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Application and growth of long-range communications technology in vehicular communications

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ABSTRACT

Long range communications technology (LoRa) has been widely used in a variety of applications and researched in different domains to exploit its full potential. Its openness makes it ideal for a variety of internet of things (IoT) installations which further allows opportunities for viable solutions in vehicular communications. Hence, a bibliometric analysis was performed to distinguish the application and growth of the technology specifically in vehicular communications. The scoping review processes from Arksey and O'Malley was applied to guide the review process. The selected scholarly works adhered to the PRISMA-Sc framework where 385 articles from two main electronic databases, i.e., Scopus and Science Direct which discussed LoRa in vehicular communications contexts were assessed. This study aims to examine how LoRa's research has grown from year 2010 to 2021 among the scholars and determine key areas discussed in LoRa's vehicular communications research. Findings from 70 studies in the final analysis indicated that LoRa has been widely studied based on application, theoretical or protocol and performance. However, it has not been widely explored in vehicular context. Hence, our findings support the global research community in this context.

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1. INTRODUCTION

Intelligent transportation systems (ITS) are moving rapidly from connected vehicles to autonomous vehicles on the road. Vehicular communication is an important element for the deployment of advanced ITS applications [1]–[3]. Vehicle to vehicle (V2V) communication allows vehicles to transmit important messages with other vehicles which may avoid collisions, reduce travel time, and support autonomous driving. It is one of the four main constituents of V2X, which also includes vehicle to infrastructures (V2I), vehicle to pedestrians (V2P), and vehicle to network (V2N) [4]–[6]. Communication between vehicles is achieved using different communication technologies, including dedicated short-range communication (DSRC), long-range communications (LoRa), and cellular networks (LTE/5G) [7]–[9]. With the push of governmental forces, V2V is moving closer to reality. In 2020, the National automotive policy (NAP) 2020 has initiated on V2V technology research and development strategies. The hope is that by year 2030, communications among

V2V-equipped vehicles will support positive driving behaviors and significantly reduce the number of road accidents occurrence [10]. The V2V applications, issues, challenges, and research directions are presented in [4]. LoRa is a physical layer technology for long range bidirectional wireless communication [11], [12], which can be used with any media access control (MAC) layer. It operates at a frequency below 1.0 GHz by transmitting radio frequency signals within unlicensed industrial, scientific, and medical (ISM) bands, i.e., 868 MHz in Europe, 915 MHz in Australia and North America, and 433 MHz in Asia. This implies that anyone with the necessary devices to communicate on the LoRa spectrum may do so for free which makes it very attractive to the industries [13]. The proposed MAC layer for LoRa is long range wide area network (LoRaWAN) which can be deployed and maintained by users at their own cost [12]. However, even though the network i.e., LoRaWAN is publicly accessible to use, the hardware necessary to capture and modulate the network's frequencies is licensed and patented by a few significant market holders. LoRa itself is a patented technology of Semtech [12], [13] Semtech invented and patented LoRa, a physical layer technology for bidirectional wireless communication. A general overview of LoRaWAN network structure is shown in Figure 1.

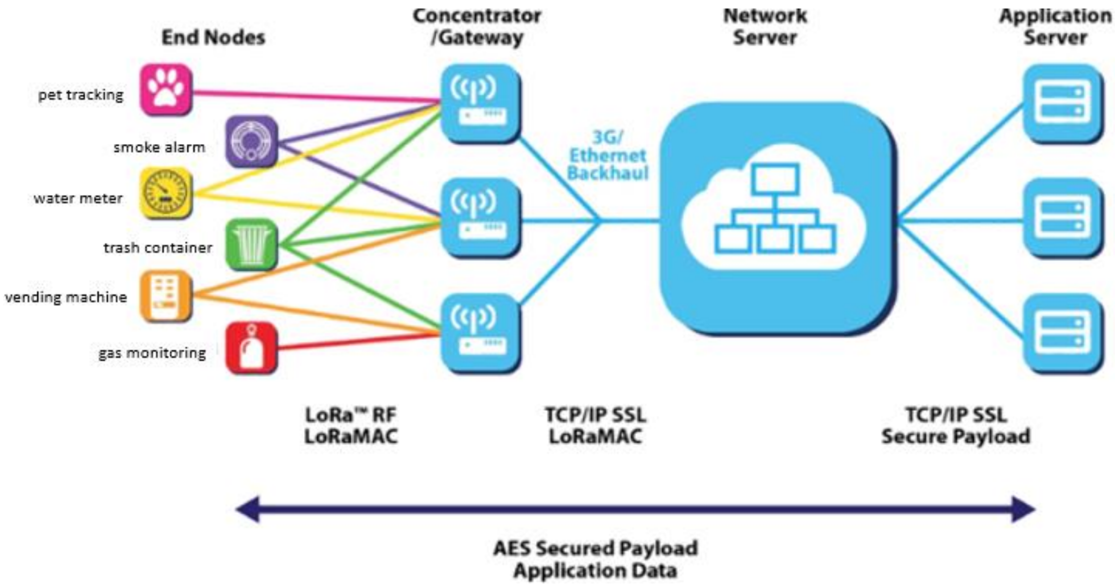

Figure 1. LoRa network structure [12]

LoRa technology offers itself as a generic solution for IoT. However, since LoRa is has low power consumption, flexible and the connectivity can be extended to any location, academic and researchers explore its behavior in greater depth in vehicular communication [14]. In a recent review, a qualitative investigation of LoRa for smart city solution involving sensors, complementary technologies, data science and citizen interaction was conducted following the PRISMA approach and strengths, weaknesses, opportunities, dan threats (SWOT) analysis. Including LoRa-based solutions is said able to improve productivity, manage energy, monitor human health, and improve operational efficiency in smart cities [15].

A comprehensive LoRa study was conducted by [13] to provide an overall view of LoRa modulation, including the data rate, frame format, spreading factor, and receiver sensitivity. The results reveal that LoRa modulation offers strong interference resistance due to the chirp spread spectrum modulation and high receiver sensitivity. Field testing demonstrates that LoRa can provide adequate network coverage up to 3 km in a densely populated suburban region. The spreading factor, like the data rate, has a substantial influence on network coverage. As a result, LoRa is particularly suited to low-power, low-throughput, and long-distance networks.

LoRa uses a modulation technique known as spectral propagation modulation with error correction support [16], [17]. The modulation scheme of chirp spread spectrum (CSS) broadcasts the signal using the entire channel bandwidth, thus allowing it to be more robust to noise and frequency offsets. This technology is also used on radars [18], [19]. Significant research is also being conducted in the field of LoRa-based communication, including the definition of a robust and reliable architecture as well as testing the reliability and performance in real-world scenarios [20], [21]. Moreover, Marais *et al.* [22] presents a summary of suggested LoRa and LoRaWAN testbed evaluation metrics derived from the literature. A relationship exists between the signal-to-noise ratio (SNR), bit error rate (BER) and packer error rate (PER) while the spreading factor (SF) influences the maximum bit rate, payload size and the transmission delay.

In this paper, we present a scoping review using the bibliometric analysis and the PRISMA-Sc for LoRa in vehicular communications context which is lacking in the current literature. We will concisely explain the method in section 2. In section 3, we discussed on the results and findings. Finally, in section 4, we concluded the scoping review and bibliometric analysis.

2. METHOD

The scoping review from [23] involves five processes, i.e., identifying research questions, identifying relevant studies, study selection, charting, collating, summarizing, and reporting results as illustrated in Figure 2. The research question provides the roadmap for subsequent stages. In this study, the following research questions were identified: i) how extensive is the research on long range communication (LoRa) technologies in vehicular communication context for the past decade? and ii) what are the areas of research in vehicular communications which applies LoRa including the performance metrics and the relevant validation schemes?

Figure 2. Scoping review processes

Next, relevant studies were identified by adhering to the PRISMA extension for scoping reviews (PRISMA-ScR) framework [24]. Using this framework, relevant keywords, core concepts, key areas and gaps were able to be identified and summarized from high number of sources through careful and rigorous review processes [25], [26]. The well-known electronic databases for scholarly work, i.e., Science Direct and Scopus were utilized to retrieve relevant works to our study. Moreover, both databases include vast number of peer-reviewed articles which are globally acknowledged. It considered only documents published in English between 2010 and 2021 that matched the search strings. Initial investigation discovers that research on LoRa has arisen in various subject areas. Almost 50% of documents related to LoRa communication technology implementation are in the computer science and engineering subject areas, whereas 27.74% are in medicine and dentistry. Other studies are in the areas of environmental science, energy, agriculture, biological science, and social sciences Table 1.

Afterwards, we use Boolean logic connectors, i.e., AND, OR, NOT to connect multiple search terms in the search strings. We also apply the filtering method provided in each electronic database to develop and include as many research articles as possible in relation to the identified research questions. The main search terms focused on terms commonly used to represent LoRa. The second group of search terms included keywords related to factors, experiments, implementations, and performance measures applied to obtain specific results on the main search terms from the databases. The third group of search terms were related to the vehicle communications context and common terms. The filtering methods included journal articles and conference proceedings in the area of computer science and engineering. See Table 2 for details on the search strings applied to retrieve the articles from the databases.

Table 1. Subject area of LoRa research

Subject Area	Science Direct		Scopus		Total
	No of documents (N= 3,879)	%	No of documents (N=25,549)	%	%
Computer Science	703	18.12	6371	24.94	24.04
Engineering	746	19.23	6540	25.60	24.76
Medicine and Dentistry	738	19.06	7474	29.25	27.91
Biochemistry, Genetics and Molecular Biology	463	11.94	4189	16.40	15.81
Environmental Science	391	10.08	2391	9.36	9.45
Energy	313	8.07	2362	9.24	9.09
Agriculture and Biological Science	443	11.42	-	-	1.51
Neuroscience	394	10.16	-	-	1.34
Social Sciences	268	6.91	-	-	0.91
Psychology	189	4.87	-	-	0.64
Physics and Anatomy	-		2598	10.17	8.83
Chemistry	-		2122	8.31	7.21
Material Science	-		1796	7.03	6.10
Immunology and Microbiology	-		1774	6.94	6.03

Table 2. Search strings

ID	Search strings (ScienceDirect)
#1	"LoRa" OR "long range communication" OR "LORAWAN"
#2	"Implementation" OR "application" OR "factors" OR "measures" OR "performance" OR "experiment"
#3	"Vehicle communication" OR "vehicular communication" OR "V2V" OR "vehicle to vehicle" OR "VANET" OR "connected vehicles" OR "vehicular network"
#4	#1 AND #2
#5	#1 AND #3
#6	#2 AND #3
#7	#1 AND #2 AND #3

The initial search results from both databases yielded 385 articles. The bibliographic citation file (".ris" file format) was imported into Rayyan [27] which enables the article review process to be remotely collaborated among our members. There were 20 duplicates that were detected and resolved to ensure a single copy of each related document. This citation information i.e., author and source information, bibliographic information, abstract and keywords are critical components which guide and influenced the members screening decisions of the yielded articles. The eligibility criteria were defined as in Table 3.

Out of the 385 articles retrieved from the initial search and filtering method, two reviewers first screened the titles and abstracts for eligibility and found that 112 articles do not focus on vehicular communication or LoRa in vehicular communication context. Later, full-text screening was performed by two reviewers on 253 articles. 96 studies either do not have the sought information based on our research questions or lack of findings were reported. Hence, the articles were excluded. The reviewers again thoroughly examined the full texts of all the potentially eligible articles to confirm their inclusion. A total of 157 articles met all the criteria identified. A third reviewer was consulted if both reviewers did not reach an agreement on certain articles. The results of the selection according to the PRISMA flow diagram are shown in Figure 3.

Table 3. Eligibility criteria

Inclusion Criteria	Exclusion Criteria
– Articles published in English	– Articles which no clear methodology
– Articles published between 1st January 2010 and 31st December 2021	– Articles which do not relate to LoRa technology
– Research focused on vehicular communication	– Articles which members have no access to the full text
– Articles published as original articles, reviews or conference proceedings	– Articles which do not have any relevant information which can provide support to answering the research questions
– Research primarily focused on LoRa in vehicular communication context	

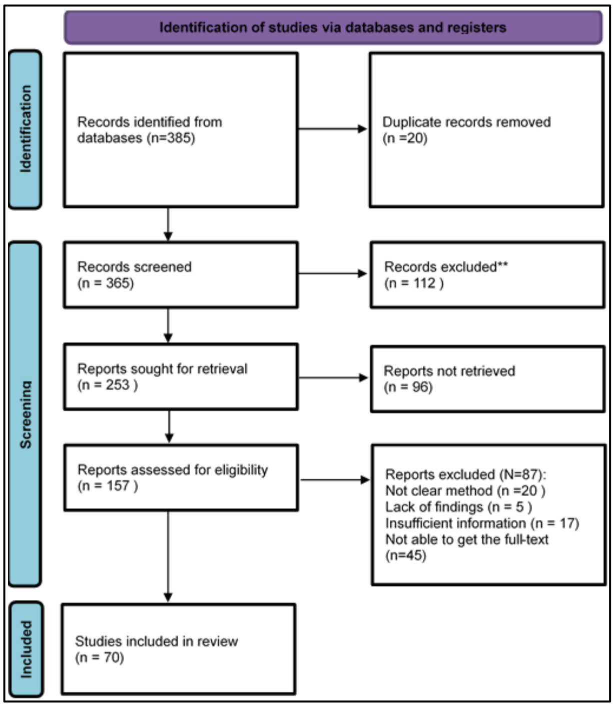

Figure 3. PRISMA flow chart

Afterwards, analysis of the final set of selected articles were performed to provide input for our investigation including the number of documents, citation number, country productivity and key terms. We performed a bibliometric analysis with the aid of VOSviewer version 1.6.7 [28] to analyze the relationship and connections among the selected articles from the scoping review in relations to LoRa and its use in vehicular communication. Keywords and related concepts were explored and interpreted from the visualizations generated by the software. Bibliographic and article information co-occurrences viewed in collaborative network maps revealed the research patterns associated with LoRa in vehicular context. A summary from these articles helps to summarize the fragmented research of LoRa and vehicular communication that aims to assist future researchers in enriching their work in this area.

In view of the data charting process, information from the included articles were summarized and tabulated using a narrative review approach. Additionally, numerical analysis was conducted on the number of articles presenting the related information to demonstrate the extent of research in particular theme. The final report was prepared to present the findings and analysis of this study which is hoped to fulfil the research gap in this area.

3. RESULT AND DISCUSSION

In general, there were 2,867 articles mentioning LoRa from the electronic databases. Amongst those, more than five publications were published by 66 countries individually. France, Italy, China, India, and United States are the most productive countries in publishing articles related to LoRa as shown in Table 4. The co-authorship of links from one researcher to another researcher is indicated by the total link strengths, championed by France which we believe is attributed by the Mobility 3.0 program launched by ATEC-ITS France. The program aims to speed up the massive transformation of the current intelligent transportation ecosystem which includes companies, local authorities, and research centers, as well as the Government.

Table 4. Top 10 countries for LoRa implementation work

No	Country	Documents	Citations	Total Link Strength
1	France	162	1277	471
2	Italy	174	980	405
3	China	237	981	277
4	United Kingdom	97	621	233
5	United States	157	927	205
6	Brazil	78	358	196
7	Spain	97	486	185
8	South Korea	80	373	178
9	India	163	325	147
10	Portugal	63	292	146

Figure 4 presents a mapping of the author’s keywords with a minimum value of ten occurrences from the articles. Keywords are grouped into four main clusters represented by different colors. Keywords which are commonly listed together by the authors belong to the same cluster. For instance, in this study, wireless sensor networks, LoRa, the internet of things, wireless technologies, and Wi-Fi have similar colors, suggesting that these keywords were closely related and usually occurred together. However, the thickness of the lines depends on the strength of the relationship [29]. In addition, bigger font size and size of the circles reflects higher number of articles with the keyword. In this case, most authors identified Internet of things as one of the keywords for their published work related to LoRa.

Further analysis on the co-occurrence of keywords reveals that the term internet of things (IoT) is also related to V2V communication and ITS. This bridges two different clusters, i.e., red- IoT and green-V2V and LoRa. Other keywords which co-occur with these terms include accidents, wide area network sensors, wireless sensor network, low power, and intelligent vehicle highway system, as shown in Figure 5.

Moreover, there are probabilities that two articles are related to a common subject matter such as LoRa and vehicular communications. This was revealed from the bibliographic coupling analysis in final selected articles (n=70) which shows the productivity of authors from 27 countries with a minimum of five citations per document. The relationship among these authors is shown in Figure 6.

Authors addressing similar research area may have commonly cited at least one article, represented by the value of the total link strength (TLS). This is true for 22 out of 27 countries from the selected articles. The highest is the United States (TLS=5), followed by Italy (TLS=3), and Japan, China, and Spain (TLS=2) as in Table 5.

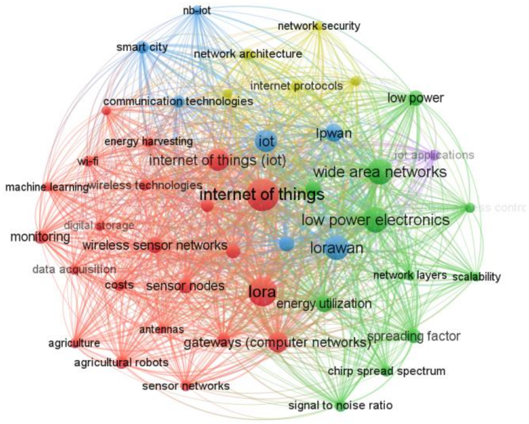

Figure 4. Co-occurrence analysis of keywords using search string #4

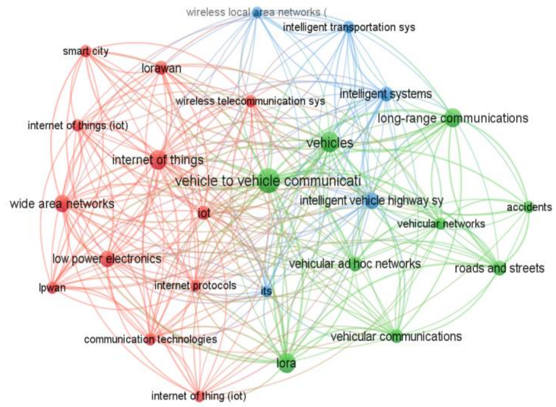

Figure 5. Co-occurrence analysis of the keywords (n=70) (min 5 occurrence of all keywords)

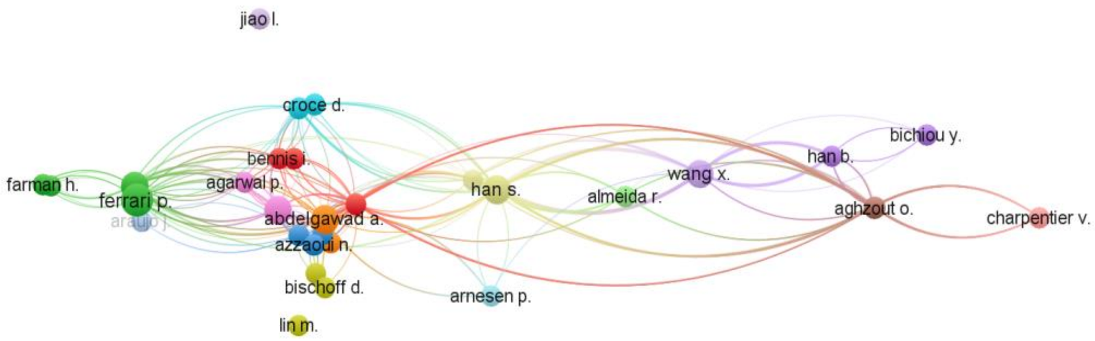

Figure 6. Cluster maps based on authors of LoRa in vehicular context articles

Table 5. Top 5 Countries from 27 countries (n=70)

No	Country	Documents	Citations	Total Link Strength
1	United States	13	284	5
2	Italy	8	61	3
3	China	10	88	2
4	Japan	3	13	2
5	Spain	6	60	2

In total, from the year 2010 to 2021, there are 230 authors with an average citation rate of 6.03 per document. LoRa-based vehicular communications-related papers were published in a number of publications. However, most of the selected articles that we review (n=70) were published in the journals listed in Table 6. The articles from these publications have the highest number of citations and can be categorized in specific use case or implementation area.

All articles were grouped into application, theoretical, and experimental groups based on the proposed solution for specific issues or problems that have been identified. The group of application articles refers to articles which reported the use of LoRa in road scenarios. Moreover, articles which introduced a new/modified protocol, framework or architecture were group as theoretical/protocol. Articles which focused on reporting experimental results of LoRa performance were denoted as experimental articles. The review refers to review articles that provide a summary of the research domain.

A synthesis and composition of articles selected are presented based on the categorization of the main themes as in Table 7. Despite the assortments of articles, the inclusion and exclusion criteria have enabled the categorization process to be conducted in a meticulous manner. However, due to limited space, the narrative review only covers articles within the theme which we selected for presenting related research on LoRa in vehicular communication contexts.

Over the past 10 years, LoRa has been applied to solve vehicle-related problems such as vehicle monitoring system, traffic management, and air quality monitoring system. However, these systems focused on vehicle-to-infrastructure or infrastructure-to-vehicle and not directly vehicle-to-vehicle technology. LoRa has been mentioned numerous times to be selected due to its minimal power requirements, long signal range and ability to improve the transportation systems. We listed ten most related publications in our point of view which presents the research direction in the vehicular communication context. The data charting for the application theme includes the source, main author's country, type of application and the main objectives of the study as seen in Table 8.

Table 6. Journal impact (highest citations)

Journal Name	CiteScore (2020)	SJR (2020)	SNIP (2020)	Total citations
Transportation Research Part C: Emerging Technologies	14.0	3.185	3.547	172
Sensors (Switzerland)	5.8	0.636	1.555	77
Energies	4.7	0.598	1.161	40
IEEE Transactions on Vehicular Technology	14.9	2.075	3.116	27
Chinese Journal of Aeronautics	4.7	0.719	1.767	26
IEEE Access	4.8	0.587	1.421	11

Table 7. Type of work for LoRa research in vehicular context

Subject area	No of documents	Percentage
Application	24	34.72
Theoretical/Protocol/Framework	20	28.47
Experimental	17	24.30
Review	9	12.50

Table 8. Scoping review results (application)

Source	Country	Application	Objectives
[30]	India	Emergency vehicle traffic management	To track active location of emergency vehicles based on RSUs and provide smooth mobility at traffic junctions via a long-range WAN routing protocol (LoRaWRP).
[31]	Spain	Remote vehicle monitoring	To monitor vehicles via a UNIX-based network interface for low power-wide area network (LPWAN) communications which applies (LoRaWAN).
[32]	China	Vehicle-borne information acquisition system	To demonstrate and verify information acquired from vehicle intelligent sensor, GPS, LoRa and 3G/4G technologies for bulk grain containers.
[33]	China	Long range cyclist sensing system	To sense cyclist using LoRa backscatter technology as means of preventing accidents.
[34]	Taiwan	LoRa-based LPWAN vehicle diagnostic system	To reduce consumers' data transmission fee of smartphone and achieving driving safety by providing vehicle diagnostics data via LoRa.
[35]	India	Traffic clearance system for emergency vehicle	To allow direct communication between emergency vehicle and nearby LoRa nodes to enable smooth passing through junctions with traffic lights.
[36]	Spain	Wireless traffic flow detection system	To detect traffic flow on highways using Short LoRa
[37]	China	Water quality monitoring system	To monitor water quality monitoring system based on LoRa and USV for pollution prevention and ecological protection.
[38]	India	Vehicle emissions detection	To collect the exhaust emissions from gas sensors using embedded system incorporated with wireless sensor network and alert vehicle owners.
[39]	Japan	Vehicle management system	To estimate the arrival time of rental cars.

Table 8 provides insights to the application of LoRa in relation to vehicles including vehicle management and monitoring, as well as traffic management. Nevertheless, applications of LoRa are also found in smart city applications [15], [40] including pipeline management [19], water quality monitoring system [37], smart lamp posts [41], garbage collector trucks tracking [12] and pollution monitoring [42], [43]. Applications of LoRa in other areas may also provide insights to researchers working on LoRa in the context of vehicular communication. For instance, Haiahem *et al.* [44] found that user location can be determine based on an abnormal received signal strength indicator (RSSI) value of less than -70 dBm. Furthermore, most likely, there are diverse applications of LoRa in vehicular context and others which are yet to be reported.

The data charting process for the second research theme found that researcher have also reported work on algorithms, methods, architecture, or framework to address some of the pertinent issues or challenges in LoRa deployment such as interference, latency, congestion, and security. Table 9 listed the ten articles selected based on the availability of the information including objective of their studies and key findings or outcome as well as the evaluation methods used to evaluate their proposed solutions. Simulation is the most used method to emulate a road traffic environment. Generally, researchers will bring forward the implementation in a real traffic condition upon satisfactory simulation results.

Table 9. Scoping review results (protocol)

Source	Country	Objectives	Key Findings/Output	Evaluation Methods
[45]	China	Overcome LoRa limited bit rate with modulation based on fractional Fourier transform	MuLoRa significantly improve the transmission bit rate MuLoRa is more flexible to meet the performance requirements of rate, power, collision avoidance and BER in different application scenarios in the future high data rate IoT era.	Simulation
[46]	Pakistan	Extend VANET's network capability via LoRaWAN	Integration was able to increase the network coverage and improve the energy consumption of corresponding loT applications.	Proof of Concept using SUMO
[47]	China	Loss differentiation rate adaptation (LDRA) protocol for vehicular safety communication	Considering reliability and performance, LoRa has substantial capabilities in highway environment.	Simulation
[48]	Rusia	Study the application of LoRa technology in the SDIoV network	A set of requirements for the use of LoRa technology as an IVC subsystem.	A laboratory test bench
[49]	Saudi Arabia	Examine the use of LoRa transceiver model with Matlab Simulink.	A comparison outcome of the simulation of LoRaWAN with the standard of LoRaWAN in terms of power and bandwidth.	Simulation
[50]	Spain	Analyze the operability of LoRa technology in an urban environment, using a hybrid network of concentrator nodes.	Hybrid wireless sensor network of long range and low power for mid-size city	Lab scale; Urban environment with three static gateways
[51]	India	Provide solution for massive traffic congestion and unbalanced traffic flow.	An algorithm, which uses intelligent switching of LTE and LORAWAN	NS-3 simulation (heavy traffic during peak hours with toll)
[52]	India	Effective sharing of the Intelligent transportation system sensory data.	A knowledge distillation-based transportation (KDT) system to process sensory data of transportation system using LoRa.	Simulation
[53]	India	Provide solution for interference caused by simultaneous communication between multiple LoRa nodes and a LoRa gateway.	A Beta distribution-based reputation model for estimating the association time duration between each LoRa node and LoRa gateways and Bayesian Game strategy which accommodates unknown private information of the LoRa nodes.	Simulation
[54]	Switzerland	Address localization of battery-operated devices.	RTK-GNSS module combined with a LoRa to achieve geo-localization with minimal wireless radio infrastructure requirements	Simulation

Articles which discussed findings from series of experiments intended to evaluate the performance of LoRa are categorized under the theme of experiments. In general, the experiments are conducted to understand the behavior and assess the performance of LoRa before any actual implementation. More experimental studies need to be performed before the LoRa technology can be established as appropriate for vehicular communication [55]. Possible optimization and configuration required for moving vehicles in different road environments is necessary to reach its full potential [12]. For example, LoRa communication performance was also studied in a mixed traffic environment which consists of V2V and non-moving vehicles [56]. Doppler effect was analyzed during the experiments like the work in [57], [58]. However, different configuration and experimental settings were performed by the studies including urban and suburban road environments as well as the forest [59]. The studies found that the smaller SFs are more appropriate for mobile nodes or in this case, the vehicular communication context. The Doppler effect has less effect on the SFs and communication is still reliable when the SF is 12 and the vehicles are travelling at a speed lower than 25 km per hour [57]. Additionally, application of mobile LoRa gateway by the roadside and a transmitter mounted on moving vehicles improved the communication performance in a Line-of-Sight scenario [58]. Moreover, direct V2V and V2I communication which bypass the LoRaWAN server is proposed to reduce the LoRa communication latency [60]. We selected ten of the articles under this subject area based on relevancy to our current project. Table 10 listed articles specifically aimed to assess LoRa's performance in vehicular context. We summarized the objectives, experimental setup or scenario, key findings and the performance measures used for this purpose.

Table 10. Scoping review results (Experiments)

Source	Country	Objectives	Experimental Setup/Scenario	Key Findings	Performance Measures
[18]	Italy	To assess usability of the LoRa wide area network (LoRaWAN) protocol in the context of vehicular networks	Elliptical track with a LoRaWAN Gateway positioned exactly in its center	LoRaWAN is robust also in case of transmissions taking place in motion, with limited signal degradation in the case of highest speed values.	▪ Received packets percentage ▪ Received signal strength indicator ▪ Signal to noise ratio ▪ Spreading factor
[56]	Brazil	To evaluate the communication between V2I, V2V, and stationary vehicles using LoRa te chnology including the Doppler effect.	Simulations were carried out with no network traffic while field test was limit to two vehicles testing	SF7 had a better reception ratio and SNR than SF 12. LoRa technology is more efficient in applications that require few characters in transmission and in situations where it is not necessary to send packets frequently.	▪ Signal strength ▪ Reception ratio ▪ Signal-to-noise ratio
[60]	Japan	To identify the exchange of road state information using LoRa under V2X environment	Field tests were carried out using two vehicles in non-line-of-sight positioning	Designed system has the capability for delivering the road state information in realistic speed on actual public road	▪ Received signal strength index ▪ Throughput ▪ Delivered data
[61]	Australia	To conduct energy performance analysis and modelling of LoRa prototyping boards (marketed as "extremely low power")	Field tests were conducted 5 times on four different boards	Proposed a design method which enables one to predict the power required to operate a battery- or energy harvesting-powered system and estimate the transmission interval ahead of time.	▪ Multiple frame power analysis ▪ Message size comparison ▪ TX power comparison ▪ data rate comparison
[62]	United States	To address the challenges such as reliability, data handover, time criticality, modularity, and energy efficiency with vehicles on the move under different practical scenarios.	Field tests were carried out using multiple RSUs placed at 320 m apart from each other with different vehicle speed	Reduce latency by offering direct V2V and V2I communication via LoRa technology.	▪ Kalman filter ▪ parametric testing using ANOVA ▪ power energy analysis
[59]	Brazil	To analyze LoRa performance in an urban mobility environment.	Simulation was carried out using NS-3 simulator	LoRa is suitable for event-driven activities.	▪ Packet delivery ratio (PDR) ▪ Packet inter-reception (PIR) time ▪ Received signal strength indicator
[63]	Japan	To investigate a lightweight and distributed physical layer key generation scheme adapting LoRa in V2V and V2I environment	Field tests were carried out using two remote control cars with different testing condition	Scheme could generate the same key for both V2V and V2I context under different environments	▪ Received signal strength indicator
[64]	Colombia	To design and implement tracking system using LoRa technology in V2V and V2I environment.	Field tests were carried out with three experiments performed during system deployment and two experiments performed with the already deployed system	System focuses on the components of communication between vehicles, the management center and with presentation of information to the end users.	▪ Received signal strength indicator
[65]	China	To classify LoRa and LoRaWAN deployment in V2X environment.	Field tests were carried out where gateway placed at office and LoRa device on one vehicle	LoRa and LoRaWAN manage to show the competence of the transmission performance	▪ Receiving Rate ▪ Latency
[66]	China	To analyze LPWAN for V2X communication under several scenarios.	Simulations were carried out using Monte Carlo model	LPWAN perform better in V2I than V2V environments	▪ Bit error rate ▪ Signal-to-noise ratio

The final subject area or research theme in this study refers to review/survey papers on LoRa. Since previous work on this context is limited, we extended our review to papers discussing internet-of-things, smart cities and V2X as well. A systematic literature review using PRISMA Guidelines was conducted on the use of LoRa in the development of smart cities. 96 papers were selected and classified according to LoRa usage in the domain either healthcare, agriculture, environment, traffic, industry, energy or waste management. Authors also reviewed LoRa communication network and transport capabilities in smart city environment. Smart energy and smart waste environment have received great attention among the researchers from year 2015 to 2019 [15]. In an earlier review, 54 selected research papers were referred to identify application trends in LoRa. Five main categories were proposed i.e., analysis/survey/factual discussion, performance/technical evaluation, real deployment/experimental/prototype implementation, simulation/modeling/network stack/software and applications [67].

Another study surveyed low power and LoRa technologies such as random phase multiple access (RPMA), Sigfox, LoRaWAN, LTE-M, narrowband internet of things (NB-IoT) and IEEE802.11ah which could be considered for machine to machine (M2M) communication like V2V including the openLPWA and proprietary low power wide area (LPWA) solutions. For M2M applications which require high data rate transmissions, the IEEE802.11ab and cellular-based technology are proposed instead of the LPWA network [11]. Similarly, a narrative review on V2X technology platforms and solutions as well as challenges was conducted with the aim to evaluate the adaptability of DSRC, cellular networks and hybrid methods in the V2X communication and its effect on ITS [7]. In addition, a summary of the primary V2V benefits linked to driver safety, with an emphasis on the most recent improvements in these systems is available from [6]. Emphasis was given to the data management aspect of V2V applications aimed to improve traffic management, road safety, direction and route optimization, and driver assistance. A survey by [68] proposed LoRa networks' capacity and performance to be assessed based on the physical (PHY) characteristics, deployment features and hardware selection, data transmissions, LoRa MAC protocols and applications as well as policies. Summary tables of related articles in each category are provided for other researchers to support their work in similar directions.

4. CONCLUSION

In this study, we have provided a literature scoping review on the LoRa communication in vehicular communications. The review and selection of articles adheres to PRISMA-Sc framework and can be replicated by other researchers. We also developed a literature-driven analysis using a bibliometric analysis tool to map and identify research directions related to LoRa in vehicular context that could provide valuable insights.

In general, even though the scoping review processes is not a systematic search similar to the systematic review process, the scoping review was able to help researchers to identify complex and subjective selection criteria as well as map key themes in the related research domain. Moreover, the bibliometric analysis provides a non-traditional way of getting insights on co-occurrences of the articles based on authors, country, citations and keywords trends. This reveals collaborative initiatives among researchers across the globe who have studied LoRa especially in vehicular context.

Nevertheless, this study does not include all articles published in the research domain. Only two electronic databases (Scopus and Science Direct) were utilized to acquire the articles. Despite the study's limitations, to the best of our knowledge, there is no article which has adopted this kind of approach to investigate LoRa in vehicular context. Useful insights from bibliographic coupling and co-occurrence analysis may support findings from the scoping review and vice versa.

Our results show that over the past years (2010 to 2021). Studies in LoRa have grew consistently with main focused on the protocol or theoretical, applications and performance evaluations. This is understandable since LoRa is basically a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technology.

The potential of long-range (LoRa) is still being explored in different domains. However, our attempt to visualize the bibliographic coupling of the articles reveal that very few authors are working across other countries in this area including China, Italy, United States and Spain. Most articles are home-grown with no evident collaboration initiatives from global researchers in similar domain. Keywords mapping also revealed that LoRa is mainly tagged with internet-of-things, low power, wireless sensor, and sensors. This reveals that research of LoRa in vehicle context particularly vehicle-to-vehicle communication is not fully explored and future work in this direction will provide feasible solutions to the global traffic monitoring and management system.

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