State-of-the-art IoV trust management A meta-synthesis systematic literature review (SLR)

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In the near future, the Internet of Vehicles (IoV) is foreseen to become an inviolable part of smart cities. The integration of vehicular ad hoc networks (VANETs) into the IoV is being driven by the advent of the Internet of Things (IoT) and high-speed communication. However, both the technological and non-technical elements of IoV need to be standardized prior to deployment on the road. This study focuses on trust management (TM) in the IoV/VANETs/ITS (intelligent transport system). Trust has always been important in vehicular networks to ensure safety. A variety of techniques for TM and evaluation have been proposed over the years, yet few comprehensive studies that lay the foundation for the development of a “standard” for TM in IoV have been reported. The motivation behind this study is to examine all the trust models available for vehicular networks to bring together all the techniques from previous studies in this review. The study was carried out using a systematic method in which 31 papers out of 256 research publications were screened. An in-depth analysis of all the trust models was conducted and the strengths and weaknesses of each are highlighted. Considering that solutions based on AI are necessary to meet the requirements of a smart city, our second objective is to analyze the implications of incorporating an AI method based on “context awareness” in a vehicular network. It is evident from mobile ad hoc networks (MANETs) that there is potential for context awareness in ad hoc networks. The findings are expected to contribute significantly to the future formulation of IoVITS standards. In addition, gray areas and open questions for new research dimensions are highlighted.
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A Meta-Synthesis Systematic Literature Review (SLR)

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Abstract

In the near future, the Internet of Vehicles (IoV) is foreseen to become an inviolable part of smart cities. The integration of vehicular ad hoc networks (VANETs) into the IoV is being driven by the advent of the Internet of Things (IoT) and high-speed communication. However, both the technological and non-technical elements of IoV need to be standardized prior to deployment on the road. This study focuses on trust management (TM) in the IoV/VANETs/ITS (intelligent transport system). Trust has always been important in vehicular networks to ensure safety. A variety of techniques for TM and evaluation have been proposed over the years, yet few comprehensive studies that lay the foundation for the development of a “standard” for TM in IoV have been reported. The motivation behind this study is to examine all the trust models available for vehicular networks to bring together all the techniques from previous studies in this review. The study was carried out using a systematic method in which 31 papers out of 256 research publications were screened. An in-depth analysis of all the trust models was conducted and the strengths and weaknesses of each are highlighted. Considering that solutions based on AI are necessary to meet the requirements of a smart city, our second objective is to analyze the implications of incorporating an artificial intelligence (AI) method based on “context awareness” in a vehicular network. It is evident from mobile ad hoc networks (MANETs) that there is potential for context awareness in ad hoc networks. The findings are expected to contribute significantly to the future formulation of IoVITS standards. In addition, gray areas and open questions for new research dimensions are highlighted.

Introduction

After the rise of the Internet of Things (IoT), several new technologies have merged to form vehicular ad hoc networks (VANETs), which have evolved significantly over the last decade. The IoT has attracted researchers' attention in that it enables the unification of VANETs with the Internet (Alam et al. 2015; Hamid et al. 2019; Xie et al. 2017). The IoV and social Internet of Vehicles (SIoV) have set in motion a paradigm shift in vehicle technology and innovation (Contreras-Castillo et al. 2018; Jabri et al. 2019; Zia et al. 2020). An overview of the main components of the IoV, which is presented in Figure 1, includes vehicles with an on-board unit (OBU), a roadside unit (RSU), and cloud connectivity. VANETs and ITSs are looking forward to the implementation of the IoV (Alam et al. 2015) as an essential part of smart cities as a future vision of metropolitan areas (Contreras-Castillo et al. 2018; Fangchun et al. 2014). Vehicle manufacturers and smart city planners alike are looking forward to equipping their vehicles with smarter technology. Currently, implementation issues such as safety, policy, infrastructure standards, ethics, and specifications still exist, although the next wave of technology aims to implement vehicular networks either partially or fully.

The wireless nature of vehicular networks increases their vulnerability to threats (Alzamzami & Mahgoub 2020; Hasrouny et al. 2017). Malicious vehicles could divert traffic according to an organized strategy that may lead to disaster. A malicious activity would lead to traffic congestion and accidents, resulting in a possible risk to human life. The Internet connectivity to the
vehicular network has increased the attack surface. The flexibility of vehicular networks needs to be such that they are able to accommodate vehicles that join and leave the network at any point in time (Patel & Jhaveri 2015). These networks have no geographical limits because of their mobile characteristics. In this situation, vehicle-to-vehicle (V2V) communication is very significant. The availability of a centralized network is a common problem in VANETs, which means that vehicles may come under an unsupervised network at times. The disadvantage of a centralized network is the well-known single point of failure (SPoF) problem, where only a single point of disruption could lead to network unavailability. Previously (Fangchun et al. 2014), a broad overview of the IoV and related future challenges, such as communication, security, and dynamism, was presented. Another study discussed the basic visionary idea of the IoV (Mbelli & Dwolatzky 2016), including potential benefits in coming years, and security was also considered as being an important concern for the future of the IoV. The development of the IoV greatly depends on the availability of intelligent systems for which there currently is a great need (Fangchun et al. 2014). VANETs present multidimensional security problems, and make security one of the basic challenges for ad hoc networks. The available trust evaluation and management solutions for VANETs / IoV need to be improved (Qiu et al. 2016; Sumithra & Vadivel 2018; Yao et al. 2017).

Security, privacy, standards, and many other challenges would have to be overcome before a full-fledged vehicular network could be implemented (Lin et al. 2008). Vehicular networks possess unique characteristics in addition to those of many other types of networks, in that they require their own standards and protocols to manage the network. To overcome the problem of trust among the nodes in a vehicular network, researchers have proposed many models for trust evaluation in VANETs. Considering the security of a vehicular network, trust is one of the most important challenges (Hasrouny et al. 2017; Saini et al. 2015; Yao et al. 2017). Messages received by a node, such as information about accidents, traffic congestion, construction work in progress, natural disasters, and others, require the integrity of the information to be verified before action is taken. Vehicles with malicious intentions can divert traffic along specific routes. Many different techniques and methods have been adopted as approaches for trust evaluation over the years (Yao et al. 2017).

Over the years, several models for “vehicular network TM” have been proposed, and many researchers continue to work on trust models. Different techniques are being used to achieve the highest level of security using trust. As trust is a qualitative property, it is difficult to standardize. When the next generation of vehicular networks is implemented in the future, standardized TM would be necessary.

The purpose of our review is to conduct an in-depth exploration of the current models that have been presented to ensure that trust exists among the nodes of vehicular networks. Second, we aim to identify the strengths and weaknesses of existing models. Our final objective is to explore the potential implementation of context awareness in vehicular networks. The vehicle network is a dynamically changing network thus requires dynamic solutions. The dynamic system should be able to adapt according to the context to deal with the changes. Context
awareness is one of the AI solutions that provides adaptivity to a system. Adaptivity is the transforming ability to fit in a certain condition, Context awareness can enable adaptation [1]. As context awareness is an emerging area of artificial intelligence (AI), context awareness has many advantages yet to be explored.

An adaptive mechanism needs to be used to ensure trust in a dynamic system (Yan et al. 2016). The importance of an environment-adaptive TM scheme for VANETs was discussed (Pathan 2016) and it was concluded that the unwavering security infrastructure of VANETs lacks the ability to meet the security requirements. The trust evaluation system must be flexible and robust to adapt to different situations [2]. The TM deals with vast variable information, context awareness is the way to use available information depending on the situation, context awareness does not rely on static system inputs. In a research study [3], authors discussed the need for VANET TM schemes to be adaptive to the environment. A study on the implications of AI in context awareness (Kofod-Petersen & Cassens 2005) considered the usefulness of AI techniques to build the context. We conclude our study by presenting researchers with advice to enable them to solve different problems in vehicular networks.

Trust

Trustworthiness is the level of legitimacy, and trust can be evaluated against the data or node in VANETs and ITS. Apart from securely delivering data between nodes, the integrity of the received content is important (Ma et al. 2011; Yao et al. 2017; Zhou et al. 2015). Trust is an important component of vehicular network security (Ma et al. 2011; Sumithra & Vadivel 2018). Other researchers (Ma et al. 2011; Saini et al. 2015; Yao et al. 2017) also discussed trust as a key security challenge owing to the dynamic nature of a vehicular network. Trust could be static where a trust level is assigned to certain types of vehicles/nodes such as RSUs or “police cars”; on the other hand, it could be dynamic where trust is developed based on interaction (Ma et al. 2011).

An objective of VANET security is to prevent messages from being forged during communication (Hasrouny et al. 2017). In repute-based systems, it is difficult for a vehicle that recently joined the network to prove its trustworthiness to the other nodes. In VANETs, the trustworthiness of data is of greater significance than that of a node because of the nature of these ad hoc networks (Hasrouny et al. 2017; Raw et al. 2013). Data-centric trust and verification in V2V communication in VANETs need to be studied in more detail. Trust evaluation techniques can be classified into three types (Hasrouny et al. 2017; Raya & Hubaux 2007; Saini et al. 2015; Soleymani et al. 2017; Sumithra & Vadivel 2018; Yao et al. 2017) as shown in Figure 2. The trust model that evaluates trust based on the available information is data centric. Entity centric trust model considers the trust associated with vehicle nodes.

TM

The responsibility of the TM system is to manage the real-time and long-term trust of the nodes in a network. Second, to determine the legitimacy of the message received from different nodes in the network. Most of the early TM models were based on data and entity, now the trend is moving towards hybrid TMs. The main problem areas include trust evaluation during fewer
node availability, uninterrupted centralized connectivity, and dealing with the dynamic nature of the network. Moreover, researchers are facing new challenges while developing TM for IoV.

**Rationale for the review**

IoV is an emerging field that lacks standards and needs to be standardized before IoV is implemented as part of smart cities. TM is one of the key components of IoV security. Previously, several TM models for VANET / ITS were presented, and these studies serve as the basis for IoV. In the absence of a comprehensive analytical study, this SLR provides a clear and comprehensive overview of the available evidence. In addition, our work helps to identify research gaps in our current understanding of the field. The objective of this review is to provide a basis for the developers of TM models for IoV. Our findings laid the foundation for the Intelligent TM System.

**Intended audience**

The article was intended to support academic and industry researchers working on TM in ad hoc vehicle networks, in particular the emerging field IoV. The work is not limited to IoV, the findings are equally beneficial for those working on IoT security. The open challenge sections are specifically presented to researchers who are new to the field of vehicle communication and need a strong research gap.

The remainder of the paper is organized as: section 2 presents the methodology of the systematic literature review (SLR), section 3 contains the results and discussion, and section 4 discusses the findings and challenges.

**Survey Methodology**

This research was conducted by using a method known as systemic literature review with the purpose of analyzing the limitations of this topic in a targeted way. Furthermore, we opted for meta-synthesis to help us identify problematic issues in current techniques and establish workable projections for further research in the area. The systematic study is based on existing PRISMA guidelines (Kitchenham 2004).

**Justification of SLR**

1. **Lack of SLR in TM**

As discussed in the “existing review” section, few review studies have focused on TM in VANETs; furthermore, an SLR has not yet been carried out for the IoV. There has been a surge in SLRs that collect and review existing knowledge, to help new researchers entering this particular field of research.

2. **Lack of focused studies**

Most of the review studies on VANETs encompass the entire security paradigm, with TM included as a single section. Contrary to this, our study focuses entirely on TM in vehicular networks.

3. **Support related fields**
This SLR would be equally helpful for those interested in IoT security, especially for device-to-device communication. Security has always been concerned with the IoT, many security threats emerge during IoT communication (Mollah et al. 2017) and trust is one of the solutions to ensure security (Jing et al. 2014). Second, the SLR is also intended to serve to apply context awareness to different types of ad hoc networks.

**Review protocol**

The review protocol for this study is based on the guidelines of a renowned review protocol PRISMA (Moher et al. 2009) and (Kitchenham 2004). We formulated the following protocol for this specific study as in Table 1.

**Objectives of the study**

Table 2 lists the research questions that cover the research objective of our SLR. The primary objective of this SLR is to analyze the core techniques that are used to manage trust among nodes in a vehicular network and motivated the construction of (RQ1): What are the current techniques for trust evaluation/management in the vehicular network? To identify the unique and useful aspects of each model (RQ2): “What improvements are being proposed for solving these problems?” To determine the weaknesses and strengths of each study, we highlight the gray areas of current models, which are expected to open new research dimensions. Finally, (RQ3) asks “Is context awareness suitable for the development of trust in a vehicular network?” We believe that the answers we provide to these questions culminate in a comprehensive study that not only offers new perspectives, but also opens new research dimensions.

**Selection criteria**

**1. First phase**

This study focuses on the existence of trust among nodes in vehicular networks. To formulate the search terms, we used different literature surveys on vehicular networks and searched online repositories. We initially started with the terms listed in the following section. A total of 256 articles were collected at the end of the first phase.

**Key terms**

Following key terms and search queries, searched for in different repositories. The key search terms are driven by research questions using PRISMA guidelines.

- IOV
- VANET
- ITS
- Vehicular network
- Trust evaluation
- Trust management
- V2V communication
- MANET
- “VANET” or “IOV” or “ITS” and “trust management” or “trust evaluation”
236 “VANET” or “IOV” and “trust management” and “V2V communication”
237 “MANET” and “trust management” or “evaluation and “context awareness”
238 “IOV” and “trust management” and “V2V communication”
239 “Internet of vehicles” and “trust evaluation” and “V2V communication”
240 “Context aware” and “VANET” and “trust management” or “trust evaluation”
241
2. Second phase
242 Because of the large number of articles that were retrieved in first phase, the second step
243 involved tool-based filtering. Filtering by using the citation tool allowed us to identify duplicate
244 studies from different sources and versions. At the end of this phase, we had a collection of 120
245 articles from different repositories.

3. Third phase
248 In this phase, the focus was “abstracts” other than the entire metadata. By considering the
249 abstract of each paper, irrelevant data could be removed, 73 papers were excluded by this
250 process which resulted in 47 articles remaining in our collection.

4. Fourth phase
251 Finally, all the remaining papers were read in detail. This process led to the exclusion of
252 papers that did not meet the selection criteria or standard or were beyond the scope of our work.
253 During this phase 16 articles were excluded, finally, 31 research articles were selected to conduct
254 the study. The SLR selection process is illustrated in Figure 3.

Scope of study
256 Our study focuses on the following statement:
258 In-depth analysis of present trust evaluation and management in vehicular networks and
259 implications of context awareness in trust establishment in vehicular networks.

Limitations of study
261 The following related areas are beyond the scope of our study:
262
263 • Routing protocols for the VANETs
264 • Cyber-attacks on VANETs

Results and discussion
265 The intense, in-depth study we conducted yielded significant results. In this section, we
266 summarize our findings, followed by a discussion. All three of the research questions were used
267 to analyze the papers with respect to the findings. Before the research questions are discussed,
268 selected statistics are presented below. Finally, following a detailed analytical discussion, we
269 present the open research challenges and directions to researchers in the field.

Type of studies
270 Table 3 presents the trends of studies conducted for trust evaluation and lists the year,
271 category, and type of article (“J” for journal or “C” for conference). The studies were categorized
272 as data-centric, entity-centric, or hybrid. Our final collection of selected papers contained 13
“conference” articles and 19 “journal” articles. This number is based on the limitation of our study, and might vary for any other study. Figure 4 shows the number of publications on TM that appeared during a certain decade. The Figure 4 also shows the number of papers excluded during the fourth phase while filtering the abstracts.

Critical characteristics of trust models

Table 4 presents certain important features of the trust model that were identified, i.e., the use of a central authority (CA), the authentication that was used, new node mechanism, uncertainty handling, and validation. These are a few of the most critical aspects of any TM system. A detailed discussion of the significance of these properties can be found in the discussion section.

Simulation tool used in TMs

Most of the papers contain a discussion of the simulator that was used in the particular study. These simulators are listed in Table 5. The purpose of specifying the simulator is to lay the ground for researchers to choose simulation tools for further study.

Existing review studies

To the best of our knowledge, a few review articles on trust evaluation and management have been reported. A few studies partially considered trust, but these reviews were not sufficiently comprehensive. The review studies in which TM in vehicular networks was discussed are presented in Table 6 (Arif et al. 2019; Kerrache et al. 2016; Soleymani et al. 2015; Sumithra & Vadivel 2018). Other than focused studies, several review articles on VANET security included a discussion on trust. This includes (Sumithra & Vadivel 2018) who, in their review study presented at a conference, discussed the fundamentals of VANETs and related security. Their focus was on fuzzy logic-based systems. Another conference presentation (Arif et al. 2019) on a survey of trust relating to VANETs, focused on secure routing and the quality of service in future technical and non-technical directions. A journal review article (Kerrache et al. 2016) was published on TM in VANETs, including a security overview, attacks, and available trust solutions. Another review study on TM specifically selected ten trust models and their performance was analyzed (Soleymani et al. 2015), the second focus of this study was the use of Fuzzy logic in TM.

RQ1. What are the current techniques for trust evaluation/management in the vehicle network?

Approach by TMs

The core approaches adapted by trust models are listed in Table 7, in which models that have certain key approaches in common are combined. By analyzing the data provided in Table 7, it is easy to identify the most and least commonly adapted approaches and the most common aspects
of different models. The commonly employed approaches were extracted from Table 7 and are plotted in Figure 5 for easy understandability. The bar graph in Figure 5 highlights the top ten parameters used in different studies. Experience is the topmost property adapted by most of the trust models, followed by neighbor-opinion and vehicles with special roles.

The core techniques, methodologies, and related components used by each TM model are summarized in Table 8. As discussed in section 1, TM models can be categories as: data-centric, entity-centric, and hybrid. Previously, researchers mostly focused on data-centric TMs, after which they realized that node properties are an important part of any TM, resulting in the proposal of many entity-based models. Hybrid models, are a combination of both of these techniques. Other than these three categories, certain other characteristics play an important role in TM, as discussed in this section. The aim of the discussion is to clarify the concepts behind different techniques that are expected to lay the foundation for unification during the standardization process. Furthermore, the discussion highlights certain aspects warranting further research.

1. Data-centric trust models

These models are based on data (message) for trust evaluation. A data-centric model (Chen et al. 2010), with the aim of improving the scalability using trust, was proposed. The authors evaluated the trust by using an opinion-based approach to identify malicious nodes by evaluating the trust. In addition, they used a cluster and role-based approach with the majority opinion being one of the key elements of this approach.

A few similar models (Minhas et al. 2010b; Raya & Hubaux 2007), in which a neighboring vehicle provides its opinion on the trustworthiness of events, were presented. The trust is computed on the basis of the highest vote. A drawback of these models is that messages can only be communicated among specified nodes in one group. These models can be used for distributed attacks using “neighbor node opinion.” A second drawback of these models is that opinion calculation methods are not clearly defined.

Other researchers (Shaikh & Alzahrani 2014) presented a decentralized TM system for VANETs. The scheme is based on different values calculated for the location and time to evaluate the trust. Their model seems effective in certain situations, but has limitations. Based on similarity, another trust model (Yang 2013) used the similarity between a node and the data to evaluate the trust level. Although a unique method of similarity was introduced, the technique was not validated. The trust was calculated based on direct and indirect experiences. The experimental details were not discussed, although the model seems to belong to the research field theoretically.

A model based on vehicle behavior and a Markov chain (Gazdar et al. 2012) was presented. The Markovian state transition was used to allocate and evaluate the trust of a node. In this model, all the vehicles act as monitors within their related perimeter. The model is distributed and maintains the record of trust locally. In another study (Wu et al. 2011), the researchers proposed an RSU-based data-centric trust model. An earlier data-centric trust model (Raya et al. 2008) considers role-based desperation, where nodes related to governmental organizations hold
more trust credibility. In contrast, the model also considers the node trust level. Bayesian inference and the Dempster-Shafer theory are used to handle uncertainty.

The data centric approach is used by earlier TMs, which lack the use of information associated with the node (entity). Entity centric and hybrid models have better capabilities than data centric models. It can be concluded from the above discussion that, even though the data centric approach is less effective, yet this approach is important for TM. It can play a key role in a hybrid TM system (Yao et al. 2017).

2. Entity centric trust models

These models are based on building trust against vehicle (entity). In a recently presented entity-centric trust model (Soleymani et al. 2017) the level of trust is assessed by fuzzy logic, using experience and probability. Authentication is based on the local ID and the location of the sender also plays a major role in the model. Another entity-centric distributed trust model (Haddadou et al. 2014) is based on the allocation of credit to the nodes used for TM. The model identifies the malicious node and motivates selfish nodes by awarding credits if they participate. The node is initially assigned a credit value, which increases or decreases over the time period.

A trust protocol based on a time frame (Ya et al. 2015) is presented with the aim of identifying malicious vehicles in the network. The trust value of a node is determined by the feedback from the neighboring nodes. A hybrid trust model that considered location privacy (Chen & Wei 2013) was presented. The presented technique is based on beaconing, where the movement of nodes plays an important role. A combination of direct and indirect trust was used in this model to evaluate the trust, which was validated using Dempster-Shafer evidence. An ant colony-based cluster trust model was proposed (Sahoo et al. 2012). Clusters were formed by using different parameters such as direction and speed. The head of a cluster was selected based on a higher trust level. Trust was based on neighbor opinion.

A model based on prior experience, neighbor-suggestions, and CA was used to build node trust (Mármol & Pérez 2012), which was achieved by using the reward and punishment method. The trust was determined in a fuzzy fashion to facilitate assessment by the system. Other entity-centric models (Cui et al. 2019; Li et al. 2013) used a mix of CA and cryptography. The primary problem with these models is that, once the vehicle has been authenticated, it cannot act maliciously. A decentralized agent-based trust model (Minhas et al. 2010a) using role, experience, and opinion, was presented. Another trust model (Biswa et al. 2011) was based on node-ID and local authentication by the public key, where digital signatures play a key role in this model for node identification. The assumption that “an authenticated node is trustable” is not realistic in VANETs. A scheme to ensure trust during communication in a VANET was proposed (Li et al. 2012). They set the “trust” as the reputation score of any node in the network. A message from highly reputed vehicles is considered trusted. However, experience is involved in building a reputation. Another unique aspect of their work is the feedback against the reporting vehicle.

An entity-centered framework for trust evaluation without a centralized system was proposed (Gazdar et al. 2018). The framework focuses on immediate knowledge between adjacent cars.
Their system is also effective for fake message detection. The solution is based on the self-organization of nodes in a network rather than depending on centralized authorities. The trust level of a vehicle is evaluated using different parameters. Neighboring vehicles play an important role in trust measurement. Based on the discussion and analysis of entity-centric techniques, it is firmly established that these models are the core of any trust model. Without considering the entity, the performance of trust models is compromised. On the other hand, simply relying on the entity for trust evaluation is also not the ultimate solution.

By discussion and analysis of entity-centric techniques, it is firmly established that these models are the core of any trust models. Without considering entity the performance of trust models is compromised. On the other hand, relying just on the entity for trust evaluation is also not the ultimate solution.

3. **Hybrid trust models**

Most of the recent models are hybrid models, combining data and evaluate the legitimacy of the received message. A proposed hybrid trust approach (Yao et al. 2017) for VANETs is based on the assignment of classified weights to different entities of the system. The model applies experience and utility theory, and the authors assumed certain attributes and the pre-assignment of weight. A renowned group (Wei et al. 2014) applied a hybrid approach, based on a combination of Bayesian rules to find the trust and Dempster-Shafer theory for handling uncertainty. The approach is based on direct and indirect trust to calculate the overall trust. A hybrid framework for TM, based on neighbor nodes, was presented (Ahmed et al. 2017). The model divides trust into three categories: events, nodes, and recommendations. Based on consistency and similarity, the trust for a certain event is calculated and updated. The presence of legitimate events and nodes in the system is an assumption. In a long-term trust relationship model (Biswas et al. 2016) the main trust evaluation body is the RSU supported by CA at the top. The model assumes that all the vehicles in the networks are registered with the CA and maintain a certain level of trust.

A trust evaluation study based on cluster and intrusion detection is presented to deal with different attacks (Sedjelmaci & Senouci 2015). The trust level is evaluated using majority voting by neighbor nodes. The model is subdivided into three: local, cluster head, and RSU. Trust is managed by the cluster head. The node is categorized in the list of trusted, suspicious, and attackers. The authors in (Rawat et al. 2015) worked on a combination of two different approaches, probabilistic and deterministic. The probability of a malicious node is calculated using Bayesian. The deterministic part calculates the trust message by calculating distances using signal strength, arrival time, and location. By most reliable nodes among adjacent cars (Abdelaziz et al. 2014), a new idea of filtering is used as a forwarding process. The implementation of the system avoids engaging in a network with cars recognized as likely dishonest users. A trust list is maintained locally by every vehicle, which is based on node interaction. Node velocity is used to determine the neighbors. The last message received serves as an integral part in evaluating trust since piggybacking is used.
In a cluster-based trust framework, misbehaving vehicles are sorted by assessing their speed variation (Wahab et al. 2014). The system is based on a reward scheme for motivation. To counter the trust and untrusted nodes, the Dempster–Shafer module is set in place as a watchdog. The cluster head plays the main role in their model. The model seems very complicated and unrealistic in real situations. A study (Li et al. 2013) based on a centralized TM, all the nodes monitor neighboring nodes and forward their opinion to the centralized system. The central system finally calculates the trust value based on new and previous data. RSU also plays an important role in this system.

In a study (Zhang et al. 2013) researchers worked on a peer opinion based trust model, and peers after receiving a message provided their opinion and forwarded the message. The model combines many sub-modules, such as propagation, trust evaluation, and peer-to-peer trust modules. Finally, trust is monitored and managed by a CA. An RSU-managed trust model, using role and experience, was presented (Monir et al. 2013) and is unlike other models that associate the driver ID with trust evaluation. The trust level of a vehicle increases with time in terms of experience. A penalty for malicious nodes is also part of the system, which reduces the trust level of the node in the future.

Overall, hybrid models have more adaptability and dynamicity. As vehicular networks require dynamic solutions, it is essential to design a trust model in a hybrid manner. The hybrid models allow multiple dimensions and the properties of both data and nodes to be used for trust evaluation.

RQ2. To what extent are the proposed models effective?

In this section, we discuss the critical aspects of a trust model with respect to existing models. The purpose of the discussion is to facilitate the establishment of the effectiveness of the current models.

Assumptions made by trust models

Most models made certain assumptions about their TM processes that create inflexibility. In a dynamic environment, assumptions decrease the importance of the proposed solution. For instance, assumptions made by (Chen et al. 2010; Raya et al. 2008), special-vehicles are present in every situation, is unrealistic. Another assumption made by (Sedjelmaci & Senouci 2015), “RSU is always available” which is practically unfeasible. Likewise, (Abdelaziz et al. 2014) assumes that all nodes are moving with the same velocity, which does not match the nature of the network. So much so, every model has some assumptions that make it hard to implement in real-time. The assumptions made by the trust models are listed in Table 9. However, assumptions regarding the implementation process prove to be a major hurdle. During a real traffic event, assuming the presence of special vehicles, RSU availability, pre-assigned trust, and many others can create serious problems while evaluating the trust. During a random event and network scenario, a trust model must not assume any variable to be completely implementable.

Centralized or decentralized vehicular network

There has always been a divide on whether ad hoc networks should be centralized or decentralized. Certain models (Abdelaziz et al. 2014; Gazdar et al. 2012; Haddadou et al. 2014;
Saini et al. (2015; Shaikh & Alzahrani 2014) considered decentralization as their approach, whereas others applied a centralized approach (Hussain et al. 2016; Li et al. 2012; Li et al. 2013; Mármol & Pérez 2012; Monir et al. 2013). In a recent study (Arif et al. 2019) author recommended centralized validation for TM. The main issue is the ultimate connectivity, which is difficult to achieve in these networks. In addition, for security, centralized data storage and management is essential. Although a practical solution would be to periodically synchronize trust data with a centralized management system, completely relying on centralized management is not the best practice. On the other hand, having a solely decentralized system causes a serious threat to the ad hoc networks.

**Importance of authentication**

The first step in any security system is authentication with a vehicular network. Here, the point of dispute is “If the authentication alone fulfills the security requirements.” A VANET is likely to experience a security breach after the legitimate approval of an authenticated node. In certain studies, authenticated users were assumed to always broadcast legitimate messages (Cui et al. 2019; Li et al. 2013; Mármol & Pérez 2012). In a real situation, this may result in highly adverse security consequences, such as Sybil, DOS and DDOS, node-impersonation attacks and, message-tempering (Kerrache et al. 2016; Saini et al. 2015; Sakiz & Sen 2017). Furthermore, (Sakiz & Sen 2017) explains in their work that how an already authenticated node can be compromised by an attacker for blackhole and wormhole attacks. An authenticated node can be used for session hijacking, explains (Hasrrouny et al. 2017).

Authentication must be dynamic and efficient in order to meet the requirements of IoT/IoV (Challa et al. 2020), for which researchers are working on lightweight authentication schemes (Vasudev et al. 2020). Authors in (Wazid et al. 2020) proposed a lightweight authentication scheme for IoT sensor data. Another research work (Wazid et al. 2018) on lightweight user authentication for internet of drones for direct communication is proposed. Blockchains can be a useful tool to build lightweight authentication solutions (Jangirala et al. 2019). The result shows that lightweight authentication schemes are suitable and secure for dynamic networks. Even though authentication is an essential aspect of an ad hoc network, we cannot rely solely on authentication.

**New node entering the network**

A critical issue during TM that is not taken into consideration is the entry of new nodes into the network. The question “how to assign a new node with initial trust” remains unanswered. Certain studies (Abdelaziz et al.; Ahmad et al. 2018) assigned a new node a trust value of 1 or 0.5, but the reason for this approach is not discussed in any of these papers. An intense study needs to be conducted to formalize the mechanism whereby a new node is introduced to a vehicular network.

**Cluster approach to handle trust**

A number of studies (Chen et al. 2010; Sahoo et al. 2012; Sedjelmaci & Senouci 2015; Wahab et al. 2014) adopted a cluster approach for managing trust. It is observed in most of the studies that a cluster creates inflexibility in a network. A VANET has a dynamically changing
topology (Xu et al. 2020), and inflexibility can cause the network to malfunction. Nonetheless, this does not decrease the importance of clustering in certain scenarios. In conclusion, the cluster approach can be used in TM but in limited scenarios. Cluster management needs to be defined and standardized to be used successfully. Cluster head selection has also been discussed in certain studies.

**Role-based approaches**

The presence of special vehicles (vehicles from governmental organizations such as ambulances, police vehicles, or fire engines) in the network requires a role-based approach (Ahmad et al. 2018; Alagar & Wan 2015; Haddadou et al. 2014; Monir et al. 2013; Zhang et al. 2013). Role-based nodes are considered trustworthy in these models and are assigned a higher trust level than other nodes. The question that remains unanswered is the approach to follow when special vehicles are present in every event. Practically, it is not possible to have special vehicles everywhere; eventually, the subtraction of role-based vehicles from the network at any time would affect the performance of the trust model. Role-based nodes and their use have been the topic of many studies, and this approach might be useful in certain situations.

**RSU-based approaches**

In the early phases of VANET research, RSUs became an essential part of the VANET architecture (Behravesh & Butler 2016). Models (Alagar & Wan 2015; Biswas et al. 2011; Biswas et al. 2016; Li et al. 2013; Monir et al. 2013; Sedjelmaci & Senouci 2015; Wu et al. 2011) that used the RSU as the main authority for TM were proposed. A “trust value” was assigned to an RSU depending on its location and coverage (Biswas et al. 2016). Another RSU-based study (Alagar & Wan 2015) presented a trust scheme using role-based vehicles. Further, they considered an RSU as a monitoring and managing node that also has a trust value, and the overall network was controlled by the CA. A trust model involving RSU-based scheme (Wu et al. 2011) was proposed, in which an RSU receiving environmental change reports by all vehicles after receiving reports from the RSU is responsible for deciding whether any message is real or false. The feedback process serves to confirm the trustworthiness. However, relying on an RSU is not a practical approach, as RSUs are stationary nodes and RSU availability cannot be assured across the entire network (Chi et al. 2013; Haydari & Yilmaz 2018). Despite all of these facts, the RSU continues to remain the main component of the VANET architecture and can be used wisely in certain situations or as a supporting node.

**Fuzzy logic in TM**

Fuzzy logic is a very useful tool and is used in many AI solutions. Two research groups (Mármol & Pérez 2012; Soleymani et al. 2017) used fuzzy logic in their work to evaluate trust. According to the first group (Soleymani et al. 2017) reason for using fuzzy logic is the uncertainty within VANETs. Their results show that fuzzy logic can be used positively in trust evaluation. In a review study (Sumithra & Vadivel 2018) author elaborated on the potential need for a fuzzy logic method for the trust model in VANETs. The study found coherence between VANET and fuzzy-based solutions. The author further mentioned that fuzzy approaches lack robustness and verity adoption, however, fuzzy methods seem to be a good solution if they are
used in TM. The only disadvantage of fuzzy based TMs is the time consumed during the process of computing the trust because a vehicular network cannot afford time delays.

**Uncertainty handling while evaluating trust**

A point of uncertainty always exists during trust evaluation (Yao et al. 2017). The majority of models are unable to discuss the uncertainty in their solutions. A trust model without the ability to handle uncertainty is considered an incomplete solution. Models that considered uncertainty while evaluating trust (Chen & Wei 2013; Haddadou et al. 2014; Monir et al. 2013; Wahab et al. 2014; Wei et al. 2014; Ya et al. 2015), processed the uncertainty by using probability approaches such as Bayesian, DST, and Markov processes. Researchers designing a trust model need to prioritize uncertainty handling.

**Use social media**

Social media could form a new addition to TM in IoV networks. TM in social vehicular networks was discussed on the basis of email and social media-based trust (Hussain et al. 2016). The model relies on CA to manage trust. The idea of considering social media was presented at a conference and seemed interesting, but is quite exposed to social media threats. Here it is important to note that the trust is associated with the user rather than the node. Driver-based trust faces the problem of disassociation, which might lead to miscalculation of the trust value. However, social media is an essential part of next-generation design (Zia et al. 2020).

**RQ3 Is context-awareness suitable for the development of trust in the vehicle network?**

**Context Awareness**

Vehicular networks are the most complex wireless networks and thus require flexibility in all aspects. Context awareness is an AI method that can be used to introduce flexibility to any system; contextual awareness is the ability to assess and adapt the environment (Ramos et al. 2008). Very few studies in this field have been reported, and a few studies have partly considered the context in vehicular networks (Ahmad et al. 2018; Alagar & Wan 2015; Rostamzadeh et al. 2015). Our efforts to find the true essence of context awareness in these studies were unsuccessful. However, in related fields, such as distributed, ubiquitous, and mobile ad hoc networks, several studies related to context awareness have been reported.

A study of IoT architecture for smart cities (Gaur et al. 2015) used context awareness for scenario building. Their work focuses on the representation of knowledge of the smart city architecture through contextual awareness, which has become a necessity for ubiquitous systems (Taconet & Kazi-Aoul 2010). Another study on interoperability in ubiquitous systems (Strang & Linnhoff-Popien 2003) applied context awareness with positive results. A study on VANET/ITS (Al-Sultan et al. 2013) used context awareness to assess driver behavior. The outcome of the study was that context awareness has significant potential in relation to vehicular networks. The importance of context awareness in MANETs (moloney & Weber 2005) elaborated on the importance of context implementation in a system that is equipped with sensors. Moreover, the study suggested that any systems with sensor objects that can make good use of context awareness would be beneficial to vehicular networks while using node-to-node communication.
Node-to-node context applications in MANETs were investigated (Wibisono et al. 2010) for the purpose of context building in MANETs. Context-aware systems are able to adapt to changes and increase the usability of any system and the efficacy thereof was discussed (Maneechai & Kamolphiwong 2014) in relation to distributed systems. In a futuristic study on different aspects of vehicular network security (Wan et al. 2014), the use of context awareness in such systems is strongly recommended, especially with respect to security and safety. Context awareness for automatic TM is an important field of research (Yan et al. 2014).

A survey study (Yürür et al. 2016) on context awareness for the future of mobile systems, determined that a context-aware system has the ability to sense its environment. Furthermore, by using context the network increases its security, quality, and credibility. Their work concludes by highlighting the use of context for mobile-based systems. Furthermore, IoT architecture must be intelligent, and for that, context awareness is an effective method (Sarkar et al. 2014). The forthcoming networks are intelligent networks, for which context awareness is the key method to be adopted (Bilen & Canberk 2015). A study on ambient computing (Babu & Sivakumar 2014) discussed the ability of context awareness to enable adaptation for ubiquitous systems. Further, the researchers pointed out that a system that assesses the situation and acts accordingly must be equipped with context awareness. The challenge is to design context-based security middleware for a heterogeneous system. An earlier study determined that context awareness has special characteristics that support intelligent vehicle systems (Sørensen et al. 2004), but little work has been carried out in this direction. Further, they discuss the context that can be useful in V2V communication for intelligent vehicles.

Context awareness is a necessity for upcoming ad hoc networks, especially VANETs (Aguilar et al. 2018). Their work on context modeling has significant potential in wireless networks. Further, they indicated that the application of context to ad hoc networks may be advantageous. Context awareness was employed to enhance the security of wireless networks (Lin et al. 2019). This study was based on heterogeneous networks to show the implications of context awareness. Their positive results showed that applying context awareness to security increased the adaptivity.

In a VANET context-aware study for detecting misbehaving nodes (Chi et al. 2013), the authors applied context using neighboring nodes and used mobility information to construct the context. Their work yielded positive results that were the outcome of context awareness. A context knowledge representation scheme was presented (Ruta et al. 2018). Their work shows the implications of context in wireless networks, especially IoT-related technologies and VANETs, which strongly support our research question. In a recent study, context was employed to design a safety system in VANETs (Shen et al. 2016). The concept is for vehicles to share the road environment while driving safely. Routing can be improved by context awareness in wireless networks, especially in the IoT (Dhumane et al. 2018). A context-based VANET privacy model (Emara et al. 2015) that implemented contextual privacy successfully improved location tracing. The work was evaluated against the quality of service and found to be satisfactory even after the application of context awareness.
Based on the above discussion and relevant studies, it is established that context awareness has the potential to be applied to vehicular networks for TM. Nonetheless, the term context could be interpreted to have a general meaning and many related challenges would need to be overcome. As the context has already been considered for MANETs, it could be used as the foundation for VANET/IoV as well. A comparative overview is presented in Table 10 based on a published report (Sharma & Kaushik 2019).

Summary at a glance

An overview of the different technologies, the extent to which they overlap, related issues, and the potential future of these technologies is presented in Figure 6. Furthermore, Table 11 summarizes the major properties of the trust model. Only journal articles were considered, the reason for the exclusion of the conference papers at this point is to be precise, second, they are unable to provide detailed information on methodology, experimental results and analysis. The aim of the summary is to produce a comprehensive yet brief description for researchers in the field. According to the statistics in Table 11, two very important aspects of the trust model have been ignored by most of the researchers i.e., hopping and beaconing. Most malicious activities occur during hopping and beaconing (Jang et al. 2018; Suman et al. 2017).

RSUs, an important component of the VANET infrastructure, were not considered in any of the studies. However, RSUs were included in most of the conference idea presentations. As an RSU is an important entity with many functionalities, it can be used to take maximum advantage of the resources.

Analyzing the statistics in Table 11 shows that TM is a significant problem. Most studies have ignored certain major aspects. Therefore, dynamic trust models that consider maximum aspects to attain the highest level of trust are in demand. The inclusion of all aspects in a single trust model can be challenging, therefore requires an adaptive solution. Context awareness is a method that provides flexible adaptation to a complex system (Ramos et al. 2008).

Open challenges and future research directions

Based on the analysis and observations of this study, the following are open research challenges that need to be addressed. This is expected to provide research directions for researchers interested in this field, Table 12 provides research challenges and directions related to identified gray areas. Furthermore, the future vision of IoV is discussed to provide clear goals, helping researchers to work on a broader canvas.

1) Designing intelligent TM frameworks for vehicular networks. From results, it can be inferred that TM is a complex problem thus requires Intelligent systems. This will enhance the overall performance of the TM.

2) Choosing between a centralized or decentralized approach has always been debatable. A comparative analysis of centralized and decentralized approaches for vehicular ad hoc networks is required. This analysis will provide clear benefits and drawbacks to each approach.
3) Nature-inspired computing has similarities with ad hoc vehicular networks. Detailed analytical study on the coherence of swarm computing with vehicular networks is required. Swarm computing, with its intelligent capabilities, has some characteristics similar to the vehicle network. Some research work involving ant-colony is conducted in this field.

4) Solving the “node initialization” problem for TM. Whenever a new node joins an ad hoc network different initial trust credits need to be allocated. The trust value allocation to a new node in a vehicular network is one of the challenging problems for trust models.

5) Cluster management for vehicular network trust models. The studies using cluster have no common approach for managing the trust. An in-depth study is required to analyze and provide standards. A cluster approach can also be used as a subpart of the network security solution.

6) Overcoming uncertainty while evaluating trust in VANETs. Uncertainty is one of the complex problems in trust evaluation, comprehensive solutions are required in this area to handle uncertainty. A few works have been carried out in this aspect of TM models.

7) Use of social media for security in vehicular networks. Social media has become a part of our lives, this research area needs further exploration for security implementation. Some works have been carried out in this area showing positive results.

8) Designing IoV cyber security protocols. IoV is exposed to cyber-attacks due to internet connectivity. It, therefore, requires standard security protocols, specially designed for IoV cyber-security.

9) Using context awareness for security in ad hoc networks. Context awareness provides intelligent solutions, existing work in this field shows positive results. Coherence between both fields needs to be further investigated.

10) Context knowledge representation methods for vehicular networks. Knowledge representation is one of the complex problems faced while applying context awareness. Before implementing the context awareness research needs to work out the knowledge representation methods.

11) Context awareness in the vehicular environment. Within this area some research work is carried out which shows promising results, further exploration is needed for better solutions.

**Framing the future vision of IoV, and recommendations**

IoV is expected to become part of the future smart city and intelligent transport system, the vision of future IoV is set out in the following key points and provides researches on a broad-spectrum expectation.

1) Soon, IoV is expected to be fully or partially implemented as part of smart cities.

2) Conventional security is expected to be replaced with Intelligent security solutions for vehicular networks.

3) Trust between nodes is expected to be a standard part of future vehicular network security, there is still a potential gap in this direction.

4) Fog and edge technology are also making way for vehicular networks that will be a good addition to the IoV.
5) Vehicular communication generates huge data in seconds, the Big Data has a huge potential in vehicular networks, yet to be explored. Driver behavior, traffic patterns, accident prevention, smooth traffic flow, and many other interesting discoveries and solutions can be made using Big Data analysis.

6) Context awareness has an enormous potential in the vehicular network yet to be explored and implemented in the future.

7) A mix of a centralized and decentralized network is also expected to be established.

8) Another aspect that is worthy of further investigation is the management of cloud resources during vehicular communication. Various problems arise with regard to the nature of the communication.

9) The social network seems to be part of IoV. Apart from the human social network, the social network of vehicles is also likely to be developed.

Conclusion

The IoV is a potential part of the intelligent transport solution for the next wave of smart cities. As the IoV is still in the development phase, applicable standards need to be developed and recognized worldwide. Thus, the trust models in the IoV are yet to be standardized and transformed from VANETs and the ITS. We devoted our efforts to produce a systematic review in which we examined all available trust models. The outcomes of the meta-analysis highlighted all dimensions, including gray areas. Further, to fulfill the need for intelligent solutions, we tried to establish the potential benefits of context awareness in vehicular networks, which would not only facilitate intelligent TM but also address other security issues. Our work could be useful to develop standards for TM in vehicular networks. The results of the study are equally helpful for designing IoT security solutions, as device-to-device communication is a key aspect of the future IoT.

In terms of future research, we raised open questions for researchers in the Open Challenges section. Answering each question is likely to require intense research efforts. The outcome of our work is expected to be equally fruitful for other IoT solutions, ad hoc networks, and trust-related studies.

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Figure 1

An overview of the main components of the IoV
Figure 2

Trust evaluation techniques classified into three types

Data Centric Trust Model  Hybrid Trust Model  Entity Centric Trust Model
Figure 3

The SLR selection process, and filtering in each phase
Google Scholar
Science Direct
IEEE xplore
Springer
ACM

First phase: Identification and collection of relevant studies from different database repositories. Number of articles collected = n
n=256

Second phase: Tool filtering to remove duplication and multiple version
n=120

Third phase: Abstract contemplation of sorted articles from phase 2
n=47

Fourth phase: Selected articles after completely reading and grasping the work. Article irrelevant or out of scope of our work discarded.
n=31
Figure 4

The number of publications on trust management that appeared during a certain decade

![Number of Publications](image)
Figure 5

The top ten parameters used in different studies

![Bar chart showing the commonly used parameters in different studies. The parameters are ranked from most used to least used:

1. Experience
2. Neighboring opinion
3. Role-based
4. Direct and indirect experience
5. Probability
6. RSU
7. Cluster
8. Location
9. Central authority
10. Majority opinion]
Figure 6

An overview of the different technologies, the extent to which they overlap, related issues, and the potential future of these technologies

- Trust management has become an essential part of vehicular networks
- The combination of data-centric and entity-centric TM forms hybrid approach
- Context awareness: an AI method to incorporate adaptation in any rigid system
- IoT in combination with a vehicular network makes IoV a future component of smart cities
- VANET/ITS
- IoV
- IoT
- Smart IoT Solutions
- Cognitive Trust Management
- Trust Management
- Gap
- Context Aware AI Solution
Table 1 (on next page)

The formulated protocol for this specific study based on the guidelines of a renowned review protocol PRISMA
| Title          | Clear definition of problem with type of study |
|---------------|-----------------------------------------------|
| Abstract      | Provide a comprehensive overview of the study being discussed, starting from the background. Review criteria, methodology, results, and key findings. |
| Methodology   | Objectives<br>Selection criteria<br>Scope of the study<br>Limitations |
| Introduction  | In the sense of what is already understood, the rationale for the review. A clear statement of problems being addressed, comparison, outcome and study design |
| Results/Discussion | Discussion on the outcomes with respect to research questions.<br>Limitations of the study<br>Open research challenges |
| Conclusions   | Summary of the whole study conducted, general understanding of the results, and suggestions for future research |
Table 2 (on next page)

The research questions that cover the research objective of the SLR
| No. | Research Question                                                                 | Deliverable/ outcome                                                                                                                                 |
|-----|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | What are the current techniques for trust evaluation/management in the vehicle      | In-depth analysis of current trust evaluation and management techniques. Comprehend all the available models in a single study for further research     |
|     | network?                                                                          |                                                                                                                                                      |
| 2   | To what extent are the proposed models effective?                                  | Weak and strong properties of current trust models considering real-time implementation. Identification of the gray areas of current models, that need to be investigated Effectiveness analysis in term of trust evaluation Open research challenges for researchers. |
| 3   | Is context awareness suitable for the trust establishment in the vehicle network?  | Contrast study of context awareness and vehicular network. Enlighten new research dimension for vehicular networks                                    |
Table 3 (on next page)

the trends of studies conducted for trust evaluation and lists the year
| Article                        | Year  | Category | Journal/Conference |
|-------------------------------|-------|----------|--------------------|
| (Ahmad et al. 2018)           | 2018  | Hybrid   | J                  |
| (Gazdar et al. 2018)          | 2018  | Entity   | J                  |
| (Soleymani et al. 2017)       | 2017  | Entity   | J                  |
| (Ahmed et al. 2017)           | 2017  | Hybrid   | J                  |
| (Biswas et al. 2016)          | 2016  | Hybrid   | C                  |
| (Hussain et al. 2016)         | 2016  | Hybrid   | C                  |
| (Sedjelmaci & Senouci 2015)   | 2015  | Hybrid   | J                  |
| (Haddadou et al. 2015)        | 2015  | Entity   | J                  |
| (Rawat et al. 2015)           | 2015  | Data     | J                  |
| (Ya et al. 2015)              | 2015  | Entity   | J                  |
| (Rostamzadeh et al. 2015)     | 2015  | Hybrid   | J                  |
| (Alagar & Wan 2015)           | 2015  | Entity   | C                  |
| (Abdelaziz et al. 2014)       | 2014  | Entity   | C                  |
| (Wahab et al. 2014)           | 2014  | Hybrid   | J                  |
| (Shaikh & Alzahrani 2014)     | 2014  | Data     | J                  |
| (Wei et al. 2014)             | 2014  | Hybrid   | C                  |
| (Yang 2013)                   | 2013  | hybrid   | J                  |
| (Chen & Wei 2013)             | 2013  | Hybrid   | J                  |
| (Li et al. 2013)              | 2013  | Hybrid   | C                  |
| (Zhang et al. 2013)           | 2013  | Hybrid   | J                  |
| (Monir et al. 2013)           | 2013  | Entity   | C                  |
| (Rehman et al. 2013)          | 2013  | Data     | C                  |
| (Li et al. 2012)              | 2012  | Entity   | J                  |
| (Gazdar et al. 2012)          | 2012  | Hybrid   | C                  |
| (Sahoo et al. 2012)           | 2012  | Entity   | J                  |
| (Mármol & Pérez 2012)         | 2012  | Entity   | J                  |
| (Minhas et al. 2011)          | 2011  | Entity   | J                  |
| (Biswa et al. 2011)           | 2011  | Entity   | C                  |
| (Wu et al. 2011)              | 2011  | Data     | C                  |
| (Chen et al. 2010)            | 2010  | Data     | C                  |
| (Raya et al. 2008)            | 2008  | Data     | C                  |
Table 4 (on next page)

The important features of the trust model that were identified
| Article                        | CA (Central Authority) | Authentication/ PKI | New node mechanism | Uncertainty handling |
|-------------------------------|------------------------|---------------------|--------------------|---------------------|
| Ahmad et al. 2018             | yes (for role based)   | no                  | 0.5 initial value  | no                  |
| Gazdar et al. 2018            | no                     | no                  | no                 | no                  |
| Soleymani et al. 2017         | no                     | yes                 | no                 | no                  |
| Ahmed et al. 2017             | no                     | yes                 | no                 | no                  |
| Biswas et al. 2016            | yes                    | yes                 | no                 | no                  |
| Hussain et al. 2016           | yes                    | yes                 | no                 | no                  |
| Sedjelmaci & Senouci 2015     | no                     | no                  | no                 | no                  |
| Haddadou et al. 2015          | no                     | RSA, elliptic curve cryptography | no | Markova chain |
| Rawat et al. 2015             | no                     | x                   | no                 | Probabilistic approach |
| Ya et al. 2015                | yes                    | yes                 | new node initial trust value 0.5 | By location |
| Rostamzadeh et al. 2015       | no                     | no                  | no                 | no                  |
| Alagar & Wan 2015             | yes, CA, GTA           | yes                 | Start with 0 trust | no                  |
| Abdelaziz et al. 2014         | no                     | no                  | new node initial trust value 0.5 | no |
| Wahab et al. 2014             | no                     | no                  | no                 | Dempster-Shafer     |
| Shaikh & Alzahrani 2014       | no                     | no                  | no                 | no                  |
| Wei et al. 2014               | no                     | no                  | no                 | no                  |
| Yang 2013                     | no                     | no                  | 0.5 (Based on similar vehicle) | no |
| Chen & Wei 2013               | yes                    | yes                 | no                 | Dempster-Shafer evidence |
| Li et al. 2013                | yes, RMC               | no                  | no                 | no                  |
| Zhang et al. 2013             | yes                    | no                  | no                 | no                  |
| Monir et al. 2013             | yes, GTA               | no                  | Start with 0       | By calculation      |
| Rehman et al. 2013            | no                     | no                  | no                 | no                  |
| Authors               | Trusted | Signed | Remote Access | PKI   |
|-----------------------|---------|--------|---------------|-------|
| Li et al. 2012        | no      | yes    | no            | no    |
| Gazdar et al. 2012    | no      | no     | no            | no    |
| Sahoo et al. 2012     | no      | no     | All new vehicles are trusted | no |
| Mármol & Pérez 2012   | yes     | no     | no            | no    |
| Minhas et al. 2011    | no      | no     | no            | no    |
| Biswas et al. 2011    | no      | Local public key | no | no |
| Wu et al. 2011        | no      | no     | no            | no    |
| Chen et al. 2010      | no      | no     | no            | no    |
| Raya et al. 2008      | CA      | PKI    | no            | no    |
Table 5 (on next page)

The simulators used by different trust models
| Article                     | Simulator                                      |
|----------------------------|------------------------------------------------|
| (Ahmad et al. 2018)        | VEINS, SUMO, OMNET++                           |
| (Gazdar et al. 2018)       | not discussed                                  |
| (Soleymani et al. 2017)    | NS2, SUMO                                       |
| (Ahmed et al. 2017)        | OMNET++ discrete event, network simulator      |
| (Biswas et al. 2016)       | not discussed                                  |
| (Hussain et al. 2016)      | not discussed                                  |
| (Sedjelmaci & Senouci 2015)| NS-3                                           |
| (Haddadou et al. 2015)     | NS-2, SUMO                                      |
| (Rawat et al. 2015)        | not discussed                                  |
| (Ya et al. 2015)           | not discussed                                  |
| (Rostamzadeh et al. 2015)  | MATLAB                                         |
| (Alagar & Wan 2015)        | not discussed                                  |
| (Abdelaziz et al. 2014)    | NS-2                                           |
| (Wahab et al. 2014)        | MATLAB, network simulator, MobiSim traffic     |
| (Shaikh & Alzahrani 2014)  | SWANS++                                        |
| (Wei et al. 2014)          | not discussed                                  |
| (Yang 2013)                | not discussed                                  |
| (Chen & Wei 2013)          | not discussed                                  |
| (Li et al. 2013)           | NA                                             |
| (Zhang et al. 2013)        | not discussed                                  |
| (Monir et al. 2013)        | MATLAB                                         |
| (Rehman et al. 2013)       | not discussed                                  |
| (Li et al. 2012)           | Groove Net                                     |
| (Gazdar et al. 2012)       | Veins                                          |
| (Sahoo et al. 2012)        | not discussed                                  |
| (Mármol & Pérez 2012)      | TRMSim-V2V                                      |
| (Minhas et al. 2011)       | SWANS                                          |
| (Biswas et al. 2011)       | not discussed                                  |
| (Wu et al. 2011)           | NS-3                                           |
| (Chen et al. 2010)         | not discussed                                  |
| (Raya et al. 2008)         | MATLAB                                         |
Table 6 (on next page)

The review studies in which "vehicular network TM" is discussed
| Review study          | Year | Type of publication | Focus        |
|----------------------|------|---------------------|--------------|
| (Sumithra & Vadivel 2018) | 2018 | Conference          | Fuzzy logic  |
| (Gillani et al. 2018) | 2018 | Conference          | Secure routing |
| (Kerrache et al. 2016) | 2016 | Journal             | Attacks      |
| (Soleymani et al. 2015) | 2015 | Journal             | Fuzzy logic  |
Table 7 (on next page)

The core approaches adapted by trust models
| Article                                                                 | Approach                                         |
|-----------------------------------------------------------------------|--------------------------------------------------|
| (Ahmad et al. 2018; Ahmed et al. 2017; Chen et al. 2010; Li et al. 2012; Máról & Pérez 2012; Minhas et al. 2011; Monir et al. 2013; Rostamzadeh et al. 2015; Sahoo et al. 2012; Soleymani et al. 2017; Wei et al. 2014; Yang 2013) | • Experience-based                               |
| (Ahmad et al. 2018; Alagar & Wan 2015; Chen et al. 2010; Minhas et al. 2011; Monir et al. 2013; Raya et al. 2008; Zhang et al. 2013) | • Role-based                                     |
| (Abdelaziz et al. 2014; Ahmed et al. 2017; Haddadou et al. 2015; Li et al. 2013; Máról & Pérez 2012; Monir et al. 2013; Rostamzadeh et al. 2015; Sahoo et al. 2012; Sedjelmaci & Senouci 2015) | • Neighbor Opinion                               |
| (Ahmed et al. 2017; Biswas et al. 2016; Chen & Wei 2013; Gazdar et al. 2018; Máról & Pérez 2012; Wei et al. 2014; Yang 2013) | • Direct and indirect experience                  |
| (Chen & Wei 2013; Gazdar et al. 2012; Rawat et al. 2015; Raya et al. 2008; Soleymani et al. 2017; Wahab et al. 2014; Wei et al. 2014) | • Probability, Markova, Dempster-Shafer, Bayesian inference |
| (Alagar & Wan 2015; Biswas et al. 2011; Biswas et al. 2016; Li et al. 2013; Wu et al. 2011) | • RSU managed trust                              |
| (Sahoo et al. 2012; Sedjelmaci & Senouci 2015; Wahab et al. 2014) | • Cluster-based                                  |
| (Rostamzadeh et al. 2015; Shaikh & Alzahrani 2014; Soleymani et al. 2017; Ya et al. 2015) | • Location trust association                     |
| (Máról & Pérez 2012; Monir et al. 2013; Zhang et al. 2013) | • Trust evaluated by central authority           |
| (Minhas et al. 2011; Sedjelmaci & Senouci 2015) | • Majority Opinion                               |
| (Li et al. 2012; Li et al. 2013) | • Centralized trust management                   |
| (Gazdar et al. 2018; Haddadou et al. 2015) | • Malicious node detection                       |
| (Ahmed et al. 2017; Wei et al. 2014) | • Direct trust                                   |
| (Shaikh & Alzahrani 2014; Ya et al. 2015) | • Time-based                                     |
| (Alagar & Wan 2015; Minhas et al. 2011) | • Agent-based                                    |
| (Soleymani et al. 2017) | • Fuzzy logic                                    |
| (Ahmed et al. 2017) | • Local ID authentication                        |
| | | • Attack based model                            |
(Ahmad et al. 2018) • Mobility behavior
(Biswas et al. 2016) • long term trust relationship
(Hussain et al. 2016) • Person(driver) based

(Sedjelmaci & Senouci 2015) • Attack based
(Haddadou et al. 2015) • Credit allocation
(Rawat et al. 2015) • Distributed trust evaluation
(Ya et al. 2015) • Deterministic
(Abdelaziz et al. 2014) • Continuous link stability

(Wahab et al. 2014) • Piggybacking
(Wei et al. 2014) • Local trust evaluation
(Yang 2013) • Hope (1,2,3)
(Chen & Wei 2013) • Reward-based
(Li et al. 2013) • Recommendation
(Zhang et al. 2013) • Similarity (data, node) theory
(Monir et al. 2013) • Beacon-based
(Rehman et al. 2013) • Reputation-based
(Li et al. 2012) • Peer-based opinion

(Gazdar et al. 2012) • Driver ID based trust
(Sahoo et al. 2012) • Thread-based
(Mármol & Pérez 2012) • Reputation score
(Minhas et al. 2011) • Feedback score(opinion)
(Biswas et al. 2011) • Distributed trust management

(Wu et al. 2011) • Ant colony message routing
(Raya et al. 2008) • Reward or punishment

(Monir et al. 2013) • 3 level fuzzy trust
(Biswas et al. 2011) • Decentralized

(Wu et al. 2011) • ID-based
(Raya et al. 2008) • Certificate less

(Wu et al. 2011) • Public key
(Raya et al. 2008) • Different trust combined

(Wu et al. 2011) • Observation reports
(Raya et al. 2008) • Feedback

(Raya et al. 2008) • Weighted voting
Table 8 (on next page)

The summary of core techniques, methodologies, and related components used by each TM model
| Article                        | Methodology                                                                                                                                 |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| (Ahmad et al. 2018)           | Trust over data and vehicle is established and finally, message trust is evaluated. “Role based vehicles” and experience play an important role. |
| (Gazdar et al. 2018)          | Neighboring-node opinion is considered. Negative trust introduced in this model. Probability is used for uncertainty handling.                   |
| (Soleymani et al. 2017)       | Trust determined by fuzzy logic, experience, and probability. Local ID authentication. Experience value is saved in the node. Location verification using time and distance. The sender location is a key factor in this model. |
| (Ahmed et al. 2017)           | Neighbor opinion, consistency, and similarity-based trust evaluation. Three subcategories of trust: events, nodes, and recommendations.          |
| (Biswas et al. 2016)          | RSU add and manage trust. Long term trust relationship is maintained. RSU supported by CA at the top layer. The model assumes that all the vehicles in the networks registered with the CA and maintains a certain level of trust. |
| (Hussain et al. 2016)         | Based on email and social trust. Trust is managed by a CA. Trust is associated with user.                                                   |
| (Sedjelmaci & Senouci 2015)   | Three categories of trust (trusted, suspicious and attacker). Majority voting-based trust. The cluster head is responsible for trust management.  |
| (Haddadou et al. 2015)        | Credit-based model removes malicious nodes. Selfish nodes get participation rewards. RSA cryptographic scheme used.                            |
| (Rawat et al. 2015)           | The trust evaluated by calculating distances using signal-strength, arrival-time and location. The probability of a malicious node is calculated by Bayesian. |
| (Ya et al. 2015)              | A time frame-based trust protocol. Feedback on report from neighboring nodes. Selfish and malicious node identification. To validate the trust response time is used. |
| (Rostamzadeh et al. 2015)     | The trust model is subdivided in multiple modules. Three security levels to assure trust. Trust is allocated to road segments.                 |
| (Alagar & Wan 2015)           | Role-based vehicles act as agents. RSU assesses the context environment and manages the system.                                             |
| (Abdelaziz et al. 2014)       | The trust model is subdivided in multiple modules. Three security levels to assure trust. Trust is allocated to road segments.                 |
| (Wahab et al. 2014)           | Role-based vehicles act as agents. RSU assesses the context environment and manages the system.                                             |
| (Shaikh & Alzahrani 2014)     | Neighbor vehicles chose the most reliable nodes among adjacent nodes to be used for hopping. Local trust management by each vehicle. Piggybacking is used by the last message. |
| (Wei et al. 2014)             | Cluster-based trust model. Misbehaving vehicles detected by speed variation. Reward allowed for motivation. Dempster-Shafer theory for counter verification. Some nodes act as watchdog in the system. |
| (Yang 2013)                   | A decentralized trust management system. The scheme is based on change in the location and time used to calculate the trust.                  |
| (Chen & Wei 2013)             | The Bayesian rule method is used to calculate the trust level. Dempster-Shafer is used for handling uncertainty.                              |
| (Li et al. 2013)              | Nodes monitor neighboring nodes. Trust is based on opinion. Final trust is calculated from new and previous data. RSU is the part of trust evaluation. |
| (Zhang et al. 2013)           | Before forwarding received messages, peer inputs their opinion. Role-based nodes are also part of the model. The central authority manages the whole network |
| (Monir et al. 2013)   | Association of driver ID with trust. CA and RSU are responsible for opinion gathering and trust evaluation. A malicious node penalizing system introduced. |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (Rehman et al. 2013) | During the hopping process trust level is increased. The multiple chains of trust threads created to finally evaluate trust.                                                                                               |
| (Li et al. 2012)     | The trust is observed as a reputation score of any node network. Experience is involved in building a reputation. Feedback is recorded against the reporting vehicle. The centralized authority shall serve as controlling authority |
| (Gazdar et al. 2012) | Based on vehicle behavior using a Markov chain. All vehicles monitor their surroundings. Local trust management.                                                                                          |
| (Sahoo et al. 2012)  | An ant colony-based cluster trust model. The cluster is made using different parameters such as direction, speed, and others. Higher trust level and neighbor’s opinion decide cluster head. |
| (Mármol & Pérez 2012)| Prior experience, neighbor suggestion are the main trust evaluators in this model with three levels of local trust storage. CA managed node trust. The reward and punishment system. The trust is determined in a fuzzy system. |
| (Minhas et al. 2011) | An intelligent agent-based approach. Trust based on experience, role, priority and majority opinion.                                                                                                      |
| (Biswas et al. 2011) | The model is based on node ID. Nodes are identified by the digital signatures. Public key verification is used for authentication.                                                                        |
| (Wu et al. 2011)     | An RSU based trust model. The RSU is responsible for trust evaluation. Feedback process adds up to trustworthiness.                                                                                     |
| (Chen et al. 2010)   | A role-based trust model. Experience and neighbor node opinion.                                                                                                                               |
| (Raya et al. 2008)   | The distributed trust model is based on role-based desperation. Government-related vehicles hold a higher trust level. Bayesian inference and Dempster-Shafer theory are used to handle uncertainty. Event-specific trust is observed. |
Table 9 (on next page)

The assumptions made by the trust models
| Article | Assumptions made by the studies |
|---------|---------------------------------|
| (Ahmad et al. 2018) | Government vehicles, public transport and vehicles with a higher mileage are highly trusted. |
| (Ahmed et al. 2017) | At least one true (legitimate) event and node must be the part of network. |
| (Biswas et al. 2016) | Predefined RSU trust value. CA always keeps a trust record of all vehicles. |
| (Sedjelmaci & Senouci 2015) | Uninterrupted RSU availability. All RSUs are connected to the wire. |
| (Haddadou et al. 2015) | All types of nodes (legitimate, malicious and selfish) are present in the system. All nodes are allocated with Initial credit. |
| (Rawat et al. 2015) | Presence of at least one malicious vehicle in the network. |
| (Ya et al. 2015) | The omnipresence of reliable intersection vehicle. Presence of “geographic in-charge” nodes in the network. Use of uniform technology by all the vehicle. |
| (Rostamzadeh et al. 2015) | Initial trust allocation against road segment. |
| (Alagar & Wan 2015) | OBU is always a secure device and uniform all over the network. |
| (Abdelaziz et al. 2014) | The neighbor nodes have the same velocity. |
| (Shaikh & Alzahrani 2014) | The event always occurs at the end of the road segment. Nodes are in line of sight. |
| (Chen & Wei 2013) | Frequent single hopping message broadcast only. Third party CA is always trusted. Pseudonyms change frequently. |
| (Zhang et al. 2013) | Pre-allocated roles. |
| (Li et al. 2012) | Keys are managed by OBU. The clock is in OBU and always secure. |
| (Gazdar et al. 2012) | All vehicles in the network must report the event. All vehicles must forward receive messages. |
| (Sahoo et al. 2012) | Highway traffic only. |
| (Mármol & Pérez 2012) | Same route daily. |
| (Minhas et al. 2011) | Vehicle manufacturers issue security certificates. Special vehicles are always present in network. |
| (Chen et al. 2010; Raya et al. 2008) | |
| (Biswas et al. 2011; Gazdar et al. 2018; Hussain et al. 2016; Li et al. 2013; Monir et al. 2013; Rehman et al. 2013; Soleymani et al. 2017; Wahab et al. 2014; Wei et al. 2014; Wu et al. 2011; Yang 2013) | Not discussed |
Table 10 (on next page)

A comparative overview of VANET and MANET
| Property          | VANET       | MANET       |
|------------------|-------------|-------------|
| Mobility         | High        | Low         |
| Size             | Large       | Small       |
| Movement         | Geographic paths | Random in limited space |
| Protocol         | 802.11p     | 802.11a     |
| Topology         | Fast-changing | Slow changing |
| Power            | Unlimited   | Limited     |
| Node speed       | Very high   | low         |
| Interaction time | low         | High        |
| No of nodes      | Unknown     | Can be restricted |
| Anonymity        | High        | Low         |
| Node variation   | Very High   | Low        |
Table 11 (on next page)

summarizes the major properties of the trust models (only journal articles were considered)
| Study                        | CA Authentication | RSU Experience | Swarm Cluster | Opinion Hopping | Special nodes Fuzzy logic decentralized | Beaconing Credit allocation | Node Initialization Uncertainty |
|-----------------------------|-------------------|----------------|---------------|-----------------|----------------------------------------|-----------------------------|-----------------------------|
| (Ahmad et al. 2018)         | yes               | no             | yes           | no              | no                                     | no                          | yes                         | no                          |
| (Gazdar et al. 2018)        | no                | no             | yes           | no              | no                                     | no                          | yes                         | no                          |
| (Soleymani et al. 2017)     | no                | yes            | no            | no              | no                                     | no                          | no                          | no                          |
| (Ahmed et al. 2017)         | no                | yes            | no            | no              | yes                                    | no                          | no                          | no                          |
| (Wahab et al. 2014)         | no                | no             | no            | no              | no                                     | no                          | no                          | yes                         |
| (Shaikh & Alzahraei 2014)   | no                | no             | no            | no              | no                                     | no                          | yes                         | no                          |
| (Yang 2013)                 | no                | no             | yes           | no              | no                                     | no                          | no                          | yes                         |
| (Chen & Wei 2013)           | yes               | yes            | no            | no              | yes                                    | no                          | no                          | yes                         |
| (Zhang et al. 2013)         | yes               | no             | no            | no              | yes                                    | no                          | no                          | no                          |
| (Li et al. 2012)            | no                | yes            | no            | no              | yes                                    | no                          | no                          | no                          |
| (Sahoo et al. 2012)         | no                | no             | yes           | yes             | yes                                    | no                          | no                          | yes                         |
| (Mármol & Pérez 2012)       | yes               | no             | yes           | no              | yes                                    | no                          | no                          | yes                         |
| (Minhas et al. 2011)        | no                | no             | yes           | no              | yes                                    | no                          | no                          | no                          |
Table 12 (on next page)

research challenges and directions related to gray areas
| S. No. | Related domain       | Challenge                                                                 | Research direction                                                                 |
|-------|----------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| 1.    | TM frameworks        | Development of Intelligent TM                                            | Trust management requires intelligent solutions, intelligent solutions in trust management are missing. |
| 2.    | Network              | Choosing between a centralized or decentralized network                  | A comparative study is required between centralized and decentralized approaches for ad hoc networks. |
| 3.    | Intelligent computing| Implementing concepts of nature-inspired computing (NIC) in vehicular ad hoc networks | The vehicular network has similarities with nature-inspired computing such as swarm computing and ant colony. The scientific coherence needs to be explored. |
| 4.    | Network initialization| Introducing a new node in ad hoc network                                 | While managing the trust new node entry in a network is a problem that needs to be addressed. |
| 5.    | Network cluster      | Cluster management                                                        | The cluster formatting and management for vehicular network needs to be standardized. |
| 6.    | Uncertainty          | Handling uncertainty while managing trust                                 | One of the complex problems while working on trust evaluation is uncertainty. Comprehensive solutions are required to handle uncertainty. |
| 7.    | Social media         | Use of social media for security                                          | The role of social media in enhancing the vehicular network security needs to be explored. |
| 8.    | Cybersecurity        | Preventing cyber attacks                                                  | The greatest threat to IoV security is cyber-attacks. IoV desperately requires cybersecurity protocols. |
| 9.    | Artificial intelligence | Use of context-awareness in ad hoc networks                                | The use of context awareness in ad hoc network security is a huge research area, that needs to be explored. |
| 10.   | Context awareness    | Implementation and knowledge representing                                | Implementing context awareness is a huge research area, especially knowledge representation in ad hoc networks. An intense in-depth research exercise is required in this direction. |