Internet of Things (IoT) in transportation: exploring vehicular ad-hoc networks (VANETs) feasibility

Adrian E. Coronado Mondragon*
Royal Holloway University of London, School of Business and Management
Egham Hill, Egham, UK, TW20 0EX
adrian.coronado@rhul.ac.uk

Christian E. Coronado Mondragon
School of Ocean Technology
Fisheries and Marine Institute of Memorial University of Newfoundland and Labrador
P.O. BOX 4920, St, John's, NLL, Canada
christian.coronado@mi.mun.ca

Etienne S. Coronado
Networking and Telecommunications Professional Services
Toronto, Ontario, Canada
etienne.coronado@gmail.com

*** Corresponding author**

Abstract

Vehicular ad-hoc networks (VANETs) represent a significant IoT technological development that can support transportation management. This research investigates the feasibility of deploying VANETs using the principles of clusters in an industry scenario comprising haulage operations in a confined geographic location. We use simulation to model a VANET solution to enable data traffic associated with the exchange of messages between the vehicles and road side units. The proposed solution designed and dimensioned to reduce queuing delays demonstrated the suitability of VANETs as a solution that can support transportation operations associated to logistics. The results are associated to the characteristics of an industry scenario comprising haulage operations in seaport operations. By using a cluster configuration in IoT-VANETs, requests from members of the cluster are channelled through the cluster head, this eliminates the need for each mobile node to communicate directly to the road side nodes which prevents overwhelming the network with individual requests.

Keywords: Internet of Things (IoT) and vehicles; transportation management; vehicular ad-hoc networks; clustering principles; port logistics

Biographical notes:

Adrian E. Coronado Mondragon received the PhD degree from the Department of Systems Engineering, Brunel University, West London, UK. He is Senior Lecturer in Technology and Operations Management at the School of Business and Management, Royal Holloway University of London. His research interests cover technology adoption in supply chains, modularity, manufacturing supply chains and Internet of Things (IoT) and distributed ledger technology in logistics.

Christian E. Coronado Mondragon received his PhD in Industrial Engineering from the Department of Industrial Engineering at the Montreal Polytechnic School in Montreal, Canada. He currently serves as Academic Director of the Master's Program in Technology Management at the Marine Institute of Memorial University of Newfoundland. His areas of specialisation include innovation, creativity, statistical quality control, intellectual property quality systems and digitalisation.

Etienne S. Coronado received his PhD from the Department of Electrical and Computational Engineering from the University of Sherbrooke, Quebec, Canada. He has extensive experience as an information security architect within the telecommunications sector. His areas of expertise include security in cellular, network, computational cloud and applications and Internet of Things (IoT).

1. Introduction

The interest on Internet of Things (IoT) has been growing substantially in recent years. It is well acknowledged the future of the Internet will consist of heterogeneously connected devices that will further extend the borders of the world with physical entities and virtual components (Li et al., 2015). Ashton (2009) coined the term IoT to refer to uniquely identifiable interoperable connected objects with radio-frequency identification (RFID) technology. In IoT many of the things that surround us will be on the network in one form or another (Gubbi et al., 2013). IoT will let Web-connected machines of all kinds communicate with each other and with users, creating a rich flow of data about their location and status (Booz & Co., 2011). By 2020, companies will be spending about £250bn a year on IoT, with half of all that spending coming from the manufacturing, transport and utility industries (Financial Times, 2017).

Researchers have related IoT with numerous technologies such as wireless sensor networks (WSN), barcodes, intelligent sensing, RFID, low energy wireless communications, cloud computing and others (Li et al., 2015). Advances in sensor technology and ubiquitous broadband communication have set the foundation for IoT; hence in IoT large volumes of unstructured data are generated by all kinds of mobile devices and sensors. Integration of sensors/actuators, RFID tags, and communication technologies serves as the foundation of IoT and explains how a variety of physical objects and devices around us can be associated to the Internet and allow these objects and devices to cooperate and communicate with one another to reach common goals (Van Kranenburg et al., 2011).

The emergence of autonomous vehicles and the growing importance of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication are evidence that as vehicles have increasingly powerful sensing, networking, communication, and data processing capabilities, IoT technologies can be used to enhance these capabilities and share under-utilised resources among vehicles in the parking space or on the road (Xu et al., 2014). Vehicular ad-networks (VANETs) can play an important role in the realisation of IoT where the data gathered from sensors can be then transmitted to control centres via V2V and V2I communication systems (Mishra et al., 2016). VANETs represent a key technology that possesses extensive capabilities to enable vehicles become full participants of IoT. Furthermore, these days applications have reached the development of autonomous ships (Munim, 2019). VANETs are suitable for initiatives involving intelligent transportation systems. For example, intelligent transportation systems for accessible transportation services can enhance organisation operational efficiency (Man, 2019).

VANETs relate directly to important layer-based IoT protocols found in existing architectural models. Some of these IoT protocols identified by Postcapes (2018) comprise of Infrastructure (e.g. IPv4/IPv6), Communications/Transport (e.g. Bluetooth, WiFi, LPWAN) and Identification (e.g. IPv6, EPC, uCode) among others. In the view of Anwer and Guy (2014) VANETs are a distinctive class of mobile ad-hoc network and an integral component of Intelligent Transport Systems (ITS) in which moving vehicles are connected and communicate wirelessly. It is expected applications supported by VANETs will continue to grow and evolve to eventually achieve an accident-free driving environment (Faezipour et al., 2012). Since VANETs have the potential to reduce traffic accidents and improve driving comfort, many academic institutes, vehicle manufacturers and governmental organisations are progressively paying more and more attention to VANETs (Tian et al., 2012). In addition to the emphasis on road safety applications, it is non-safety VANET applications which also offer a myriad of opportunities. For example, it is expected VANETs to play an important role in transportation and logistics operations as in the view of Glass et al. (2010) modern logistics practices and international trade often require distribution channels and greater use of information technology. In IoT, transportation of goods using haulage vehicles can benefit from using VANETs for messaging instructions and transmitting data related to logistics operations, which may result in less vehicle congestion and also less harmful emissions released to the atmosphere.

Although VANETs offer numerous advantages as an IoT-enabled technology, there are also important challenges related to their adoption including large scale deployment and high mobility. Regin and Menakadevi (2019) pointed that because of the fast growth in wireless communications, VANETs face many challenges over wireless communication networks with congestion occurring when vehicles are in the dense part while the network node is carrying more data than it can handle. Nodes in vehicular environments are much more dynamic with most motor vehicles usually travelling at high speed and changing their position constantly (Liang et al., 2015). Zhang and Jin (2013) pointed out that many attractive applications over VANETs need data to be transmitted to remote destinations through multi-hop data forwarding, but some unique characteristics of VANETs (i.e., high node mobility, dynamic topology changes with frequent link breakage, and unstable quality of wireless transmission) may incur unstable data delivery performance.

In IoT applications based on VANETs, especially those related to safety-related applications, require low message delivery latency (Tian et al., 2012). In VANETs queuing delays and long latency can occur as a result of vehicles overwhelming a network with individual requests. As a result this has a negative effect on the performance of both safety and non-safety applications. It is precisely this situation that gives the opportunity to explore solutions that may be able to mitigate the effects of queuing delays and long latency.

Network clustering is relevant in improving the performance of VANETs. The work by Alsuhli et al. (2019) highlighted that scalability and the highly dynamic topology of VANETs are the biggest challenges that slow the roll-out of such a promising technology. The researchers argued that adopting an effective VANET clustering algorithm can tackle these issues in addition to benefiting routing, security and media access management. One of the solutions envisaged by the researchers comprise a general-purpose resilient double-head clustering (DHC) algorithm for VANET. The principles of clustering in VANETs was adopted by Regin and Menakadevi (2019) who proposed a density based dynamic clustering devices algorithm to determine node density of the precise location in a lane and deliver a practical solution to congestion. The researchers achieved outstanding results in terms of average cluster number, cluster head duration and average cluster member duration. Sharif et al. (2020) work involving VANETs proposed a cluster based IoT-enabled routing technique in static and dynamic transportation. The researchers' technique provided benefits in transmitting packets efficiently in a network even with low vehicle density.

The aim of the study is to investigate the principles of network clustering to improve the performance of VANETs as a suitable technology to support IoT in transportation and address the challenges involving queueing delays and long latency that can occur as a result of vehicles overwhelming a network with individual requests. We identified a transportation scenario comprising a seaport location relying on haulage vehicles. In a seaport location more than one vessel can be docked and unloaded at the same time, resulting in several simultaneous unloading jobs. As a result there is a need to allocate several haulage vehicles to deal with all the different jobs.

Given the significant importance of VANETs as a technological development in IoT that can support transportation but also the challenges comprising queuing delays and long latency, the research question to be investigated in this work is as follows:

- What is the feasibility of deploying VANETs as an IoT technology using clustering principles for haulage operations in a seaport location?

The next section provides a background of current research involving VANETs and network clustering, followed by a discussion on the characteristics of the transportation scenario selected in this research and the justification for using VANETs to support IoT in transportation.

2. Literature review

The next subsections cover a review on VANETs and clusters followed by the particularities of transportation operations as a key industry sector.

2.1 Research on IoT – VANETs and cluster configuration for the support of transportation operations

In the view of Li et al. (2015) the emerging wirelessly sensory technologies have significantly extended the sensory capabilities of devices and therefore the original concept of IoT is extending to ambient intelligence and autonomous control. It is precisely these capabilities that promise to make a major impact on economic activities. IoT is expected to offer promising solutions to transform the operation and role of many existing industrial systems including transportation and manufacturing systems (Xu et al., 2014). In the particular case of transportation when IoT is used for creating Intelligent Transport Systems (ITS), the transportation authority will be able to track each vehicle's existing location, monitor its movement, and predict its future location and possible road traffic (Li et al., 2015).

IoT technologies have a promising future in transportation as stated in the previous paragraph, hence we believe VANETs represent a key role in IoT support of transportation. Various sources were accessed to identify current research work on VANETs as this technology addresses several important challenges. The work by Liang et al. (2015) classified research on VANETs in areas that include: routing, security, privacy as well as safety and non-safety applications. According to the authors research involving routing covers routing protocols and algorithms (i.e. geocast/broadcast, multicast and unicast) whilst security and privacy research involving VANETs addresses security architectures and secure communications schemes. Also Liang et al. (2015) highlighted that applications in vehicular environments can increase road safety, improve traffic efficiency, and provide entertainment to passengers. Generally speaking VANETs applications can be organized into two major classes: safety applications and non-safety applications. Regarding safety applications VANETs allow vehicles to send warning messages to neighbor vehicles or drivers to mitigate potential collisions and with the help of high speed wireless V2V communications, potential danger could be detected before the driver can perceive them, such as sudden braking of a leading vehicle or intersection collision (Tian et al, 2012). Non-safety applications can be classified into several subclasses based on their specific intended purpose such as traffic convenience and efficiency applications, infotainment applications, and comfort/entertainment applications (Liang et al, 2015).

Research on VANETs in transportation is not as developed as other technologies like Radio Frequency Identification (RFID) and sensor network which have been thoroughly investigated. Examples include: from the use of RFID for embedded intelligence of transactions and movements, health and risk status of cargo in ports (Siror et al., 2011); the use of simulation-based real-time control systems for real-time truck dispatching on a surface mine transport system (Jaoua et al., 2012) to the interoperability of passenger information systems (Tibaut et al., 2012).

Although technologies such as RFID and sensor networks have had a major impact on transportation, VANETs represent an attractive alternative as it supports IoT creation of ITS giving the ability to track a vehicle's existing location, monitor its whereabouts, fully support messaging and predict its future location. Anwer and Guy (2014) highlighted that in VANETs, vehicles can use numerous wireless access technologies to communicate with other vehicles and road side base stations as this is to improve traffic management and monitoring and enable the driver and passengers to access infotainment/entertainment services. The authors identified VANETs protocols and classified them into five categories including: cellular systems, Wireless Local Area Network (LAN)/Wi-Fi Standards; Dedicated Short Range Communication (DSRC)/Wireless Access for Vehicular Environment (WAVE) Standard; Communications Access for Land Mobiles (CALM) Standard and miscellaneous standards including Bluetooth, ZigBee, and Infrared. The authors surveyed some of the key vehicular wireless access technology standards such as 802.11p, P1609 protocols, Cellular System, WiMAX, Microwave, Bluetooth and ZigBee among others which serve as a base for supporting both safety and non-safety applications. Wi-Fi is optimised for indoor use rather than motor vehicles. WiMax supports high-speed data transmission but it cannot be used for vehicle-to-vehicle safety. A comprehensive review of these technologies can be found in the works by Ribeiro (2005) and Marousek et al. (2008).

Standards such as IEEE 802.11p represent a very important iteration of VANETs given the advantages it has over other technologies. In their work DhilipKumar et al. (2013) addressed VANETs based on the IEEE 802.11p standard which is an additional draft amendment to the IEEE standard that features support for Wireless Access for Vehicular Environment (WAVE). Essentially it deals with the data link layer and physical layers of the open system interconnection model, and its purpose is to provide a wireless communications environment between short road side distances and mobile radio frequency units. VANETs based on the 802.11p standard possess more capabilities compared to cellular networks/4G – LTE Networks. DSRC based on the IEEE 802.11p standard is a next generation wireless vehicle network technology with an increasing role in VANETs. One of the particularities of DSRC-based VANETs is the expected capability to operate at 33 dBm and provide coverage over a range of up to 1000 m with a data rate up to 27 Mbps (NHTSA, 2015) per channel (including two control channels and seven service channels). DSRC technology operates in the Super High Frequency (SHF) Band at 5.9 GHz, where radio waves propagate mainly in the Line-of-Sight as well as due to multipath propagation (Zhao et al., 2012). Figure 1 illustrates the architecture of a VANET platform, here we can find private and haulage vehicles which carry on-board units (OBUs) that allow them to exchange data with the access points which represent road side units (RSUs). Switches and routers direct the data to the cloud and from there to application servers. Other IoT-enabled technologies can be connected to the cloud including smart meters, hand held units, RFID and many more.

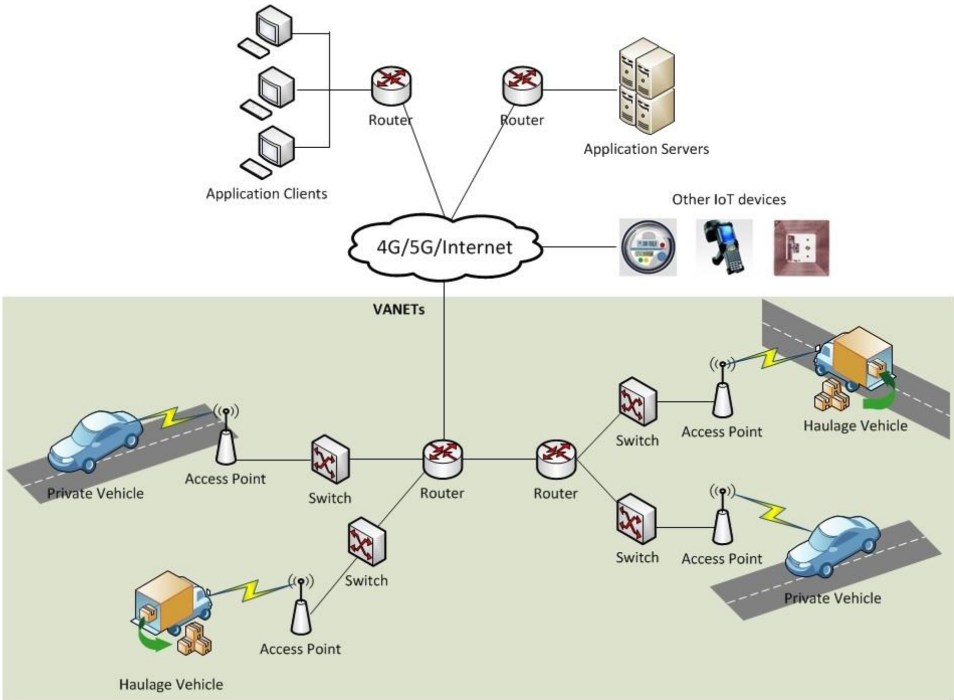

Figure 1. Architecture of a VANET platform in the context of IoT

Clustering represents a suitable approach for dealing with some of the challenges associated with the operation of VANETs like queuing delays and long latency resulting from vehicles overwhelming a network with individual requests. It is not the only solution as other approaches have been used to deal with queuing delays and long latency. For example, the work by Zhang and Jin (2013) considered a delay model and an improved greedy broadcast algorithm embedded with a coverage elimination rule in order to reliably and quickly disseminate data. According to them the former is used for making decisions for path selection with the aim of minimizing the transmission latency, while the latter focuses on boosting the reliability of one-hop data transmission. Propagation delay is the primary source of latency (Bhat and Quadri, 2015).

The use of clustering relies on the use of an architecture comprising of a leader that serves as the local coordinator to ensure consistent, reliable, and sequenced reactions to traffic changes. The member of the cluster is an ordinary node that communicates only with other vehicles in the same cluster. Recognised advantages of clustering include efficient mobility management (Blum et al., 2003), localisation of node dynamics (Santos et al, 2004) and better network scalability (Lin et al., 1997).

The work presented by Wu et al. (2010) described the operation principle of clustering based on the existence of two scenarios for vehicle networks: distributed and centralised networks. The distributed network is formed by on-board units (OBUs) that give ad-hoc connectivity between vehicles while the centralised network is formed by the road side units (RSUs) offering vehicles wired backbone access. Driving environments like those found in highways and motorways comprise both distributed and centralised networks. In the distributed network represented by a scenario consisting of vehicles moving parallel on a multi-lane road, OBUs (nodes) follow a straight lane direction. According to Wu et al. (2010) because vehicles are moving on the same direction they may have connection periods longer than 10 seconds due to their low relative mobility, hence the topology among these vehicles is stable enough to allow clusters to be organised.

The operation of a cluster depends on the use of navigation groups. Furthermore, the navigation groups comprising the cluster are dependent on the use of group navigation for VANETs as according to Sampigethaya et al. (2005) it facilitates: *a)* taking advantage of cooperative driving to increase safety and road capacity, *b)* monitor traffic and road conditions by collecting information and *c)* make use of the most recent location of a mobile node to provide a requested service. These three capabilities are characteristics of clusters supported by navigation groups for logistics applications. Moreover the use of clusters involving VANETs may help to mitigate some of the challenges associated to vehicle routing problems. For example Pollaris et al. (2015) indicated that vehicle routing problems loading constraints include the minimisation of the number of vehicles, total cost, total route length and total time. Having excess vehicles covering lengthy routes will result in more harmful emissions released to the environment and gridlock on the roads. A summary of the research work involving the use of cluster theory in VANETs can be shown in table 1. The next subsection explains the principles of operating network clusters and how this concept can be related to transportation operations.

Purpose of research involving the use of clustering in VANETs	**Source**
Better network scalability	Lin et al. (1997)
Efficient mobility management	Blum et al. (2003)
Localisation of node dynamics	Santos et al. (2004)
Navigation groups for cooperative driving and traffic monitoring	Sampigethaya et al. (2005)
Distributed and centralised networks involving two scenarios for vehicle networks	Wu et al. (2010)
Delay model and an improved greedy broadcast algorithm embedded with a coverage elimination rule in order to reliably and quickly disseminate data	Zhang and Jin (2013)
Vehicle routing problems loading constraints that include the minimisation of the number of vehicles, total cost, total route length and total time	Pollaris et al. (2015)
Effective VANET clustering algorithm to tackle scalability and the highly dynamic topology of VANETs in addition to benefiting routing, security and media access management	Alsuhli et al. (2019)

A density based dynamic clustering devices algorithm to determine node density of the precise location in a lane and deliver a practical solution to congestion	Regin and Menakadevi (2019)
A cluster based IoT-enabled routing technique in static and dynamic transportation to deal with scalability and VANETs topology.	Sharif et al. (2020)

Table 1. Summary of research involving clustering theory in VANETs

2.2 Using network clusters for industry scenarios: the case of transportation

In transportation, the term logistics company covers both, the logistics industry (engineering and plants for the intra-logistics and material handling, software producer for logistic applications and system integrators, etc.) and the logistics service providers (players like contract logistics, shipping companies, warehouse operators, IT service providers, consulting firms, etc.). VANETs can provide the required tracking and sensory technologies that can support complex transportation and logistics operations. The need for tracking and sensory technologies can be appreciated in the work by Li and Wang (2015). The researchers developed a scenario comprising of a prototype tracking tool that can facilitate the utilisation of sensor data, which is often unstructured and enormous in nature, to support supply chain decisions. Their research investigated the potential benefits to the chilled food chain management innovation through sensor data driven pricing decisions. Also in recent times wireless sensor networks have been used for container monitoring as a way to overcome the large variety of transformation processes that can introduce desynchronisation between the information stored in the supply chain management system and the real composition of a container (Tran-Dang et al., 2016).

The principle of clustering for VANETs applied to transportation may be suitable for a seaport location where haulage vehicles are allocated to several loading/unloading jobs. In a seaport more than one vessel can be docked and unloaded at the same time, resulting in several simultaneous unloading jobs. Although there may be different scenarios where VANETs for IoT can be deployed, we believe seaports represent a challenging setting where to test the principles of clustering in VANETs to support commercial, non-safety applications for transportation given its multimodal characteristics. There are enough reasons to support the deployment of VANETs in seaports as Chew et al. (2010) acknowledged that since container terminals represent extremely complex systems with highly dynamic interactions between the various handling, transportation and storage units, efficient IT-support and improved logistics control software systems are needed in order to meet the desired performance measures.

Multimodality is a concept that has grown in importance as the pressure mounts for logistics and transportation sectors to become more efficient. Multimodal transportation flow with time efficiency of higher reliability has been recognised as being of critical importance (Hu, 2010). Furthermore, environmental benefits can be achieved by intermodal transport (Lättilä, 2013). The pressure to adopt efficient multimodal operations is probably felt more in those seaport locations in close proximity to urban areas, as several challenges such as increase in competition with other regions, the reduction of costs, space constraints limiting expansion, the optimisation of logistics operations and the reduction of any possible negative impact on the environment among others may dictate their viability for the coming years.

Multimodal activities may be involved in the planning and scheduling of 'loading' and 'unloading' activities that can involve loading/unloading containers, Roll on – Roll off (Ro-Ro), bulk solids, bulk liquids and other types of materials and in the allocation of human resources and equipment such as cranes and trucks. The correct operation of multimodal operations in a seaport requires the deployment of a technological development like VANETs compatible with IoT specially information exchange from critical mission systems at the enterprise level to haulage vehicles in the yard dedicated to load/unload goods. More importantly, it will be possible to reduce congestion (eliminate waiting/idle times) in the yard for haulage vehicles coming to port to deliver/collect goods and reduce burnt fuel that might affect the air quality of the neighboring urban area.

VANETs comprise information and communication technology (ICT) required for the successful operation of data-rich environments characterizing modern seaport locations. Some authors have recognised ICT functions like the nerve system of a multimodal transport chain and brings multiple benefits to organisations by providing real-time visibility, efficient data exchange, and better flexibility to react to unexpected changes during shipment (Harris et al, 2015). The application of ICT in transport logistics is to facilitate activities such as cargo tracking, warehousing, and shipment notice forwarding, in support of product movement in the supply chain (Wong et al., 2009).

3. A conceptual model comprising the use of clusters based on VANETs

In transportation, logistics operations with inter-modal capabilities require organizing companies in order to define navigation groups which might be determined based on the type of materials handled or the time slots given to load/unload material. As part of the logistics operations to be accomplished, there will be need to define a navigation group leader which might be determined by criteria including proximity to the seaport premises or volumes handled. Navigation groups are needed to facilitate the management of logistics multimodal operations.

VANETs are capable of meeting the needs of multimodal logistics. In the case of logistics operations in the seaport facility and its surrounding areas, participating vehicles can be private vehicles, transit vehicles, commercial vehicles and emergency vehicles. RSUs comprise roadway, toll collection, parking management and vehicle check. Haulage vehicles represent mobile nodes carrying OBUs which interact with service applications. The idea of using clusters represents a promising way to support the deployment of VANETs in complex logistics operations such as those found in seaport sites closely located to urban areas. Figure 2 illustrates the principle of clustering operating in a seaport involving unloading operations.

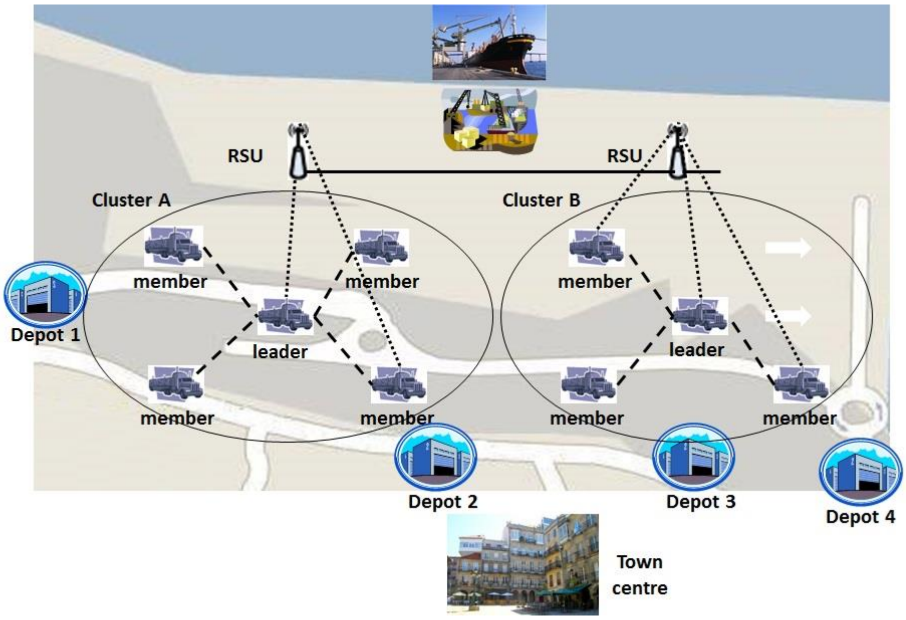

Figure 2. Illustration of the principle of clustering operating in a port location involving unloading operations

The proposed conceptual model for the operation of VANETs in seaport locations is a suitable solution given the geographic constraints facing many of these sites around the world. Seaports like the Port of Vigo – container terminal in Northeastern Spain, the Humber port terminals in Northeast England or the Kwai Tsing container terminal in the Port of Hong Kong cannot expand their sites because of geographic limitations, hence these sites must maximise the use of resources within a limited physical space. The proposed conceptual model relies on a small number of clusters suitable for a limited number of vehicles entering the site at a low maximum vehicle speed. In a geographical location characterized for limited physical space, an increase in the number of vehicles that are allowed into the premises may result in increased traffic, queueing times and delays in loading/unloading cargo.

The principle of clustering is useful in a seaport location as more than one vessel can be docked and unloaded at the same time, resulting in several simultaneous unloading jobs. Hence several haulage vehicles can be allocated to several different jobs. Clustering requires the use of a cluster head -labelled pilot truck leader- to optimize data traffic reaching the centralised servers at the port in charge of tracking and tracing vehicles. By using a cluster configuration, requests from members of the cluster are channelled through the cluster head, eliminating the need for each mobile node to communicate directly to the nodes in the seaport. The use of clustering actually may prevent overwhelming the network with individual requests. Moreover, the proposed logistics clustering solution comprising VANETs to support seaport logistics in close proximity to urban areas seem appropriate especially at a time where according to McFarlane et al. (2016) the flexibility of transport providers is significantly limited by their ability to accurately track orders and where necessary, change the routing and priority of orders.

The efficiency of information exchanged in the cluster is dependent on the use of a leader for each navigation group created, as this facilitates communication to the RSUs. By using a leader for each navigation group, vehicles do not have to constantly communicate to the RSUs as the leader does it on behalf of the group of vehicles. It is expected that company members of the navigation groups belonging to the port logistics cluster will have their vehicles registered. Haulage vehicles belonging to external organisations which are not part of the multimodal operations group based at the seaport site will have to get a temporary register to enter the site and become part of a navigation group when they come into the port and remain registered during the time they are doing activities such as delivering/collecting cargo. As these road haulage vehicles leave the seaport, they deregister and stop becoming part of the navigation group and multimodal operations group.

4. The development of the proposed conceptual cluster based on VANETs

In the view of Liang et al. (2015) in order to evaluate the performance of different architecture approaches, protocols, algorithms, and applications in VANETs, an effective research methodology is required. The researchers identified different models which can be considered the essential basis for setting up methodologies, simulations and field operational testing. VANETs models include Driver and Vehicle, Traffic Flow, Communication and Application. Simulation Methods commonly used include: Traffic Simulators and Network Simulators. This research on VANETs involving clusters fits the description of an application model as described by Liang et al. (2015) as it addresses behavior and quality of cooperative VANETs applications comprising functionality and prioritisation of information.

Operations analysis mapping and network modelling and simulation are tools considered for testing the feasibility of the cluster approach for meeting port and terminal operators' as well as urban requirements for real-time accurate monitoring. The creation of a VANET cluster to support multimodal operations is likely to help facilitate the traffic around the seaport especially in those locations surrounded by urban areas, facing limited space and physical constraints for expanding their sites. In the view of Coronado et al. (2012) a logistics network characterised for ubiquitous network access, track and trace operation is possible through periodic information updates of the haulage vehicle at any given location within the network coverage area. The architecture considered for testing the cluster model can be superimposed on the layout of a seaport terminal as depicted in figure 3.

The use of clustering in the deployment of wireless vehicle networks can have a significant impact on the performance of transportation and logistics operations. Clustering can be seen as a suitable solution given the characteristics of operation of haulage vehicles. Important characteristics include: *a)* real time track and trace capabilities of vehicles and their loads in order to respond to customer enquiries, *b)* register of accurate haulage traffic entering and moving within the port premises, *c)* elimination of costly mistakes associated to unloading material in wrong sites which can result in delays to vessel departures, *d)* accurate billing to customers. Some customers may demand very close monitoring of products, real-time updates and accuracy on drivers and operators payments, and also to comply with road legislation enforced outside seaport premises.

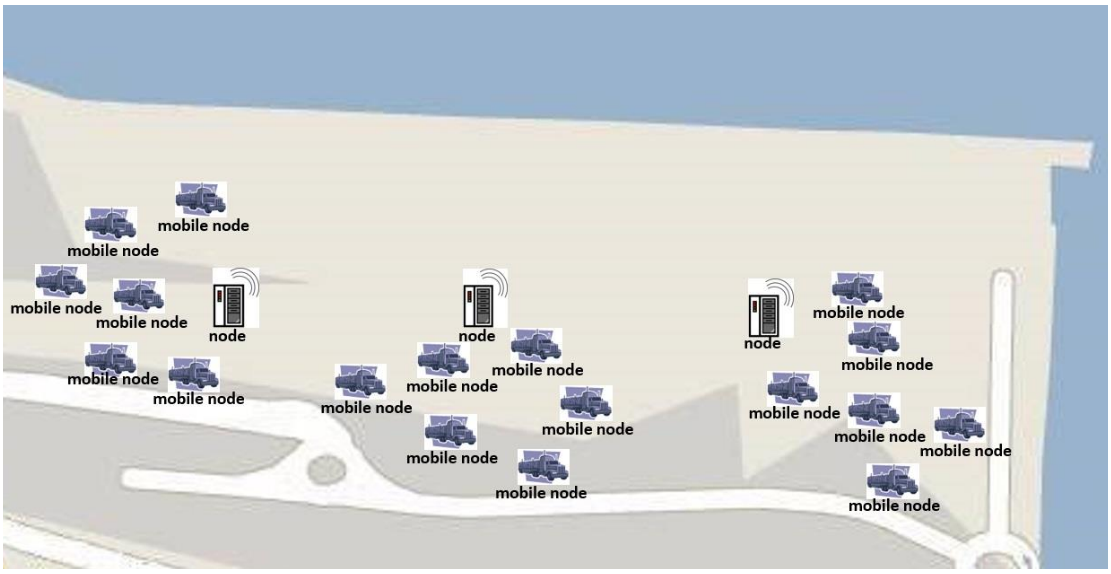

Figure 3. Diagram showing the proposed clustering model superimposed on the layout of a seaport terminal

For the proposed cluster solution we looked at the characteristics of the Port of Vigo container terminal in north eastern Spain and the area covered used in this research is approximately 3 km long by 1.5 km wide. This is a location next to an urban area, with limited available space and with no possibilities to grow the area of the site. As the case of study is a seaport, the case does include the terminals where vessels dock in the berth to get discharged, the warehouses/depots where trucks move the material from the vessels. The VANET infrastructure required to support communications in the confinement of the seaport terminal can be planned to avoid obstructions such as a tall tower of stacked containers. In this scenario an RSU may be installed at the top of a tall lamp post at 50 metres above ground level.

The principle for modelling the proposed conceptual cluster is based on the application of the node location and link connectivity design problem which was adopted from the work developed by Pioro and Mehdi (2004). Here IPV6 traffic capabilities of wireless vehicular networks like DSRC involving clusters was considered in the simulations carried out in this work. WLAN access points connected through an IP cloud comprised the proposed network with WLAN Ethernet type used to set the routers in the configuration (mobile nodes are of the wireless LAN workstation type).

For the simulation of the proposed conceptual VANETs cluster we used OPNET's® Wireless Modelling suite (OPNET, 2015) and the Application Characterisation Environment (ACE®), tools considered for the analysis of performance and data traffic. OPNET's® Wireless Modelling suite support IPV6 traffic capabilities of wireless vehicular networks like DSRC involving clusters was considered in the simulations carried out in this work. The intention of using a module tool such as ACE® is to analyze the performance of a whole communication process by simulating an application tier flow within the deployed network topology.

The clustering model was built with OPNET's® wireless modelling suite. Three clusters were included in the simulation model with each of them comprising of a leader plus five 'member' haulage vehicles. The limited geographic area hosting the port facilities was the main reason why only three clusters were included. If more clusters and vehicles were included given the limited geographic area there would be increased traffic and queueing times. Maximum speed on site was 30 mph. In the model the leader of each cluster exchanges an on-demand service request message with the wireless server which hosts an application service that can feature various functions for example, interrogating a vehicle for real-time track and trace. In the model, the leader of each cluster has the role of gateway and the maximum separation of the mobile node to the antenna is 350 m. The trajectories for the haulage vehicles were defined keeping close proximity to the wireless servers. The wireless servers used in the model are WLAN wireless Sun Ultra servers @ 300 MHz.

Operations analysis mapping and network modelling and simulation are tools considered for testing the feasibility of the cluster approach for meeting port and terminal operators' as well as urban requirements for real-time accurate monitoring. The creation of a VANET cluster to support multimodal operations is likely to help facilitate the traffic around the seaport especially in those locations surrounded by urban areas, facing limited space and physical constraints for expanding their sites. As road haulage still represents the main mode of moving goods in a seaport, the availability of services over wireless vehicle networks using the clustering principle has the potential to make transportation more efficient by enabling better track and trace of cargo, better fleet control, better route planning, close monitoring of emissions and truck usage among others. This becomes even more important when a seaport facility is in close proximity to an urban area.

5. Creating an on-demand service request for clustering solution

To test the feasibility of the clustering approach for wireless vehicle networks, an on-demand service request exchange message V2I protocol application was assembled using the OPNET® Application Characterisation Environment (ACE®) whiteboard tool. The purpose of the assembled on-demand service request exchange message is to illustrate the potential of the wireless configuration for handling increased volumes of data traffic with minimum degradation levels -critical to maintain high levels of traceability and tracking-. The proposed sequence comprises of six stages:

- The end user sends a request to the leader of the cluster,
- The leader of the cluster acknowledges the request to the end user,
- Then the end user sends a message to the leader and
- The leader forwards the message to the server.
- The response from the server is sent to the leader
- From the leader the response is sent to the end user.

A graphical representation of the stages comprising the service used in the simulation is depicted in figure 4.

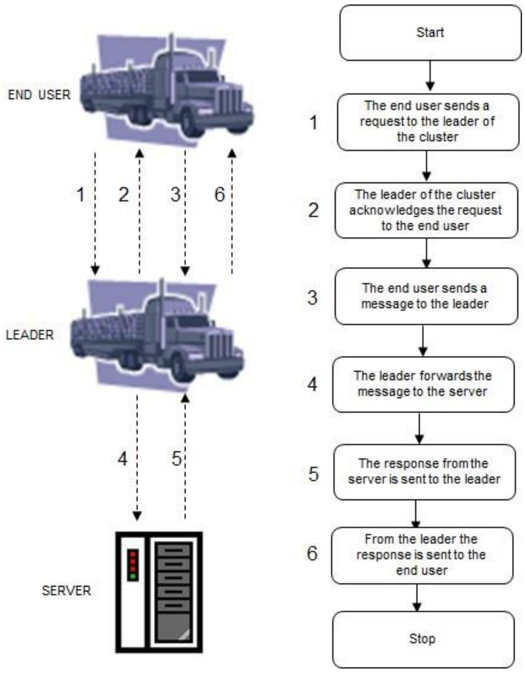

Figure 4. Sequence used in clustering for on-demand service request exchange message

The diagram in figure 4 can be represented using the ACE® whiteboard which is a robust tool suitable to evaluate the behavior of different tier processes within a simulation networking environment. The assembled on-demand service request exchange message lasts 0.460 seconds. Typical messages exchanged may include data associated to date, time, operation, contract, destination, operator, cluster, haulage id, etc. with a packet length of about 1024 bytes. Figure 5 shows the ACE® whiteboard diagram representing the service used in the simulations.

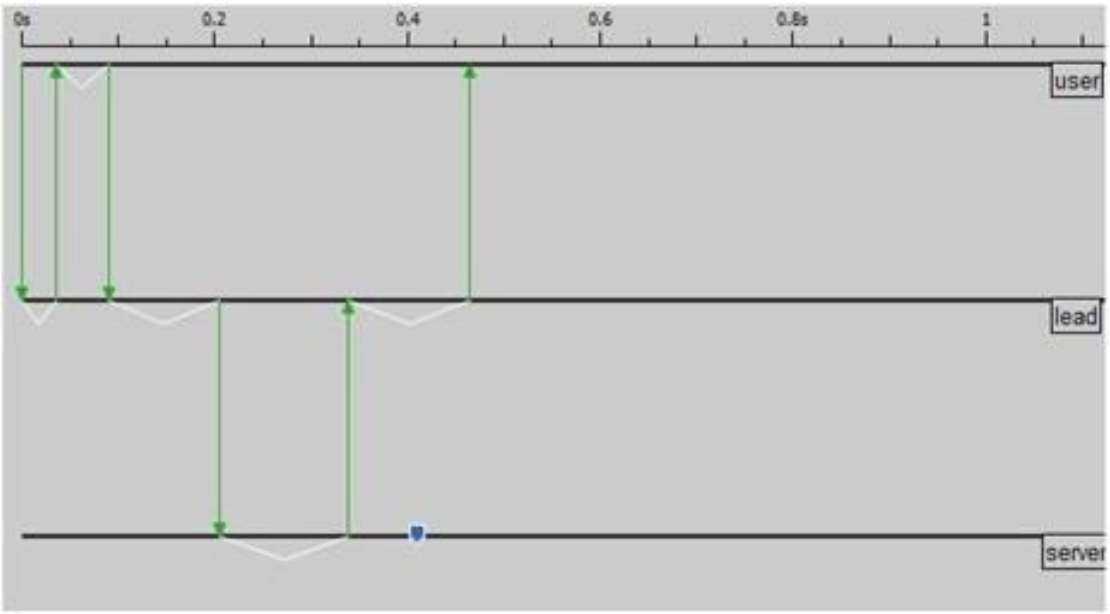

Figure 5. Graphic representation of the ACE® whiteboard sequence used in clustering for on-demand service request exchange message

In figure 5 the exchange of messages between vehicles is represented as an ACE® tier process from the origin to the destination and which is deployed in the network topology as defined in the OPNET® Wireless Modeller Suite project editor.

6. Results and discussion from modelling the cluster solution

In figure 6 it is possible to appreciate the outputs of the simulation in terms of task response time achieved for cluster 1, cluster 2 and cluster 3.

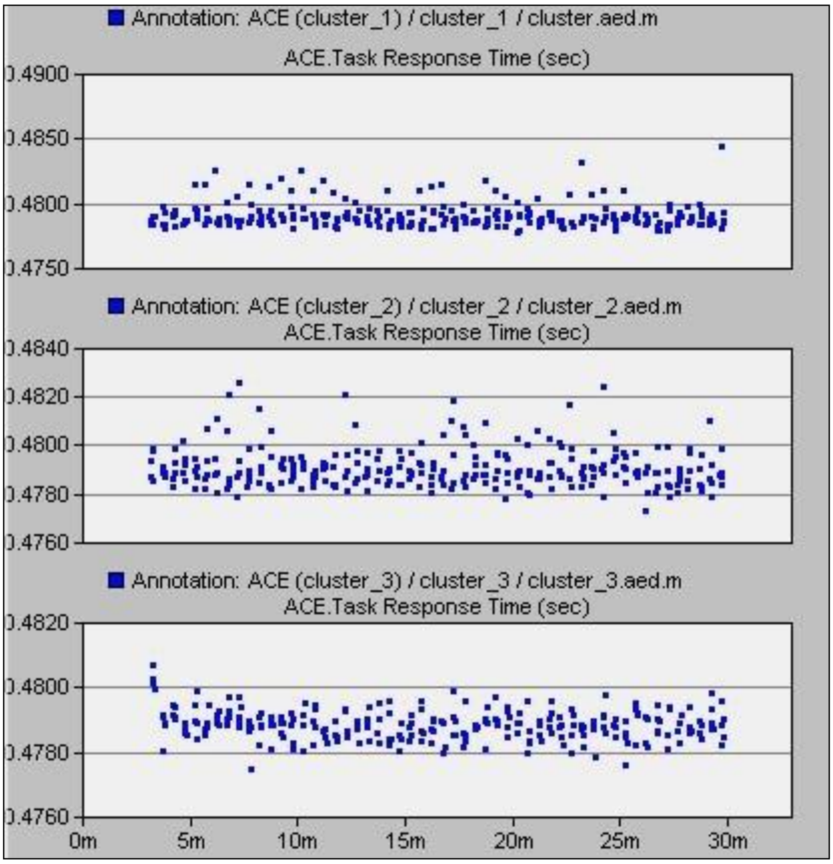

Figure 6. Results of the simulation for the three clusters using OPNET®

The task response time is the round trip time it takes for a message originated in the vehicle destined to the application server. In cluster 1 the task response time registered a value of 0.480 seconds, a delay of 20 milliseconds to the original value of 0.460 seconds of the demand service request exchange message. Cluster 2 reported a task response time of 0.478 seconds with a maximum delay of 18 milliseconds. Cluster 3 reported a task response time of 0.479 s. The maximum delay experience in cluster 3 was of 19 milliseconds. The total simulation time for the trials was 30 min. Longer periods of simulations did not reveal an increase in delays for the three clusters used. Table 2 summarises the results of the simulation.

Cluster	original message value seconds	task response time (round trip) seconds	delays milliseconds

1	0.460	0.480	20
2	0.460	0.478	18
3	0.460	0.479	19

Table 2. Results for clusters simulation

The results of the trials show that the proposed VANET-based cluster architecture operating in a port facility in close proximity to an urban area is capable of achieving negligible levels of delays which by no means compromise the need for continuous track and trace monitoring of haulage operations in the seaport terminal. From the results obtained during the simulations, it was observed that the response time values for process request-response between a vehicle and the service domain are acceptable. During the trials the speed of the trucks was fixed to 30 mph. Haulage trucks are not allowed to drive faster than 30 mph due to road safety regulations within the premises of the port terminal.

7. Conclusions

VANETs represent a key technological development that can play a key role in enabling vehicle connectivity in an IoT environment. The development of autonomous vehicles, the continuous growth of V2V and V2I communications and the availability of services over wireless vehicle networks have the potential to make transportation and in general supply chains more efficient by enabling better track and trace of cargo, better fleet control, better route planning, close monitoring of emissions and truck usage among others.

IoT is a paradigm that is supported by technological developments like VANETs. In this paper we presented an analysis of reliable data transfer for VANETs using the principles of network clusters in support of the operation of multimodal logistics operations in a seaport facility. The proposed network was designed and dimensioned to reduce queuing delays and to enhance communications between haulage vehicles and servers hosting applications that can be used for track and trace purposes among many others. The configuration used was perfectly adequate to run the simulation trials using OPNET® as it was possible to ensure a minimum of queuing delays.

This research demonstrated that clustering principles can be adopted to provide coverage for a geographical area running non-safety VANETs applications. The case presented in this paper using three clusters shows that the deployment of VANETs as a portside network can provide robust and secure access to services where reliable delivery of information between vehicles and providers must be guaranteed. This work demonstrated the suitability of clustering to improve the performance of VANETs to support data communications requirements in port logistics.

VANETs may look inconvenient in some scenarios as they are heavily dependent on installation of infrastructure for radio signal communication. Hence, the use of GPS/GSM may look as a more attractive option for the purposes of transmitting voice and data. Moreover, GPS/GSM can be used for probe data but the technology is unusable for V2V safety, therefore unable to meet future requirements and legislation about V2V and V2I communications. The study is confined to the conditions facing seaport terminals in close proximity to urban areas characterised for limited space and restrictions for area expansion.

The results presented in this paper are important as these demonstrate that VANETs can be used as the basis for the development of commercial road side services which can be accessible, reliable and secure and critical for the operation of transportation systems. The use of clustering is relevant in the deployment of next generation wireless networks such as DSRC-based VANETs in the context of IoT as road haulage still represents the main mode of moving goods.

References

Alsuhli, G.H., Khattab, A. & Fahmy, Y.A. (2019). Double-Head Clustering for Resilient VANETs. *Wireless Communications and Mobile Computing*. Volume 2019, https://doi.org/10.1155/2019/2917238

Anwer, M.S. & Guy, C. (2014) A Survey of VANET Technologies. *Journal of Emerging Trends in Computing and Information Sciences* 5(9), 661-671.

Ashton, K. (2009) Internet of things. RFID Journal – June issue [Online]. Available: http://www.rfidjournal.com/articles/view?4986 Ashton, K., 2009. Internet of things. RFID Journal – June issue [Online]. Available: http://www.rfidjournal.com/articles/view?4986

Bhat, W.A & Quadri, S.M.K. (2015) Big Data promises value: is hardware technology taken onboard? *Industrial Management & Data Systems* 115(9), 1577 – 1595.

Blum, J.J., Eskandarian, A. & Hoffman, L.J. (2003) Mobility Management in IVC Networks, Proceedings of the Intelligent Vehicles Symposium, 150-155.

Booz & Co., (2011) Designing the Transcendent Web. The Power of Web 3.0, retrieved from http://www.strategyand.pwc.com/media/uploads/Strategyand-Designing-Transcendent-Web-3.0.pdf.

Chew, E.P.,·Günther, H-O., Kim, K.H. & Kopfer, H. (2010) IT-based planning and control of seaport container terminals and freight transportation systems. *OR Spectrum* 32, 423–426.

Coronado Mondragon, A.E., Coronado Mondragon, E.S., Coronado Mondragon, C.E. & Mung'au, F. (2012) Estimating the performance of intelligent transport systems wireless services for multimodal logistics applications. *Expert Systems with Applications* 39, 3939–3949.

DhilipKumar, V., Kandar, D. & Sarkar, C.K. (2013) Enhancement of inter-vehicular communication to optimize the performance of 3G/4G-VANET, Proceedings of the 2013 International Conference on Optical Imaging Sensor and Security ICOSS, 2-3 July, 1-5.

Faezipour, M., Norani, M., Saeed, A. & Addepalli, S. (2012) Progress and Challenges in Intelligent Vehicle Area Networks. *Communications of the ACM*, 55(2), 90-100.

Financial Times, (2017) Industrial Futures. FT Big Read. Digital Business by Ed Crooks. Wednesday 28th June, 9.

Glass, D.A., Marlow, P.B. & Nair, R. (2010) The use and legal effects of carriage documents in international multimodal transport. *International Journal of Shipping and Transport* Logistics 2(4), 347-363.

Gubbi, J., Buyya, R., Marusic, S. & Palaniswami, M. (2013) Internet of Things (IoT): A vision, architectural elements, and future directions, *Future Generation Computer Systems*, 29, 1645-1660.

Harris, I., Wang, Y. & Wang, H. (2015) ICT in multimodal transport and technology trends: Unleashing potential for the future. *International Journal of Production Economics* 159, 88-103.

Hu, Z.H. (2010) A container multimodal transportation scheduling approach based on immune affinity model for emergency relief. Expert Systems with Applications, 38(3), 2632-2639.

Jaoua, A., Gamache, M. & Riopel, D. (2012) Specification of an intelligent simulation-based real time control architecture: Application to truck control system. *Computers in Industry* 63, 882–894.

Kumar, V.V. & Chan, F.T.S. (2011) A superiority search and optimisation algorithm to solve RFID and an environmental factor embedded closed loop logistics model, *International Journal of Production Research*, 49(16), 4807-4831.

Lättilä, L., Henttu, V. & Hilmola. O-P. (2013) Hinterland operations of sea ports do matter: Dry port usage effects on transportation costs and CO_2 emissions, *Transportation Research Part E: Logistics and Transportation Review*, 55, 23-42.

Liang, W., Li, Z., Zhang, H., Wang, S. & Bie, R. (2015) Vehicular Ad Hoc Networks: Architectures, Research Issues, Methodologies, Challenges, and Trends, International Journal of Distributed Sensor Networks, Article ID 745303, 11 pages. http://dx.doi.org/10.1155/2015/745303.

Li D & Wang X (2015) Dynamic supply chain decisions based on networked sensor data: an application in the chilled food retail chain. *International Journal of Production Research*. DOI: 10.1080/00207543.2015.1047976, 1-15.

Li, S., Xu, L.D. & Zhao S. (2015) The internet of things: a survey. Information Systems Frontiers, 17, 243-259.

Lin, C.R. & Gerla, M. (1997) Adaptive Clustering for Mobile Wireless Networks, IEEE Journal of Selected Areas in Communication, 15(7), 1265-1275.

Man, T.L.L. (2019) Design of intelligent transportation systems for accessible transportation services, International Journal of Internet Manufacturing and Services, 6(3), 225-244.

Marousek, J., Andrews, S. & Dorfman, M. (2008) A comparison of communications systems for VII. In Proceedings of the 15th world congress on intelligent transportation systems, November 16–20, New York, USA.

Mishra, D., Gunasekaran, A., Childe, S.J., Papadopoulos, T., Dubey, R. & Wamba, S. (2016) Vision, applications and future challenges of Internet of Things: A bibliometric study of the recent literature. *Industrial Management & Data Systems*, 116(7), 1331 – 1355.

Munim, Z.H., (2019) Autonomous ships: a review, innovative applications and future maritime business models, Supply Chain Forum: An International Journal, https://doi.org/10.1080/16258312.2019.1631714

McFarlane D., Giannikas V. & Lu W. (2016) Intelligent logistics: Involving the customer. *Computers in Industry*, 81, 105-115.

NHTSA, (2015) DOT HS 809 859 nhtsa. Vehicle safety communications project task 3 final report. Identify intelligent vehicle safety applications enabled by DSRC, March.

OPNET® Technologies (2015) http://www.opnet.com/

Pioro, M & Medhi D. (2004) IP routing flows and capacity design in communications and computer networks. Morgan Kaufmann, pp. 213, 221.

Pollaris, H.,·Braekers, K.,·Caris, A.,·Janssens, G.K. &·Limbourg, S. (2015) Vehicle routing problems with loading constraints: state-of-the-art and future directions. *OR Spectrum*, 37, 297–330.

Postcapes, 2018. IoT Standards and Protocols. https://www.postscapes.com/internet-of-things-protocols/ accessed on: 11/04/2020.

Regin, R. & Menakadevi, T. (2019). Dynamic Clustering Mechanism to Avoid Congestion Control in Vehicular Ad Hoc Networks Based on Node Density. Wireless Personal Communications, 107(4), 1911-1931.

Ribeiro, C. (2005) Bringing Wireless Access to the Automobile: A Comparison of Wi-Fi, WiMAX, MBWA, and 3G. 21st Computer Science Seminar, Polytechnic School of the University of Sao Paulo. http://www.pcs.usp.br/~pcs5712/ribeiro.pdf.

Sampigethaya, K., Huang, L., Li, M., Poovendran, R., Matsuura K. & Sezaki, K. (2005) CARAVAN: Providing location privacy for VANET, Proc. of Embedded Security in Cars (ESCAR).

Santos, R.A., Edwards, R.M. & Edwards, A., (2004) Cluster-Based Location Routing Algorithm for Inter-Vehicle Communication, Proceedings of Vehicular Technology Conference, 914-918.

Sharif, A.; Li, J.P., Saleem, M.A., Saba, T. and Kumar, R., 2020. Hybrid Clustering Scheme for Data Delivery Using Internet of Things Enabled Vehicular Ad Hoc Networks in Smart City Traffic Congestion. Journal of Internet Technology, 21(1), 149-157.

Siror, J.K., Sheng, H. & Wang, D. (2011) RFID based model for an intelligent port. *Computers in Industry*, 62, 795–810.

Tian, D., Wang, Y., He, L. & Zhang, X. (2012) A Trusted Multi-hop Broadcasting Protocol for Vehicular Ad Hoc Networks. Proceedings 2012 International Conference on Connected Vehicles and Expo. IEEE Computer Society. 18-22. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6519536.

Tibaut, A., Kaucic, B. & Rebolj, D. (2012) A standardised approach for sustainable interoperability between public transport passenger information systems. *Computers in Industry* 63, 788–798.

Tran-Dang, H., Kromenacker, N. & Charpentier, P. (2016) Containers monitoring through the Physical Internet: a spatial 3D model based on wireless sensor networks. *International Journal of Production Research*, DOI: 10.1080/00207543.2016.1206220, 1-14.

Van Kranenburg, R., Anzelmo, E., Bassi, A., Caprio, D., Dodson, S. & Ratto, M. (2011) The internet of things, in Proceedings of 1st Berlin Symposium Internet Society, Berlin, Germany, pp. 25–27.

Wong, C.W.Y., Lai, K.H. & Ngai, E.W.T. (2009) The role of supplier operational adaptation on the performance of IT-enabled transport logistics under environmental uncertainty. *International Journal of Production Economics* 122, 47–55.

Wu, S.H., Chen, C.M. & Chen, M.S. (2010) An Asymmetric and Asynchronous Energy Conservation Protocol for Vehicle Networks. *IEEE Transactions on Mobile Computing* 19(1), 98-111.

Xu, D.L., He, W., Wu, S. (2014) Internet of Things in Industries: A Survey", IEEE transactions on industrial informatics, 10(4), 2233-2243.

Zhao, X., Kivinen, J., Vainikainen P. & Skog, K. (2002) Propagation characteristics for wideband outdoor mobile communications at 5.3 GHz. *IEEE Journal on Selected Areas in Communications* 20, 507–514.

Zhang, L. & Jin, B. (2013) Dubhe: A Reliable & Low-Latency Data Dissemination Mechanism for VANETs. *International Journal of Distributed Sensor Networks*, Article ID 581821, 16 pages. http://dx.doi.org/10.1155/2013/581821.

Figures

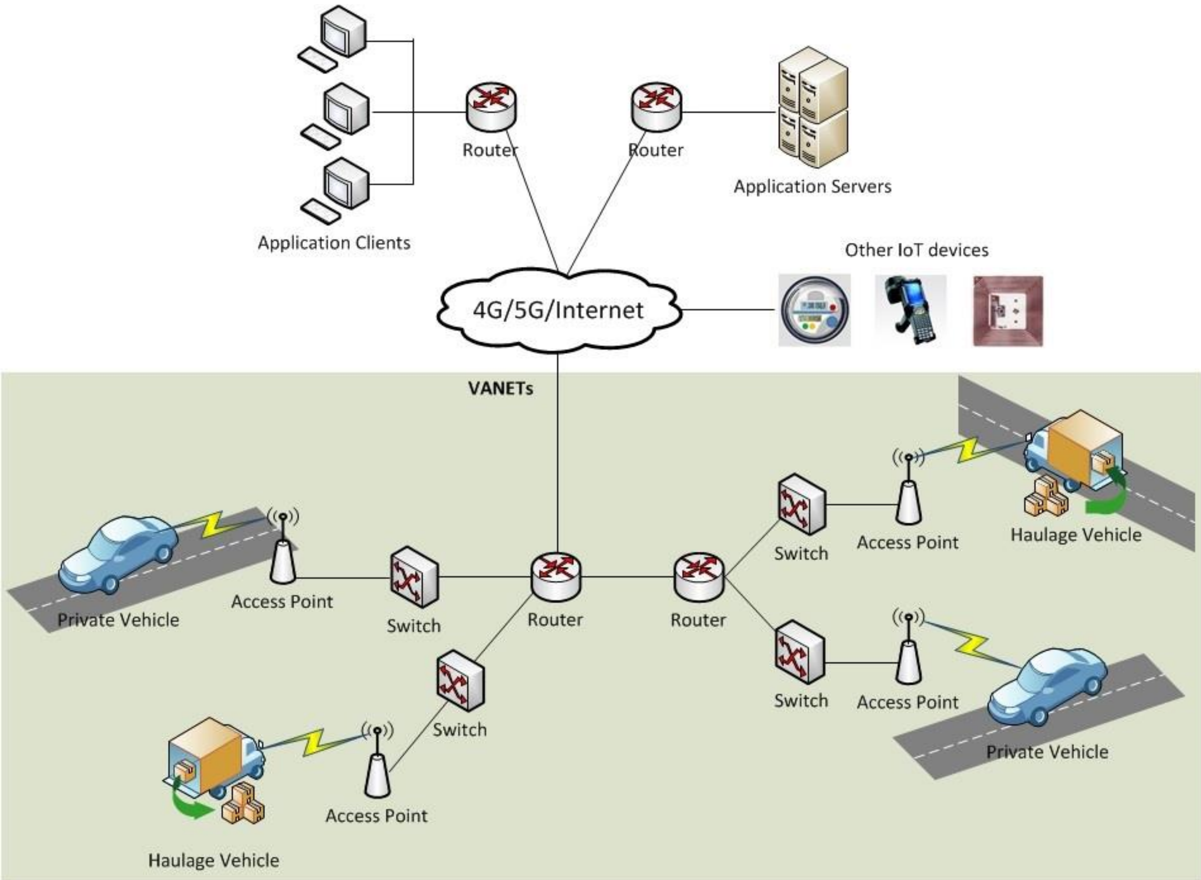

Figure 1. Architecture of a VANET platform in the context of IoT

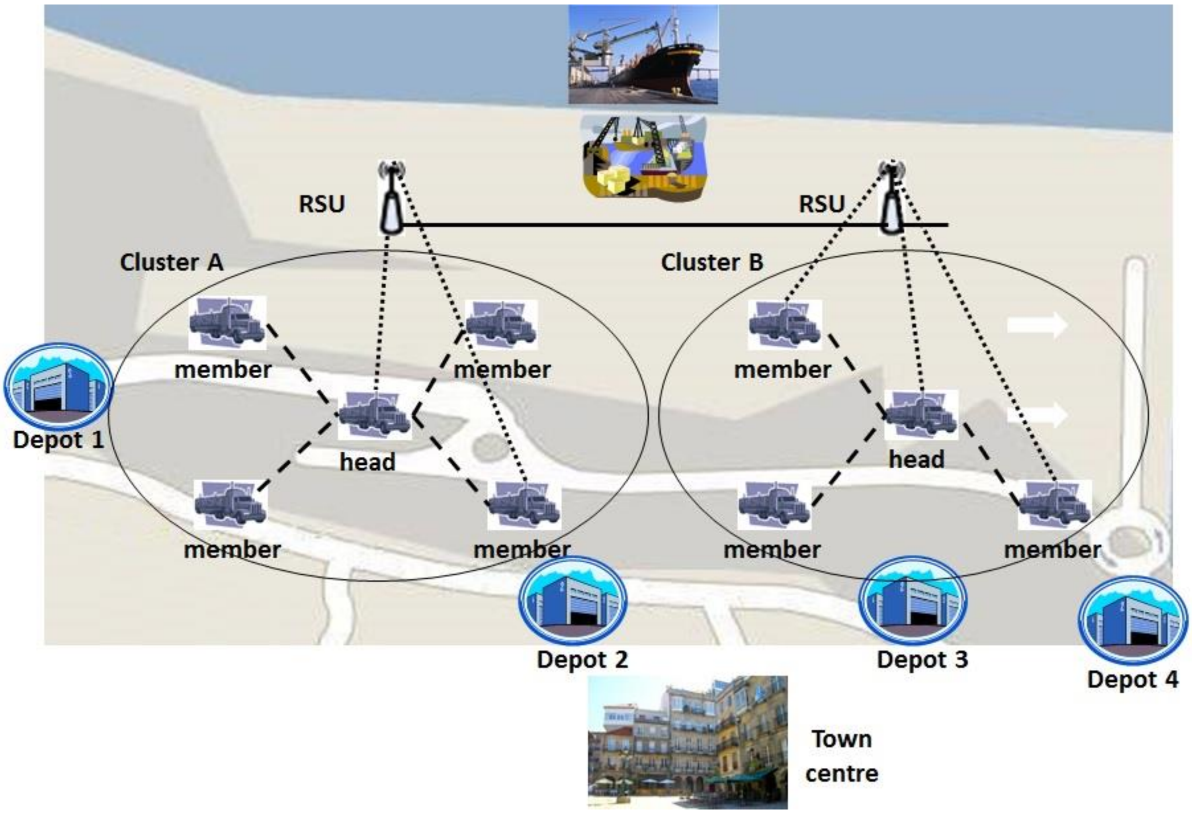

Figure 2. Illustration of the principle of clustering operating in a port location involving unloading operations

Figures

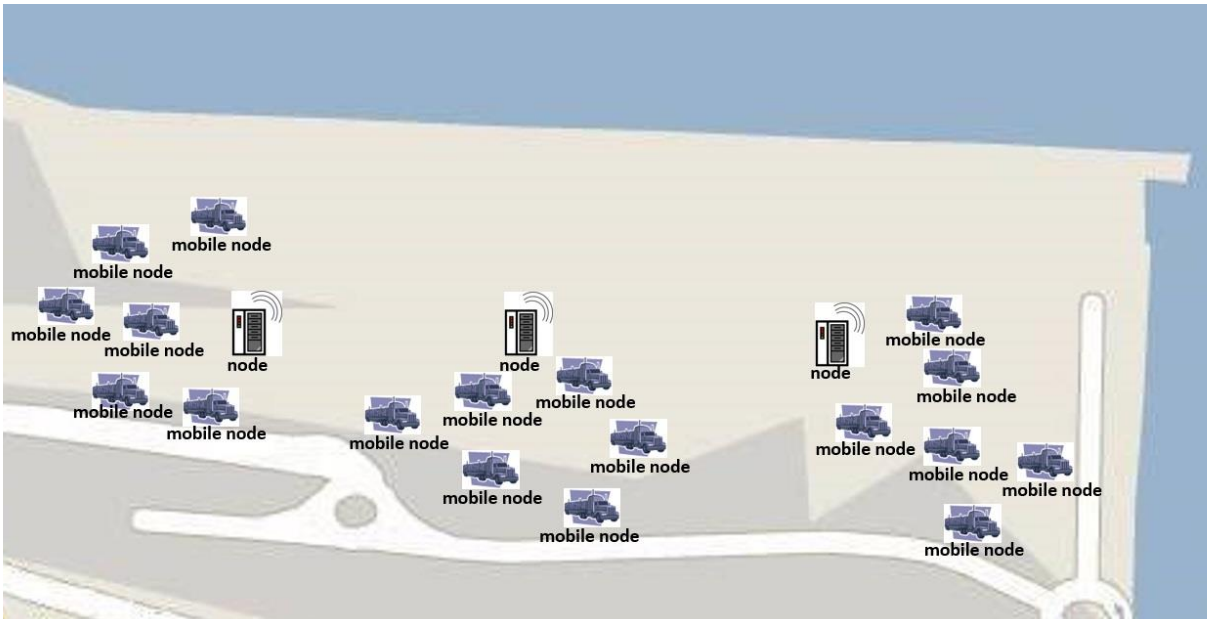

Figure 3. Diagram showing the proposed clustering model superimposed on the layout of a seaport terminal

Figures

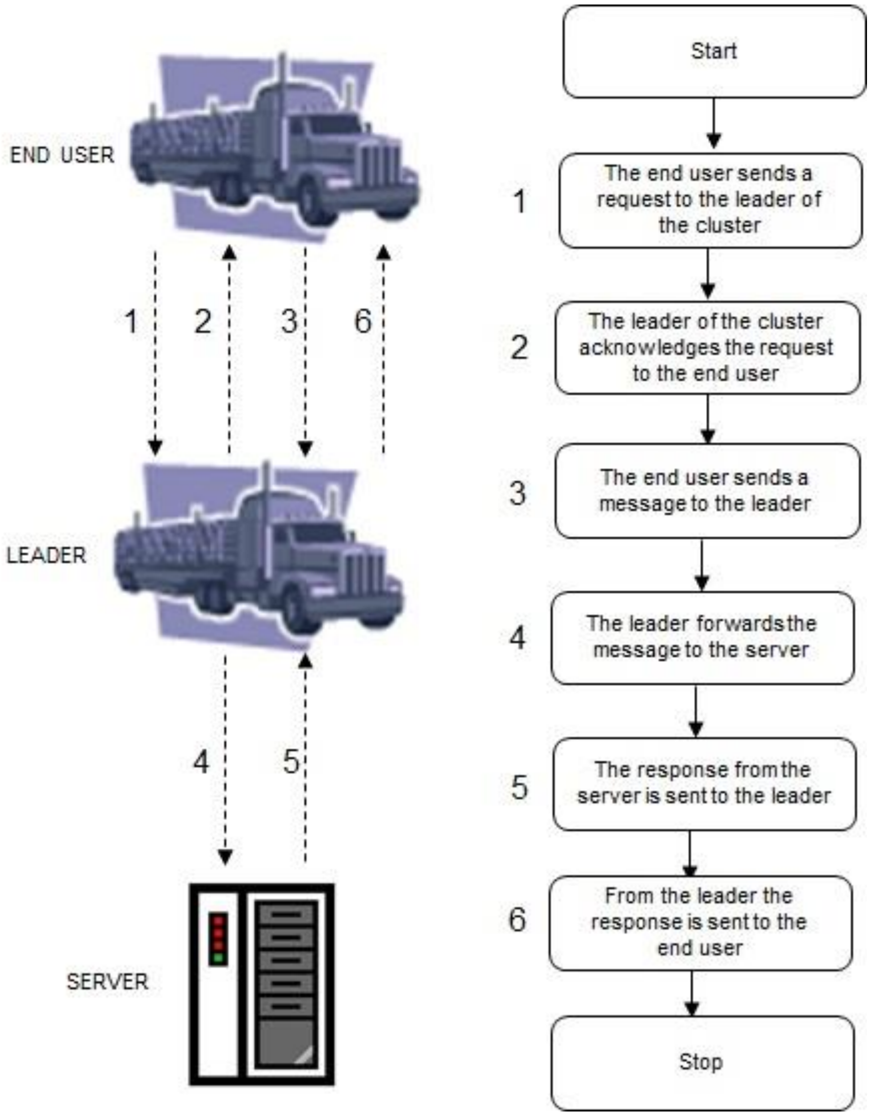

Figure 4. Sequence used in clustering for on-demand service request exchange message

Figures

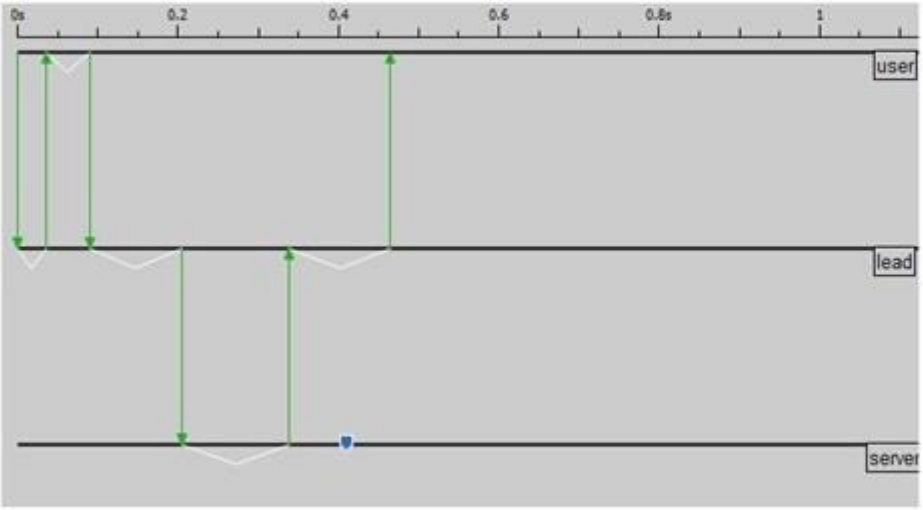

Figure 5. Graphic representation of the ACE® whiteboard sequence used in clustering for on-demand service request exchange message

Figures

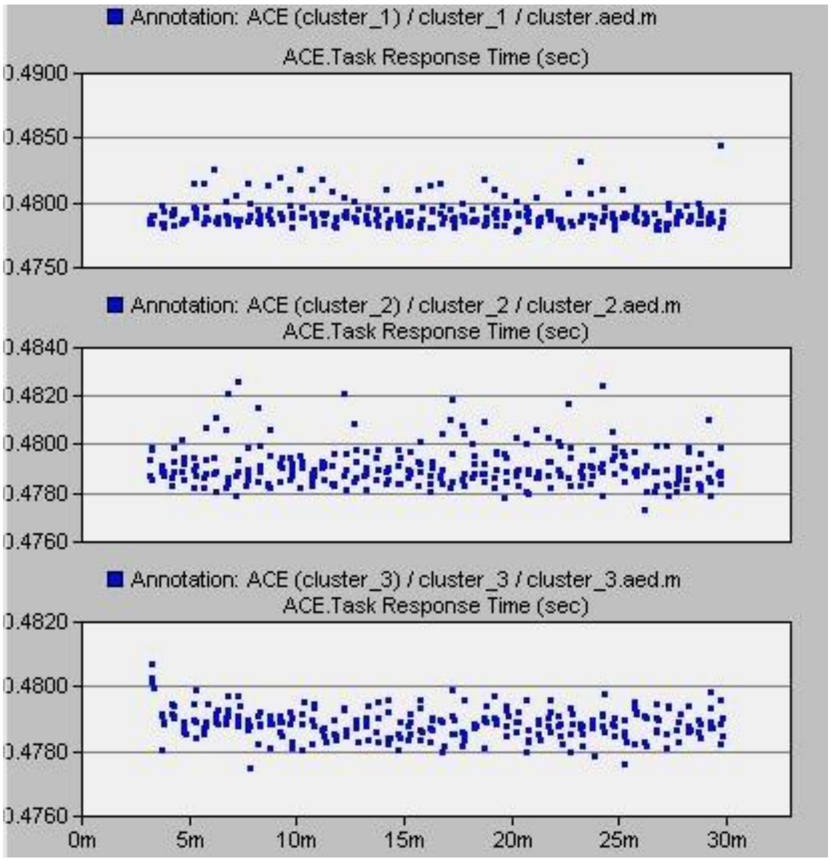

Figure 6. Results of the simulation for the three clusters using OPNET®

Tables

Purpose of research involving the use of clustering in VANETs	Source
Better network scalability	Lin et al. (1997)
Efficient mobility management	Blum et al. (2003)
Localisation of node dynamics	Santos et al. (2004)
Navigation groups for cooperative driving and traffic monitoring	Sampigethaya et al. (2005)
Distributed and centralised networks involving two scenarios for vehicle networks	Wu et al. (2010)
Delay model and an improved greedy broadcast algorithm embedded with a coverage elimination rule in order to reliably and quickly disseminate data	Zhang and Jin (2013)
Vehicle routing problems loading constraints that include the minimisation of the number of vehicles, total cost, total route length and total time	Pollaris et al. (2015)
Effective VANET clustering algorithm to tackle scalability and the highly dynamic topology of VANETs in addition to benefiting routing, security and media access management	Alsuhli et al. (2019)
A density based dynamic clustering devices algorithm to determine node density of the precise location in a lane and deliver a practical solution to congestion	Regin and Menakadevi (2019)
A cluster based IoT-enabled routing technique in static and dynamic transportation to deal with scalability and VANETs topology.	Sharif et al. (2020)

Table 1. Summary of research involving clustering theory in VANETs

Tables

Cluster	original message value seconds	task response time (round trip) seconds	delays milliseconds
1	0.460	0.480	20
2	0.460	0.478	18
3	0.460	0.479	19

Table 2. Results for clusters simulation