When LPWAN Meets ITS: Evaluation of Low Power Wide Area Networks for V2X Communications

Yuke Li[1,2,3], Linyao Yang[1,2,3], Shuangshuang Han[1,2,4], Xiao Wang[1,2,4], Fei-Yue Wang[1,5]
[1] The State Key Laboratory for Management and Control of Complex Systems,
Institute of Automation, Chinese Academy of Sciences, Beijing 100190, China
[2]Qingdao Academy of Intelligent Industries, Qingdao, 266109, China.
[3]School of Computer and Control Engineering,
University of Chinese Academy of Sciences, Beijing 100049, China
[4] Vehicle Intelligence Pioneers Inc., Qingdao, 266109, China
[5] Research Center for Military Computational Experiments and Parallel Systems Technology,
National University of Defense Technology, Changsha 410073, China
Email: {liyuke2014, yanglinyao2017, shuangshuang.han, x.wang, feiyue.wang}@ia.ac.cn

***Abstract*—Recently low power wide area network (LPWAN) is widely researched and deployed due to its excellent performance of supporting large coverage, low power consumption and massive capacity. LPWAN might offer brandnew solutions to Vehicle to anything (V2X) communications, which is faced with the challenge of supporting massive connections due to the dramatically increasing number of vehicles. In this paper, after surveying the existing V2X communication technologies, we compare the traditional technologies with the representative LPWAN technologies according to their performance metrics. After the careful comparison and selection, Long-Range (LoRa) and enhanced machine type communication (eMTC) are introduced to V2X communication due to their support for mobility. Moreover, their performance are evaluated in both V2I (vehicle-to-infrastructure) and V2V (vehicle-to-vehicle) communication environments via Monte Carlo simulations.**

***Index Terms*—eMTC, ITS, LoRa, LPWAN, V2X communications**

I. Introduction

Intelligent transportation systems (ITS) utilize communication, information and control technologies to coordinate the behaviour of the vehicles, which is expected to propel transportation to be more safe and efficient [1]–[7]. V2X communications, as a key part of ITS, incorporates V2I, V2V and vehicle-to-pedestrian (V2P) communications. V2X communications transmit information from a vehicle to any entity that may affect the vehicle and is known as a powerful and effective method to improve the road safety, reduce road crashes and ease traffic congestions. However, V2X communications still suffer from many major problems. Report released by Bernstein predicted that the amount of connected cars will reach over 250 million by 2020 [8], at that time nearly one fifth of the world's cars will be equipped with wireless Internet capabilities. By 2040, the global number of cars on the road will nearly be doubled and reach up to two billion [9]. The increasing number of vehicles forces the increasing demand for massive connections and large scale of coverage, which bring new challenges to V2X communications.

LPWAN, as a new paradigm of Internet of Things (IoT), has been broadly investigated for its ability to solve the coverage, power consumption and connection problems faced by other communication technologies. There are many technique candidates that have been pushed into global markets by several competing communication technology providers, such as LoRa [10], Sigfox [11], Narrowband IoT (NB-IoT) [12], eMTC [13] and Ingenu [14], etc. [15]. Most LPWAN members have the ability to provide high-quality communications with the coverage of up to 10 km and the connection abilities of over one million devices with the expenses of very low power consumptions [15]. LPWAN has been widely explored in many IoT applications, such as smart buildings [16], smart gas and water meter [17], smart streetlights, smart parking [18], etc. It is predicted that the global LPWAN market will grow from 1,01 billion dollars in 2016 to 24,46 billion dollars by 2021, at a compound annual growth rate of 89.3% [19].

These remarkable properties of LPWAN may offer inspirations to solve the problems in V2X communications. The traditional V2X communication technologies contains dedicated short-range communication technology (DSRC), cellular technologies, and other wireless access technologies, such as Radio Frequency Identification (RFID), Bluetooth, ZigBee, WLAN, etc. [20], [21]. Compared with these traditional V2X communication technologies, LPWAN can support more than millions of devices per cell with a longer battery life of over two years and a larger scale of coverage. However, LPWAN technologies exchange small amount of data traffic and most of them are insensitive to latency. With all the properties considered, LPWAN is suitable for delay-tolerant applications such as traffic efficient applications rather than safety applications. Up to now, only a few literatures have studied LPWAN in ITS scenarios. In [22], the authors proposed a LoRa-based LPWAN vehicle diagnostic system. In [23], a LoRa-based vehicular monitor was introduced. In [24], an experimental study of LPWAN was carried out in mobile environments. However, in spite of the increasing popularity of research in LPWAN, little is known about the LPWAN applied in V2X communications.

In this paper, we select the representative LPWAN technologies and apply them to V2X communications to analyze their performance in six typical V2X communication scenarios. The main contribution of this paper are on two holds. On the one hand, we survey the existing communication technologies in the V2X communications, including traditional technologies such as DSRC, cellular networks, ZigBee, etc., as well as typical LPWAN technologies such as LoRa, eMTC and NB-IoT. The performance metrics such as data rate and latency of these technologies are investigated and compared in detail. On the other hand, after the analysis, two representative LPWAN technologies, i.e., LoRa and eMTC, are applied to V2X communications and their performance in both V2I and V2V scenarios are evaluated.

The rest of the paper is presented as follows. In Section II, an overview of V2X communication technologies are introduced and compared with the typical LPWAN technologies by their key performance indicators. In Section III, the details of the channel model are presented. In Section IV, the simulation results are presented and analyzed. Finally, Section V concludes this paper.

II. Overview of V2X Communication Technologies

There are several potential solutions for V2X communications: DSRC, cellular network technologies and other wireless access technologies. Due to the remarkable performance of LPWAN in capacity and coverage, it can be seen as one potential solution for V2X communications. In this section, we survey the available communication technologies in V2X communications and then offer a comprehensive comparison between traditional technologies and LPWANs.

A. *Traditional V2X Communications Technologies*

DSRC is a short-range wireless communication technology specifically designed for vehicular ad hoc networks (VANETs). DSRC is mainly based on two standards: At PHY and MAC layers, DSRC use IEEE 802.11p standard; and for middle of the stack, DSRC employs standards defined by IEEE 1609 group [25]. DSRC operates at 5.850-5.925 GHz and the spectrum is divided into seven 10 MHz channels, each DSRC band is either divided into multiple channels or used as a single channel according to the supporting communication standards. DSRC utilizes diverse formats to transmit information, and the key feature is the basic safety message (BSM), which provides a good support for safety applications [25]. DSRC provides a high data rate (3-27 Mbps) [26] and low latency communication with a coverage range of under 1 km.

Cellular networks are long-distance communication technologies using base stations to relay messages, which have evolved from 2G to 4G and 5G (being proposed currently). Cellular networks support a country-level mobility and have a large-scale usage on mobile devices for its widely deployed base stations. 4G is more suitable for ITS communications for its high speed and Internet access and a cellular vehicular network has been proposed to integrate ITS services in 4G [27]. While 2G and 3G require high latency of a few seconds, 4G has reduced it to tens of milliseconds. The main drawbacks of cellular networks include lack of broadcasting mechanism and requirement for operation fees. Despite of these drawbacks, cellular networks can be used to provide connections for V2I and V2V communications and services for passengers such as traffic management and entertainment.

RFID uses radio signals to record data of an object without seeing or touching the carrier [28]. It can work on various frequency bands, with very low latency and a coverage range typically less than 10 m. RFID provides a good support for mobility thus it can be used for automatic recognition and has some applications on automated toll collection [21].

ZigBee is a low-speed and low-power wireless network with a data rate under 250 Kbps. It is built on IEEE 802.15.4 standards and operates on the unlicensed ISM bands. ZigBee has a flexible network management which is called self-organization [29] and a good support for mobility. It also has low latency partly due to its short handshake time and high throughput. ZigBee is widely used in wireless sensor networks (WSN) and has many applications on consumer electronics and industrial control. With these characteristics, ZigBee can be used to transmit the disposed sensing data such as acceleration of nearby vehicles and provides a more energy-efficient solution for vehicle identification [30].

Infrared (IR) is a highly directional communication technology; thus, it is suitable for single lane uses with a poor support for mobility. It has a high data rate from 1 to 128 Mbps in the distance under 100 m and very low delay (within a few milliseconds). The main drawback is that it is sensitive to severe weather [31]. With the wide bandwidth and low latency, IR can provide connections for time-sensitive data among vehicles.

Worldwide interoperability for microwave access (WiMAX) is a member of 4G technology and based on IEEE 802.16 set of standards [32]. WiMAX supports mobility and provide services with high transmission quality at a speed of over 120 km/h. It provides a high data rate (up to 75 Mbps), covers a transmission range of 50 km and has low latency (under 50 ms) [33]. Due to its high data rate and long transmission distance, it is mainly used for multimedia data transmission and provides good service of entertainment for passengers.

Bluetooth is a short-range communication technology offering an indoor coverage usually less than 10 m and works in the unlicensed industrial, scientific and medical (ISM) band. Bluetooth is equipped with a lower data rate (less than 3 Mbps) and the newest release bluetooth low energy protocol has a higher data rate which can reach to 24 Mbps [34] and the latency has also reduced to 3 ms. Due to its limited coverage and low complexity, Bluetooth can be used to transmit data between intra-vehicle devices and sensors without cables. Bluetooth also has some applications on traffic monitoring such as traffic density estimation.

Millimeter-wave (mmWave) is an extremely high frequency wireless communication technology, which operates on frequency band from 30 to 300 GHz and supports enormous communication capacity. Due to the remarkable characteristics of mmWave, i.e., it is inherently directional and sensitive to blockage because of the high carrier frequency, thus it provides limited support for mobility. It can accommodate large number of vehicles with a gigabit-per-second (Gbps) data rate [35] in ITS environment. mmWave has low latency but the short communication range because of high rain attenuation and atmospheric absorption. Considering the characteristics mentioned above, mmWave can be used to transmit high volume data among vehicles nearby.

TABLE I
COMPARISONS AMONG ITS APPLICATIONS

	eMTC(LTE Cat M1)	NB-IOT(Cat NB1)
Deployment	In-band LTE	In-band LTE Guard-band LTE Standalone
Downlink	OFDMA[15 kHz]	OFDMA[15 kHz]
Uplink	SC-FDMA[15 kHz]	Single tone [15/3.75 kHz] SC-FDMA[15 kHz]
Peak Rate	DL:1 Mbps UL:1 Mbps	DL:250 kbps UL:20 kbps(ST)
Latency	10-15 ms	1.4-10 s
UE receiver BW	1.4 MHz	200 kHz
Duplex mode	Full/Half-duplex FDD/TDD	Half-duplex FDD
UE transmit power	23 or 20 dBm	23 or 20 dBm
Power saving	PSM, eDRX	PSM, eDRX
Coverage	155.7 dB	164 dB for standalone, FFS others

B. LPWAN

LPWAN technologies can be classified into two categories in terms of their operating frequency bands. One set of LPWAN technologies including LoRa (Long Range) and Sigfox operates on the unlicensed ISM radio bands. The other set of LPWAN technologies, such as eMTC and narrowband IoT (NB-IoT) operates on the licensed bands [36]. Among unlicensed LPWAN technologies, LoRa has a relatively faster pace in development and commercialization. LoRa is also able to support localization and mobile tracking applications. As for licensed LPWAN technologies, NB-IoT and eMTC have attracted more attention due to their early step in standardization and commercialization. Therefore, in this paper, we select LoRa and eMTC as the representative LPWAN technologies to evaluate their performance in V2X communications.

1) LoRa: LoRa is a proprietary technology designed by Semtech and based on chirp spread spectrum (CSS) modulation. This modulation scheme uses wideband linear frequency-modulated pulses to modulate its spectrum. The frequency of pulses linearly changes over a stated amount of time based on the encoded information. With the help of sufficiently broadband chirps, the ability to combat against multipath fading is improved. LoRa is able to transmit signals reliably under high in-band and out-band interference, which contributes to the good coverage of about 157 dB [37]. There are four key parameters for the customization of the modulation of LoRa, i.e., bandwidth, spreading factor, coding rate and carrier frequency. The selection of these parameters determines transmission range , resilience to noise, and energy consumption.

LoRaWAN [10] networks are organized as a star topology, in which some nodes served as gateways to transmit messages between end devices and central server. LoRaWAN is a specifically optimized MAC layer protocol which can provide long lasting service for energy-limited end devices. LoRa can transmit messages over very long distances through the relay of the gateway nodes. In order to schedule the receive window slots for downlink communication, LoRa also defines three options classes A, B, and C, among which class A must be supported by the end devices.

2) eMTC: In LTE Release 13, eMTC or also named by CAT-M1, has been further evolved from the existing track of MTC improvements [38], [39]. eMTC provides a large coverage of up to 15-20 dB and supports a large number of devices. eMTC is also low power consumed, with output power as low as 20 dBm, which means that the battery life is able to reach up to ten years [13]. eMTC reuses the concept of reference signals and channels, which is an extension of LTE. eMTC operates with a bandwidth of 1.08MHz, it utilizes 6 LTE Physical Resource Blocks (PRBs) to transmit or receive physical channels or signals [40]. The downlink and uplink design of eMTC is same as LTE, among which the downlink scheme is based on orthogonal frequency division multiplexing (OFDM), and the uplink scheme uses single carrier frequency division multiple access (SC-FDMA), both with 15kHz subcarrier spacing.

3) NB-IoT: Release 13, another LTE-based track called Narrowband IoT (NB-IoT) was standardized. As revealed by its name, an NB-IoT carrier uses one LTE PRB in the frequency domain for a total of 180 kHz, it can be flexibly deployed in the guard band or into the carrier of LTE, and it can also re-farm a GSM carrier. NB-IoT has a high data rate of 250 kbps for uplink and 230 kbps for downlink [41].

C. Remarks

Both eMTC and NB-IoT operate on licensed spectrum, which provides excellent security and quality of service. Both of them are able to take advantage of power saving mode (PSM) and achieve long battery life up to 10 years. There are some technical differences between eMTC and NB-IoT. Compared with NB-IoT, eMTC has a wider bandwidth and supports larger data rate up to almost 1 Mbps, which is almost four times to NB-IoT. Another major difference is mobility. eMTC has the ability to handover from cell site to cell site, which enables mobile applications, while NB-IoT is strictly limited to fixed applications. Thus, eMTC is a good choice for applications such as Voice over Long-Term Evolution (VoLTE) [42] and tracking devices. NB-IoT aims to serve the applications such as control equipment, sensors, and meters. Moreover, NB-IoT has a relatively long delay of a few seconds, while eMTC has a much smaller delay of about only ten milliseconds [43]. Thus, eMTC is preferred for latency-sensitive applications. Based on the aforementioned discussions, eMTC will be the better choice for V2X communications than NB-IoT. The comparison between eMTC and NB-IoT is shown in Table I.

The comparison among LoRa, eMTC and traditional V2X communications is shown in Table II, the major metrics such as data rate, latency, coverage range and operating frequency are listed. Compared with traditional technologies, LPWAN characterizes with low data rate, insensitive latency, but with much larger coverage and capacity. Though WiMAX is also able to provide larger coverage, the frequency of WiMAX higher than 10 GHz results in short wavelength, which makes WiMAX difficult to pass through obstacles and the performance can be easily affected by the bad weather conditions. Due to the features of LPWAN, it is suggested to be utilized for traffic efficiency applications, such as fleet management, vehicle tracking, vehicle diagnosis, etc. These applications are utilized to optimize flows of vehicles to reduce travel time and traffic congestion. The data from the sensors are collected and transmitted to the server [44]. The applications usually are not delay-sensitive but require high communication reliability. Driven by this desire, in next section, we apply LoRa and eMTC to V2X communication and evaluate their performance in both V2V and V2I scenarios.

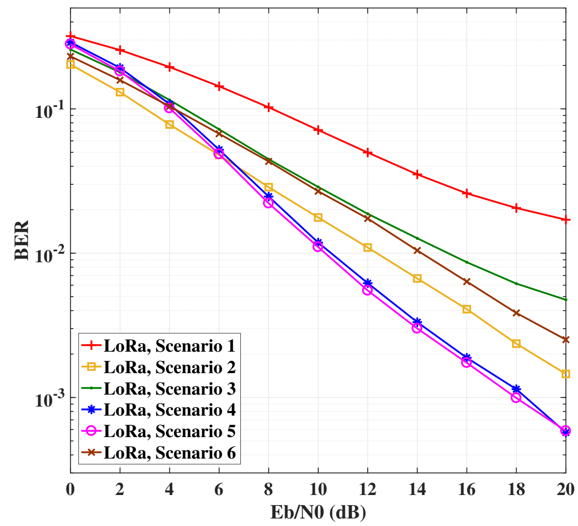

Fig. 1. The simulation results of LoRa under six V2X scenarios.

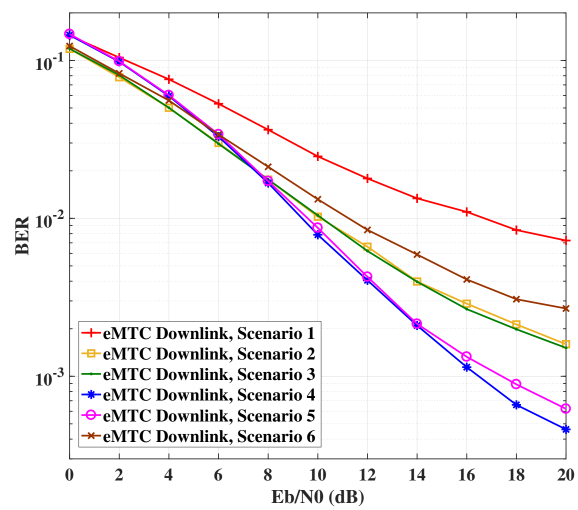

Fig. 2. The simulation results of eMTC under six V2X scenarios.

III. Channel Model and Estimation

To perform our simulations, we experiment the channel model proposed in [45], [46], which is a standard V2X channel model specifically for IEEE 802.11p standard. The measurement was carried out among six scenarios in the metropolitan Atlanta, Georgia area [47], which are

- Scenario 1: V2V Expressway Oncoming, $\upsilon = 104$ km/h, $f_D = 100$-120 Hz.
- Scenario 2: V2V Expressway Same Direction with Wall, $\upsilon = 32$-48 km/h, $f_D = 100$-120 Hz.
- Scenario 3: V2V Urban Canyon Oncoming, $\upsilon = 104$ km/h, $f_D = 900$-1150 Hz.
- Scenario 4: Roadside-to-vehicle (R2V) Expressway, $\upsilon = 104$ km/h, $f_D = 600$-700 Hz.
- Scenario 5: R2V Urban Canyon Oncoming, $\upsilon = 32-48$ km/h, $f_D = 400$-500 Hz. and
- Scenario 6: R2V Suburban Street, $\upsilon = 32$-48 km/h, $f_D = 300$-500 Hz.

Where υ is the velocity, f_D is the Doppler Shift. Channel parameters of these six scenarios are listed in Table III. Scenarios 1-6 cover both V2V and R2V channels and a wide range of Doppler shifts.

In simulations, channel is estimated by the preamble, which is located in front of data symbol and indicates an entire symbol which can be recognized by transceiver. Then, the data symbol is equalized and demodulated by the channel estimation.

IV. Simulations

In this section, we carry out Monte Carlo simulations to analyze the bit error rate (BER) performance of LoRa and eMTC versus the signal-to-noise ratio (SNR), which represents the ratio of energy per bit and the variance of the Additive White Gaussian Noise (AWGN), i.e., E_b/N_0. All of the simulation parameters are shown in Tabel III, which are selected according to the LoRa and eMTC specifications.

TABLE II
COMPARISON AMONG LORA, EMTC AND TRADITIONAL V2X COMMUNICATIONS

Technology	Operating Frequency	Data Rate	Latency	Coverage Range	Support for Mobility
Cellular Networks	0.8-3.6 GHz	20 Mbps	50 ms	10 km	Support
DSRC	5.8-5.9 GHz	3-27 Mbps	200 μs	1 km	Support
Bluetooth	2.4 GHz	24 Mbps	3 ms	10 m	Limited
ZigBee	2.4 GHz	250 Kbps	100 ms	20 m	Support
IR	2.6 GHz	1 Mbps	very low	100 m	No
RFID	125 KHz–2.45 GHz	106 kbps (13.56 MHz) 424 kbps (27.12 MHz)	low	10 m	Support
WiMAX	5.8 GHz	75 Mbps	50 ms	50 km	Support
mmWave	30-300 GHz	1 Gbps	150 μs	10 m	Limited
LoRa	868-915-433 MHz	0.3-50 Kbps	$<$2 s	3-8 km (urban) 15-22 km (rural) 15-45 km (flat)	Support
NB-IoT	900-1800MHz	Uplink: $<$250 Kbps Downlink: $<$230 Kbps	1.4-10 s	35 km	No
eMTC	DL: 729-2170 MHz UL: 699-1980 MHz	1 Mbps	10-15 ms	10 km	Support

TABLE III
SIMULATION PARAMETERS

Parameter	LoRa	eMTC
Carrier Frequency	870 MHz	880 MHz
Modulation	CCS	QPSK
Signal Bandwidth	500 kHz	1.08 MHz
Spreading Factor	7	–
Code Rate	1	1
Sample Intervel/Rate	2 μs	23.04 MHz
Subcarrier frequency spacing	–	15 kHz
Block Length	–	1536
CP Length	–	108

Before applying LoRa and eMTC to V2X communications, some measures should be taken to combat against the fast fading caused by Doppler effect in V2X communications. For LoRa, higher bandwidth and lower spreading factor parameter configurations should be selected to resist against the fast fading. Here, we set the spreading factor of LoRa to be 7 and the bandwidth to be 500 kHz. For eMTC, the interleaving grouping method is used in both downlink and uplink modulations to obtain the frequency diversity. The code rates of LoRa and eMTC are set to be 1 with channel coding omitted.

Fig. 1 shows the BER performance of LoRa in six V2X scenarios. From Fig. 1, scenario 1 shows the worst BER performance than other scenarios due to its highest Doppler shift. This can be also observed in Fig. 2. In Fig. 1, it can be seen that the performance of LoRa under scenario 1 and 2 with higher Doppler shift show worse performance than other scenarios. Thus, LoRa is sensitive to Doppler shift. In Fig. 1, we can see that the curves of scenario 4, 5 and 6 sharply decline as SNR increases. The performance of LoRa in scenario 4 and 5, i.e., R2V expressway and R2V urban canyon oncoming, superior to that of other scenarios. This reveals that LoRa might be more suitable for R2V communications.

Fig. 2 shows the BER performance of eMTC in six V2X scenarios. For simplicity, here we only consider the downlink of eMTC, which is implemented by OFDM same as in LTE systems. Fig. 2 shows the similar phenomenon as in Fig. 1. Scenario 1 with the largest Doppler shift shows the worst performance and scenarios 4 and 5 show the best performance. This reveals that the LPWAN technologies share similar performance in V2X communications. In Fig. 2, The error floor induced by Doppler shift can not be found and the bit error rate of most scenarios are lower than 10^{-2} when Eb/N_0 is larger than 15 dB. The frequency diversity can be obtained since that the subcarriers are spaced equally in a distance, which is larger than the coherence bandwidth with the help of interleaved grouping method.

V. CONCLUSIONS

In this paper, we first reviewed existing communication technologies for V2X communications, including traditional technologies such as DSRC, cellular networks, ZigBee, and etc., as well as LPWAN technologies such as LoRa and eMTC. A comprehensive comparison between traditional technologies and LPWANs in V2X communications has been investigated. It is shown that LPWAN is more suitable for traffic efficiency applications, such as fleet management, vehicle tracking, vehicle diagnosis, etc. LoRa and eMTC are selected to be applied in V2X scenarios due to their supporting for mobilit y. Simulation results demonstrated that LPWAN technologies perform better in V2I environments than V2V environments.

ACKNOWLEDGMENT

This work was supported by National Natural Science Foundation of China (61501461, 61702519, 61533019, 61503380, 61806198, and 91720000), Beijing Municipal Science & Technology Commission (Z181100008918007), and SKLMCCS (Y6S9011F69).

REFERENCES

[1] G. Giannopoulos, “The application of information and communication technologies in transport,” *European J. of Operational Research*, vol. 152, no. 2, pp. 302 – 320, 2004.

[2] F.-Y. Wang, N.-N. Zheng, D. P. Cao, C. M. Martinez, L. Li, and T. Liu, “Parallel driving in CPSS: a unified approach for transport automation and vehicle intelligence,” *IEEE/CAA J. of Autom. Sinica*, vol. 4, no. 4, pp. 577–587, 2017.

[3] N.-N. Zheng, S. Tang, H. Cheng, Q. Li, G. Lai, and F.-Y. Wang, “Toward intelligent driver-assistance and safety warning system,” *IEEE Intell. Syst.*, vol. 19, no. 2, pp. 8–11, Mar. 2004.

[4] X. Wang, K. Zeng, X. Zhao, and F.-Y. Wang, “Using web data to enhance traffic situation awareness,” in *Proc. 17th Int. IEEE Conf. on Intell. Transportation Syst. (ITSC)*, Oct 2014, pp. 195–199.

[5] F.-Y. Wang, “Parallel control and management for intelligent transportation systems: Concepts, architectures, and applications,” *IEEE Tran. on Intell. Transportation Syst.*, vol. 11, no. 3, pp. 630–638, 2010.

[6] S. A. Nobe and F.-Y. Wang, “An overview of recent developments in automated lateral and longitudinal vehicle controls,” in *Proc 2001 IEEE Int. Conf. on Syst., Man and Cybernetics*, vol. 5, 2001, pp. 3447–3452.

[7] S. Han, X. Wang, J. J. Zhang, D. Cao, and F.-Y. Wang, “Parallel vehicular networks: A CPSS-based approach via multi-modal big data in IoV,” *IEEE Internet of Things J.*, pp. 1–1, 2018.

[8] L. Mearian, *Gartner foresees 250M connected vehicles on the road by 2020*. [Online]. Available: https://www.computerworld.com/article/2875572/gartner-foresees-250m-connected-vehicles-on-the-road-by-2020.html

[9] M. N. Smith, *The number of cars worldwide is set to double by 2040*. [Online]. Available: https://www.weforum.org/agenda/2016/04/the-number-of-cars-worldwide-is-set-to-double-by-2040

[10] LoRa. [Online]. Available: https://www.lora-alliance.org

[11] SIGFOX. [Online]. Available: https://www.sigfox.com

[12] Y. P. E. W. et.al., “A primer on 3GPP narrowband Internet of things,” *IEEE Commun. Mag.*, vol. 55, no. 3, pp. 117–123, Mar. 2017.

[13] A. R.-A. et.al., “An overview of 3GPP enhancements on machine to machine communications,” *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 14–21, June 2016.

[14] Ingenu. [Online]. Available: https://www.ingenu.com

[15] Q. Song, L. Nuaymi, and X. Lagrange, “Survey of radio resource management issues and proposals for energy-efficient cellular networks that will cover billions of machines,” *EURASIP J. on Wireless Commun. and Networking*, vol. 2016, no. 1, p. 140, 2016.

[16] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, “Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios,” *IEEE Wireless Commun.*, vol. 23, no. 5, pp. 60–67, October 2016.

[17] M. Pennacchioni, M.-G. Di Benedette, T. Pecorella, C. Carlini, and P. Obino, “NB-IoT system deployment for smart metering: Evaluation of coverage and capacity performances,” in *Proc. of AEIT Int. Annual Conf., 2017*, 2017, pp. 1–6.

[18] T. Lin, H. Rivano, and F. Le Mouël, “A survey of smart parking solutions,” *IEEE Trans. on Intell. Transportation Syst.*, vol. 18, no. 12, pp. 3229–3253, 2017.

[19] “Low power wide area network market by connectivity technology (SIGFOX, LoRaWAN, Weigthless and others), technology service, network deployment, application, verticals and region,” Global Forecast to 2021. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/low-power-wide-area-network-market-41351212.html

[20] S. K. Bhoi and P. M. Khilar, “Vehicular communication: a survey,” *IET Networks*, vol. 3, no. 3, pp. 204–217, 2013.

[21] A. Maimaris and G. Papageorgiou, “A review of intelligent transportation systems from a communications technology perspective,” in *Proc. of 2016 IEEE 19th Int. Conf. on Intelligent Transportation Syst. (ITSC)*, Nov 2016, pp. 54–59.

[22] Y. S. C. et.al., “i-car system: A LoRa-based low power wide area networks vehicle diagnostic system for driving safety,” in *Proc. of 2017 Int. Conf. on Applied System Innovation (ICASI)*, 2017, pp. 789–791.

[23] C. Hsieh, Z. Ye, C. Huang, Y. Lee, C. Sun, T. Wen, J. Juang, and J. Jiang, “A vehicle monitoring system based on the LoRa technique,” *Int. J. of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Eng.*, vol. 11, no. 5, pp. 1100–1106, 2017.

[24] D. Patel and M. Won, “Experimental study on low power wide area networks (LPWAN) for mobile Internet of things,” in *Proc. of 2017 IEEE 85th Veh. Technology Conf.*, June 2017, pp. 1–5.

[25] J. B. Kenney, “Dedicated short-range communications (DSRC) standards in the united states,” *Proc. of the IEEE*, vol. 99, no. 7, pp. 1162–1182, July 2011.

[26] P. Papadimitratos, A. D. L. Fortelle, K. Evenssen, R. Brignolo, and S. Cosenza, “Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation,” *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 84–95, November 2009.

[27] T. T. et al., “Cellular vehicular networks (CVN): Prose-based ITS in advanced 4G networks,” in *Proc. of 2014 IEEE 11th Int. Conf. on Mobile Ad Hoc and Sensor Syst.*, Oct 2014, pp. 527–528.

[28] E. B. Panganiban and J. C. D. Cruz, “RFID-based vehicle monitoring system,” in *Proc. of 2017 IEEE 9th Int. Conf. on Humanoid, Nanotechnology, Inform. Technol., Commun. and Control, Environment and Manage. (HNICEM)*, Dec 2017, pp. 1–6.

[29] J. Wang, “Zigbee light link and ITS applicationss,” *IEEE Wireless Commun.*, vol. 20, no. 4, pp. 6–7, August 2013.

[30] R. A. Gheorghiu and M. Minea, “Energy-efficient solution for vehicle prioritisation employing zigbee V2I communications,” in *Proc. of 2016 Int. Conf. on Appl. and Theoretical Electricity*, Oct 2016, pp. 1–6.

[31] P. Fernandes and U. Nunes, “Platooning with DSRC-based IVC-enabled autonomous vehicles: Adding infrared communications for ivc reliability improvement,” in *Proc. of 2012 IEEE Intell. Veh. Symp.*, June 2012, pp. 517–522.

[32] A. Ghosh, D. R. Wolter, J. G. Andrews, and R. Chen, “Broadband wireless access with WiMax/802.16: current performance benchmarks and future potential,” *IEEE Commun. Mag.*, vol. 43, no. 2, pp. 129–136, Feb 2005.

[33] Y. Niu, Y. Li, D. Jin, L. Su, and A. V. Vasilakos, “A survey of millimeter wave communications (mmWave) for 5G: opportunities and challenges,” *Wireless Networks*, vol. 21, no. 8, pp. 2657–2676, 2015.

[34] J. de Carvalho Silva et al., “LoRaWAN #x2014; a low power wan protocol for Internet of things: A review and opportunities,” in *Proc. of 2017 2nd Int. Multidisciplinary Conf. on Comput. and Energy Sci. (SpliTech)*, July 2017, pp. 1–6.

[35] S. K. Agrawal and K. Sharma, “5G millimeter wave (mmWave) communications,” in *Proc. of 2016 3rd Int. Conf. on Computing for Sustainable Global Develop. (INDIACom)*, Mar 2016, pp. 3630–3634.

[36] R. Ratasuk, B. Vejlgaard, N. Mangalvedhe, and A. Ghosh, “NB-IoT system for M2M communication,” in *Proc. of 2016 IEEE Wireless Commun. and Networking Conf.*, April 2016, pp. 1–5.

[37] J. Petajajarvi, K. Mikhaylov, A. Roivainen, T. Hanninen, and M. Pettissalo, “On the coverage of LPWANs: range evaluation and channel attenuation model for LoRa technology,” in *Proc. of 2015 14th Int. Conf. on ITS Telecommun. (ITST)*, Dec 2015, pp. 55–59.

[38] Release 13-3GPP. [Online]. Available: http://www.3GPP.org/release-13

[39] C. Hoymann and et al., “LTE release 14 outlook,” *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 44–49, 2016.

[40] D. Vukobratovic, “Massive machine-type communications and revival of ALOHA,” *INFOTEH-JAHORINA*, vol. 16, 2017.

[41] J. Chen, K. Hu, Q. Wang, Y. Sun, Z. Shi, and S. He, “Narrowband internet of things: Implementations and applications,” *IEEE Internet of Things J.*, vol. 4, no. 6, pp. 2309–2314, 2017.

[42] R. Ratasuk, D. Bhatoolaul, N. Mangalvedhe, and A. Ghosh, “Performance analysis of voice over LTE using low-complexity eMTC devices,” in *Proc. of 2017 IEEE 85th Veh. Technology Conf. (VTC Spring)*, June 2017, pp. 1–5.

[43] M. E. Soussi, P. Zand, F. Pasveer, and G. Dolmans, “Evaluating the performance of eMTC and NB-IoT for smart city applications,” *arXiv preprint arXiv:1711.07268*, 2017.

[44] G. Araniti, C. Campolo, M. Condoluci, A. Iera, and A. Molinaro, “LTE for vehicular networking: a survey,” *IEEE Commun. Mag.*, vol. 51, no. 5, pp. 148–157, May 2013.

[45] X. Cheng, M. Wen, L. Yang, and Y. Li, “Index modulated OFDM with interleaved grouping for V2X communications,” in *Proc. of 2014 IEEE 17th Int. Conf. on Intell. Transportation Syst. (ITSC)*, 2014, pp. 1097–1104.

[46] Y. Li, M. Wen, X. Cheng, and L.-Q. Yang, “Index modulated OFDM with ICI self-cancellation for V2X communications,” in *Proc. 2016 Int. Conf. on of Computing, Networking and Commun.*, 2016, pp. 1–5.

[47] M. A. Ingram, “Six time-and frequency-selective empirical channel models for vehicular wireless LANs,” *IEEE Veh. Technology Mag.*, vol. 2, no. 4, pp. 4–11, 2007.