V2X concept such as IEEE 1609 Wireless Access in Vehicular Environments (WAVE), building on 802.11p WLAN, and designed to add multi-channel operation, security and a lightweight application layer. [27]

It is important to consider future technologies like machine learning as a potential resource for managing and improving efficiency and safety, allowing persistent monitoring and control, potentially identifying risks and preventing them before they become serious. Emergency response would be quicker as detection and alerting would be instant, as well as controlling intersections to assist in fast transit of emergency responders. When considering a downed station, the intelligence would be instantly aware of it, and could inform vehicles to route packets through each other to the closest stations to avoid drops in service, as well as sending a maintenance and investigation request to the appropriate individuals.

## Conclusion

In this chapter, we discussed possible future smart traffic control systems based on three future vehicular technologies that have potential to overcome the limitation posed by the current, widely used, adaptive traffic control systems. With an overview of the current traffic control systems and their limitation, as well as highlighting future vehicular concepts such as V2X communications, VCC and VSNs. We discussed the possible application of these three concepts for smarter, more efficient traffic control. The challenges and problems of each technology were raised, to inform possible research directions. We then discussed the common problems V2X, VCC and VSNs may suffer relating to effectiveness, security and privacy. Such as trust and selfishness problems, tampering issues, investigating incidents. Lastly, mentioning other vehicular future technologies that could be examined in this context, however, due to the space limitation we decided to focus on these three concepts as the most interesting and actively researched areas.

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## Appendix

| | SCATs | SCOOT | InSync |
|---|---|---|---|
| ***Place of deployment*** | Australia/Oceania, Asia | UK, Commonweath | USA |
| ***Place of design*** | Australia | UK | USA |
| ***Traffic intensity is measured with*** | One set of inductive loop detectors, In-road sensors | Two sets of inductive loop detectors | IP camcorders |
| ***Traffic intensity is measured at*** | Stop line/ every lane | Stop line & upstream end of the road/ every lane | Stop line/ every lane |
| ***What is measured?*** | Distance between vehicles | Saturation, one-way flow profile | Image processing Vehicle counting |
| ***Traffic schedule/ optimisation is based on*** | Cycle lengths, splits and offsets | Cycle lengths, splits and offsets | Finite state machine states of the intersection |
| ***Architecture*** | Centralised/ hierarchical | Centralised/ hierarchical | Centralised/ hierarchical |

**Table 1 ATCS Comparison**

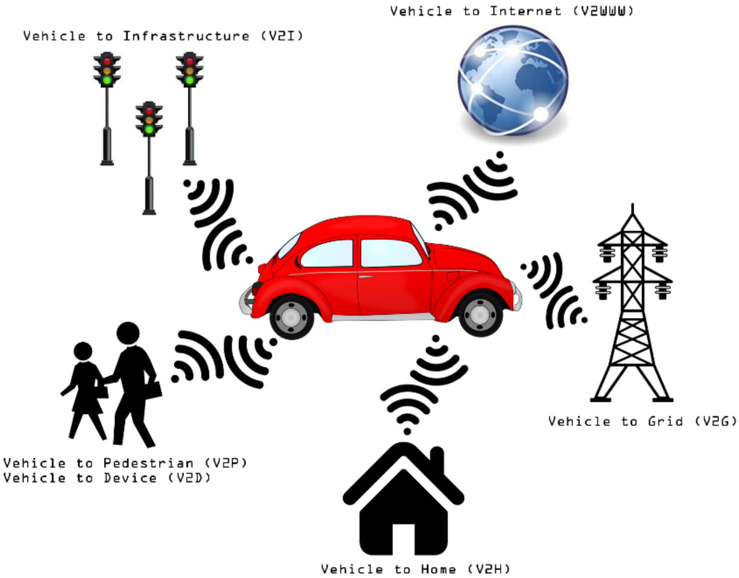


**Figure 1 V2X communications**

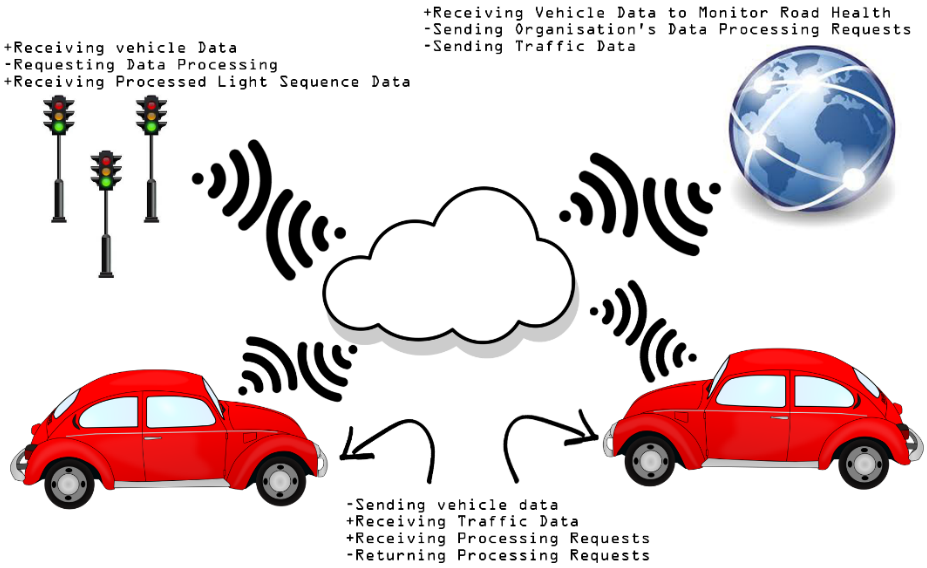


**Figure 2 VCC concept in smart traffic control**

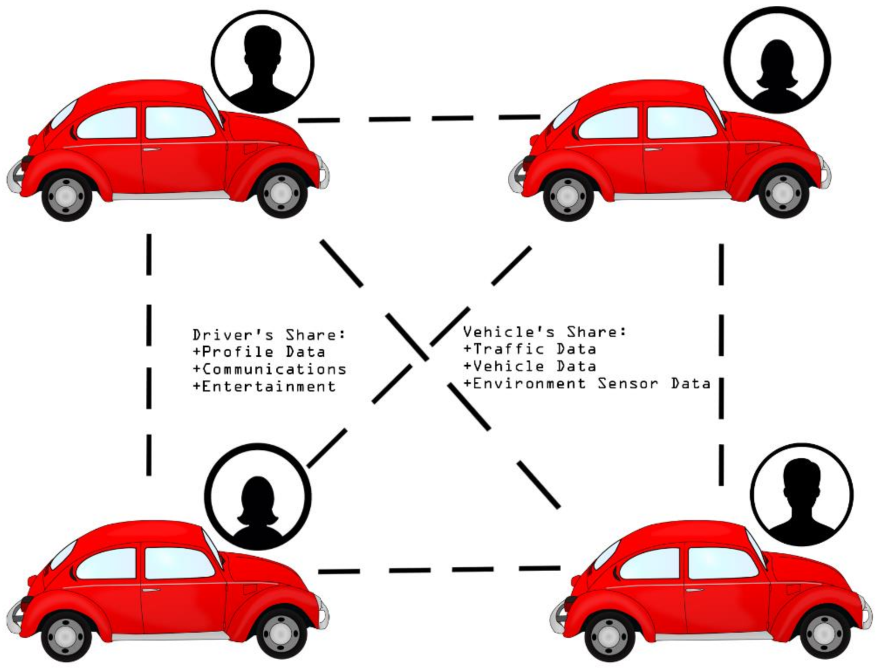


**Figure 3 VSN concept in smart traffic control**