IPv6 Communications over LoRa for Future IoV Services

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Abstract—**The advantages of all-IP scenarios is clear for both high-level protocol and application developers. However, the usage of IPv6 together with new communication technologies especially designed for Internet of Things (IoT) deployments is not straightforward. This is the case of Low Power-Wide Area Networks (LP-WAN), where packets have a restricted length and the sole IPv6 header implies an excessive load. Fortunately, the arrival of the edge computing paradigm presents a perfect frame to locate adaptation mechanisms for embedding IPv6 datagrams within these networks at the frontier between the LP-WAN and the Internet. In this line, this work presents a solution in the area of vehicular IoT, which allows the IPv6 end-to-end connectivity between a moving and an Internet node, by means of an adaptation mechanism performed in a Multi-Access Edge Computing (MEC) node attached to the LP-WAN gateway. IPv6 datagrams are compressed following recent IETF guidelines to traverse a LoRaWAN network segment in a transparent way for higher level applications. The solution has been implemented and a real test-bench has been set-up to validate the proposal and extract experimental results that reveal its suitability for traffic-efficiency and warning services in the vehicular domain.**

Index Terms—**LoRaWAN, IPv6, LoRa, LP-WAN, evaluation.**

I. Introduction

The emergence of Internet of Vehicles (IoV), which implies the evolution of vehicular connectivity towards the Internet of Things (IoT) paradigm, will entail a radical change in the way current telecommunication infrastructures are managed [1]. This transformation has to be handled taking into account the heterogeneous nature of the upcoming wave of the new Internet services. Thus, heterogeneity is one of the key points to be considered for the successful deployment of the IoV ecosystem. Differing from the current approach by which different-nature services are handled by distinct Radio Access Networks (RAN), it is expected that all this diversity of services will be supported by a common infrastructure [2]. This heterogeneity will lead the network to be highly adaptable for satisfying the end-nodes' different demands. However, with the aim of providing a common ground for ensuring interoperability among different types of systems (fixed, mobile, vehicular, etc.), a common underlaying layer should be considered. In this line, IPv6 has been adopted as a nexus to interconnect IoT devices with the Internet services; hence, the provision of such capability to in-vehicle nodes could pave the way for future smart transportation applications.

An issue detected to support the aforementioned network heterogeneity is that all these features require new network architectures permitting to push processing and network services next to the end-users, which, in most of the cases, implies increasing the end-device complexity and cost. For that reason, new network paradigms have emerged, such as fog computing or Multi-Access Edge Computing (MEC). Fog and MEC conceptual approaches differ in the location of these equipment within the different layers of the system, but they have in common the idea of sharing the load of network management. On the one hand, in fog computing, cloud-nodes are directly located on the edge of the network, i.e., among the end-nodes. This architecture was the one proposed in its inception and, nowadays, it has been extended so any equipment within the system with processing and storage capabilities can be considered as a fog node [3]. On the other hand, following the MEC paradigm, the intelligence and storage are placed at the RAN edge, i.e., in between the end-nodes and the cloud. Therefore, fog and MEC paradigms enable cloud services within the close proximity of end-users [4], alleviating network management costs at the same time a better performance is assured. These features boost the development of new applications with special emphasis on context-awareness, as it is the case of vehicular scenarios [5]. Vehicular radio-access nodes, e.g., base stations, Road Side Units (RSU), or even on-board mobile routers, have been identified as privileged points for deploying intermediate processing and managing services following the MEC paradigm [6].

Among the new wave of communication technologies coping with especial IoT needs, a recent proposal called Low Power-Wide Area Network (LP-WAN) has attracted great attention due to its beneficial characteristics of long coverage ranges, low energy consumption and high scalability [7]. It is the authors' opinion that many vehicular applications can take advantage of the long-range transmissions and scalability offered by this solution for all kinds of road transport means in the areas of alert messaging, event notifications, or vehicle monitoring, as discussed in recent IoV applications [8], [9]. In fact, LP-WAN technologies have already been applied to vehicular environments [10]. As discussed in following sections, one of the most prominent LP-WAN solutions is LoRaWAN (Long Range Wide Area Network) due to its flexibility and high-grade of adaptability to the user needs [11].

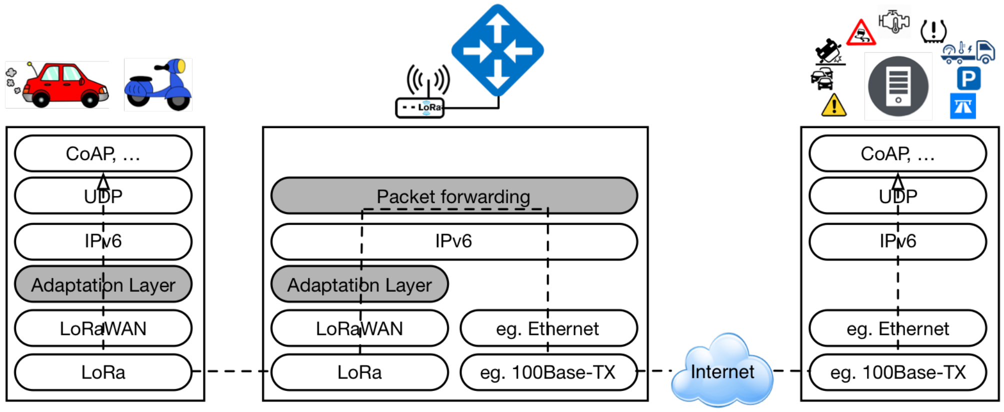

Fig. 1. Architecture of the IPv6 over LoRaWAN networking solution

As stated before, a network-level architecture compatible with regular Internet standards, e.g., IPv6, would be highly desirable for a quick integration of the whole LP-WAN system and its single end-nodes within the vast and heterogeneous IoT ecosystem. However, LP-WAN technologies are highly constrained regarding their transmission capabilities: limited bit-rate, reduced packet size, etc.; hence, the straight integration of IPv6 datagrams into LP-WAN packets is not trivial and compression mechanisms are necessary. For that reason, in this work the focus is on providing IPv6 connectivity to vehicles by using an LP-WAN link, but using a MEC-based architecture to allow this integration by using LoRa [11] technology as accessing network (please, see Fig. 1). The MEC node performs the packet translation tasks (compression/decompression) in order to interconnect the LoRa and IPv6 network segments. Thereby, bidirectional flows can be established between LoRa end-nodes and IPv6 nodes within an administrative domain or the Internet. The main contributions of this work are the following:

- A real implementation of IPv6 over LoRa is developed and tested.
- A vehicular test-bench is deployed for providing vehicles with IPv6 connectivity through LoRa links.
- A base IoV environment for smart transportation services is created, which is ready for including future processing and unloading tasks at the MEC node.

The rest of the document is organized as follows. Section II reviews the most prominent works addressing the integration of IPv6 in constrained communications systems. Section III presents an overview of LoRaWAN and its main limitations for transporting high volumes of data. The IPv6 transport over LoRaWAN is described is Section IV. The test-bench details are explored in Section V, while the attained results are presented and discussed in Section VI. The paper ends highlighting the most important conclusions in Section VII.

II. Related Work

Due to the interest devoted to the topic of allowing IPv6 communications on LP-WAN links, the Internet Engineering Task Force (IETF) has recently formed the IPv6 over Low Power Wide-Area Networks (lpwan) working group in 2016. It also considers the use of higher-layer protocols like User Datagram Protocol (UDP), and Constrained Application Protocol (CoAP) over LP-WAN networks. Two active Internet drafts are currently available addressing these issues [12], [13]. These documents propose the Static Context Header Compression (SCHC) for enabling the adaption of IPv6/UDP/CoAP headers to the stringent requirements posed by LP-WAN systems. A detailed exploration of these mechanisms will be presented in the following sections. From the academia perspective, very few works have addressed the integration of higher-layer protocols within LP-WAN architectures [14]–[16]. The work in [14] presents two different mechanisms for adapting the IPv6 header to fit it within the LoRaWAN Maximum Transfer Unit (MTU), one based on a static transformation agreement between the end-node and the gateway, and a dynamic one implying a previous negotiation. However, these mechanisms are based on IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) adaptation approach, which implies a network link with higher data rates and lower ranges than LP-WAN networks. Authors of [15] propose a similar approach, by encapsulating IPv6 packets over LoRa systems by replacing the IEEE 802.15.4 support of Contiki, in a 6LoWPAN case of study, with LoRa. Again, the same problem of protocol overhead arises when using a compression algorithm not adapted to LP-WAN but in this case the LoRaWAN layer is also removed. Finally, the work in [16] do follow the IETF lpwan guidelines, implementing the SCHC compression mechanisms and even proposing an improvement to reduce memory and processing demands in constrained devices. Nevertheless, the LP-WAN performance tests were done theoretically by using an air-time calculator instead of evaluating a real deployment.

Our work focuses on a generic IPv6 over LoRa solution to be especially evaluated in an IoV scenario. The work in [17] supports our hypothesis of using mobile LoRa nodes, indicating also that more than 15K nodes can be supported by a base station covering 2 km of radio for potential vehicular applications.

III. LoRaWAN

In this section, the LoRaWAN protocol is explored, emphasizing the strong constraints that it poses for transporting information from higher layers. Note that, although the implementation presented in this work only copes with the lowest layer (LoRa) for the moment, we consider important to detail the whole stack including the MAC specifications defined by LoRaWAN.

LoRa is based on a proprietary Chirp Spread Spectrum (CSS) modulation by Semtech. This modulation scheme permits achieving very long coverage distances of more than 10 km at the expense of reducing its transmission capabilities in terms of data rate and packet length. LoRa presents three different tunable parameters that permits it to be adapted for different scenarios. These parameters are: Spreading Factor (SF), Coding Rate (CR), and Bandwidth (BW). These factors determine the aforementioned trade-off between the achievable distance and the communication features (throughput, payload size, etc.). While LoRa defines the physical (PHY) layer of the communication stack, LoRaWAN defines the Medium Access Layer (MAC), introducing interesting characteristics such as acknowledgement schemes, security suites, or synchronization tools, among others. For further insides about LoRaWAN settings, please refer to [11]. Due to the need of employing low-bit rates for achieving long coverage ranges, the transmission's times on air are notably long; for that reason, it is highly valued to reduce packets size in order to avoid undesirable effects over the transmissions, e.g., interferences, collisions, excessive channel occupation, etc. This is the main challenge for introducing higher layer protocols inside LoRaWAN packets. Acceptable payload lengths range from 1 to 242 bytes, hence, observe that higher layer's Protocol Data Units (PDU) length should be as reduced as possible. The mechanisms employed for achieving a proper compression of the network and above layers are explored in the next section.

IV. Embedding IPv6 in LP-WAN

In this section, the IPv6 transport over LP-WAN is presented, including an overview of the header compression process under consideration.

A. General Encapsulation Proposal

The followed approach for the encapsulation process is shown in Fig. 1. As can be seen, application-level packets are encapsulated in UDP datagrams. It is assumed this protocol in order to diminish the network overload over the constrained LP-WAN link. Then, regular IPv6 datagrams are adapted to be sent over the given LP-WAN technology. For this to be done, the SCHC algorithm [12] is used. The final compressed IPv6 packet is sent as a packet payload, in a physical frame through the LP-WAN link.

As indicated in Fig. 1, the previous adaption is reverted upon the reception of the packet in the MEC node. The original IPv6 packet is then forwarded through a regular link, probably traversing the Internet, until reaching the final IPv6 destination node, which will be in charge of providing an IoV service in our study case, by implementing the application level of the concrete service.

B. Header Compression Process

As aforementioned, the Static Context Header Compression (SCHC) proposed in [12] has been adopted. This scheme is a header compression strategy and fragmentation functionality for IPv6 over low data-rate networks such as LP-WAN. It is based on a common static context that is stored in every end-device and the MEC node. The context contains information describing the content of the different fields of the packet headers and it is pre-provisioned for both extremes of the communication. Consequently, this context might not be transmitted over the LP-WAN link, e.g., it could be exchanged via an off-line method, and it must not change during the communication. This avoids resynchronization procedures and ensures the consistency of the (de)compression process. The context is composed of a set of rules that defines how to compress the different fields of the IPv6, ICMPv6, and UDP headers. The idea behind the SCHC compression is that LP-WAN traffic is very predictable. Thus, each rule is identified by a Rule-ID that represents an individual flow to/from a given device so, instead of sending the entire field values, just the Rule-ID is included in every compressed packet within each corresponding flow. The Rule-ID represents the rule that better matches the header fields and yields the greatest header compression. Consequently, every rule must also define the decompression actions to generate a valid IPv6 packet upon reception.

In this work, the rules proposed in [18] have been included in the considered static context for the ICMPv6 protocol. In addition, a rule for managing IPv6/UDP traffic has been added to the static context of our implementation, too. This rule is bidirectional and it is the only rule that applies to all UDP traffic, and it is defined as follows: (i) the source and destination ports are sent, and (ii) the length and checksum fields are suppressed. Observe that the length and checksum values can be independently computed in both extremes and the integrity of the packet can be assured by lower layers' mechanisms. As a result, the compressed size of the UDP header is just four bytes. In this work, fragmentation is not considered because all the sent packages over the network have a predefined size smaller than the maximum MTU of the adopted LP-WAN solution: LoRa.

V. Implementation and Deployment of the Solution

Concrete details of the middleware implementation used in both the end-device and the MEC node for the IPv6 encapsulation, and the real test-bench, are included in this section.

A. Integrating IPv6 over LoRa

As stated above, the implemented solution for encapsulating IPv6 packets within LoRa frames was developed following the guidelines in [12], [18], and taking as starting point the software in [19]. This solution allows end-devices to acquire an IPv6 address, hence enabling their interconnection with external networks through the MEC node. This implementation clearly differentiates two possible directions of traffic, namely, uplink and downlink traffic. For that reason, depending on the traffic direction, the actions needed to forward the packets are different. In an uplink communication, the end-device generates an IPv6 datagram, which is reduced following the SCHC compression. Then, the resulting packet is sent over the LoRa link. Note that the SCHC compression scheme does not modify the packet's payload, since it only reduces the information in the IPv6/UDP or IPv6/ICMPv6 headers and introduces the corresponding Rule-ID in a specific header field. When the uplink packet is received at the MEC node, it stores the end-device's source address in its *neighbor devices list*. Thus, this list contains the addresses of those end-nodes that accessed the external network though the MEC node. Then, following the instructions established by the corresponding Rule-ID, the received packet is decompressed, resulting in the original IPv6 packet. If the SCHC decompression procedure fails to decode the information, the packet is discarded. Finally, if the decompression is successful, the resulting packet is sent over the external network interface of the MEC node.

In turn, when the MEC node receives a downlink packet coming from its external network interface, e.g., Ethernet, the reverse steps take place and the packet is compressed using the SCHC compression procedure. The resulting packet is sent over the LoRa link and, finally, the end-node reconstructs de original packet in order to pass it up to the application layer through the complete IPv6 stack.

B. Test-Bench

In order to evaluate the integration of IPv6 over LoRa, several real-life experiments have been performed. In these experiments, a car incorporated an On-Board Unit (OBU) that served as an LoRa end-device. In addition to the OBU, in the other extreme of the communication a LoRa base station provided connectivity to the end-node, and a MEC node supported the adaptation operations described above. The OBU was formed by two main elements, namely, (i) an Arduino-compatible microcontroller board, and (ii) a LoRa radio transceiver. The microcontroller employed was the SmartEverything Fox development board by Arrow, and the LoRa transceiver used was the HopeRF RFM95W module. The antenna used by the OBU was an omnidirectional rigid model with a gain of 5 dBi. On the other hand, the MEC node communicated with the IPv6 network, i.e., the Internet, using an Ethernet interface and employed the LoRa base-station to stablish the LoRa link with the OBU. The base station employed was the RisingHF RHF2S008 model, which incorporates the Semtech's SX1301 chip. The antenna attached to the LoRa base-station was a sectorial model, adapted to work in the 868 MHz band. It presents high directionality (far-field beam-width of 65 degrees) and a gain of 8 dBi. Finally, during the whole set of experiments, the values assigned to the different LoRa configuration parameters were as follows: (i) the SF was set to 10, (ii) the CR was set to 4/5, (iii) the Explicit Header and CRC field were included, (iv) the BW was fixed to 125 kHz, and (vi) the programmed preamble was set to a value of 8 (for further insights about this parameters, please refer to [11]).

Regarding the location of the different elements of the scenario, both the base-station and the MEC node were placed in the Faculty of Computer Sciences of the University of Murcia (please, see Fig. 3). The base-station antenna was located in a window of the second floor of the building. The car followed the same predefined route in all experiments, involving a sub-urban area (Fig. 3). Thus, the scenario conditions were not the best to achieve an excellent performance of the LoRa link. However, note that the main focus of this work is validating the possibility of an IPv6 connectivity over LoRa technology and not to evaluate the performance of the PHY layer in terms of the link quality or coverage range. With the aim of evaluating the correct functioning of the IPv6 over LoRa integration, different figures of merit have considered, namely, Packet Delivery Ratio (PDR) and Round Trip Time (RTT). To this end, different tools have been employed during the experimental tests. First, by making use of the *ping6* command-line tool, a PC connected to the external network sent periodical ICMPv6 Echo Request packets to the OBU. The interval of these messages was three seconds, and the size of the payload was set to 16 bytes. Note that the *ping6* tool needed at least a payload size of 16 bytes to compute the timestamp of each Echo Reply. As a result, the total LoRa payload size of the compressed packet using SCHC was 29 bytes. Besides, in order to test the UDP protocol integration, a fleet tracking application was implemented. A PC connected to the IPv6 network sent position and speed requests using the IPv6/UDP protocol to the vehicle in a periodic manner. Whenever the OBU received a request, it obtained the solicitated parameters from its GPS module and sent them back to the solicitor through the base-station and the MEC node. The interval at which the PC sent the position requests was set to three seconds, too.

VI. RESULTS

In this section the attained outcomes from both ICMPv6 and UDP transmissions are explored. As explained above, the experiments were conducted by establishing a LoRa PHY link between the base station and a moving OBU. The first experiment was conducted considering the ICMPv6 protocol by which an external IPv6 node regularly sent ICMPv6 requests to the LoRa end-node. This permitted us to evaluate two key metrics such as the RTT and the packet delivery ratio, which are depicted in Fig. 2. In order to enrich the information provided by the figure, the vehicle speed was logged from the GPS and included in the plot. Regular RTT of about 920 ms are obtained (confidence interval of 4.8 ms, $\alpha = 0.05$). This is a long time in comparison with other transmission technologies, which is due to the low-bit rate of LoRa and the subsequent notable increase in each packet's time-on-air. Table I presents these values for the 3-different types of packets employed in this study and the specific LoRa configuration under consideration. However, these long RTT values can be considered as valid for non-critical applications in the area of traffic efficiency, such vehicle monitoring.

An unexpected outcome attained in this experiment is the high impact of the vehicle speed on the ratio of successful transmissions. Although Semtech has claimed the high robustness of LoRa modulation against Doppler effect and other mobility issues [20], the results attained in this experiment and those presented in [17] suggest that LoRa involves some difficulties to properly handle messages from/to mobile devices. Thus, observe in Fig. 2 the high correlation between the loss of

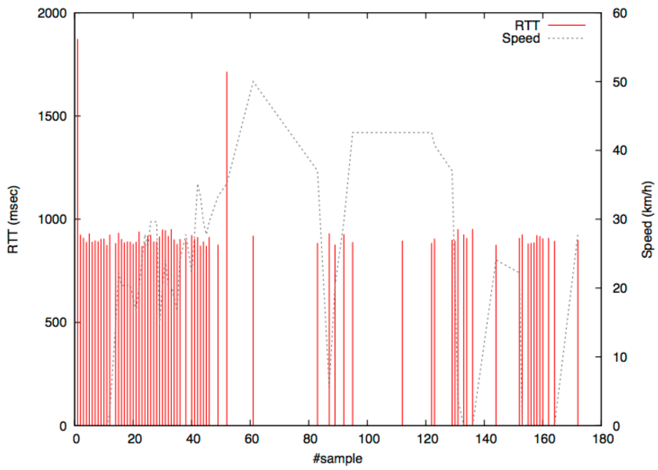

Fig. 2. Delay results obtained in the ICMPv6-based experiment.

TABLE I. PACKETS' TIMES ON AIR OVER LORA

Packet type	Size (bytes)	Time on air (ms)
ICMPv6 request/reply	29	411.64
UDP request	22	370.62
UDP reply	33	452.61

connectivity (blank spaces) and the vehicle's speed; while the PDR achieved when the vehicle was stopped was around 90%, this figure suffered a great decay when the vehicle was moving. This effect is out of the scope of this work and further research is needed for analyzing its impact on the performance of LoRa systems. Even so, despite this low-layer issues, from a higher-layer perspective, the ICMPv6 communication was correctly established between both end-points of the communication, and the interoperability between these two different-nature end-nodes was achieved. Recall that this communication was established between an IPv6 computer and the OBU by using the SCHC scheme over the LoRa link.In addition, as explained in previous sections, an UDP application has been also developed with the aim of emulating a fleet tracking service. In this case, the UDP header compression was considered, too. Thereby, an external IPv6 node simulating a fleet manager periodically polled the OBU for requesting its GPS coordinates and speed. Observe that, in addition to this information, other monitored parameters such as goods temperature and humidity, vehicle state, driver information, among many others, could be also requested by the managing system. Fig. 3 shows the GPS coordinates and speed of the tracked vehicle. When the end-node received the UDP tracking request, it extracted these parameters from its embedded GPS module and encapsulated them within the UDP payload. Thereafter, the generated datagram went through the SCHC compression process prior to its transmission within the LoRa frame. Again, observe the impact of the vehicle speed on the quality of the link. However, all the received packets were correctly decompressed and decoded at the IPv6 extreme of the communication, hence validating the correct functioning of the presented implementation.

VII. CONCLUSION

The paper presents a MEC-based approach to embed IPv6 datagrams within LoRaWAN networks. For this to be done, the IETF Static Context Header Compression (SCHC) algorithm is used. An adaptation procedure is performed at the end-device, whereas its counterpart has been developed for a MEC node attached to a LoRa gateway. The MEC node is then in charge of interconnecting LoRa end-devices with the regular IPv6 network, hence providing interconnectivity with the Internet.

The solution has been deployed in a real testbed to validate the solution under real vehicular settings and assess its basic performance figures of merit. It has been checked the proper operation of the system, at the same time round-trip delay tests of 1 ms have been obtained. The impact of speed in the performance of the LoRa channel is evident in our tests, observing a correlation between mobility and the packet delivery ratio.

This research opens a promising working line in the area of IPv6 interconnection of LP-WAN-enabled devices, with especial emphasis on the potential of this communication technology for vehicular networks. Next steps consider the implementation of a LoRaWAN (MAC) layer and a further study of the physical implications of this technology under mobility conditions.

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REFERENCES

[1] O. Kaiwartya *et al.*, "Internet of Vehicles: motivation, Layered Architecture, network model, challenges, and future aspects," *IEEE Access*, vol. 4, pp. 5356–5373, 2016.

[2] M. R. Palattella *et al.*, "Internet of Things in the 5G era: Enablers, architecture, and business models," *IEEE Consum. Electron. Mag.*, vol. 34, no. 3, pp. 510–527, Mar. 2016.

[3] R. Roman, J. Lopez, and M. Mambo, "Mobile edge computing, Fog et al.: A survey and analysis of security threats and challenges," *Futur. Gener. Comput. Syst.*, p. In press, Nov. 2016.

[4] A. Ahmed and E. Ahmed, "A survey on mobile edge computing," in *10th International Conference on Intelligent Systems and Control (ISCO)*, 2016, pp. 1–8.

[5] S.-A. Lazar and C.-E. Stefan, "Future Vehicular networks: What control technologies?," in *International Conference on Communications (COMM)*, 2016, pp. 337–340.

[6] D. Sabella, A. Vaillant, P. Kuure, U. Rauschenbach, and F. Giust, "Mobile-Edge Computing Architecture: The role of MEC in the Internet of Things," *IEEE Consum. Electron. Mag.*, vol. 5, no. 4, pp. 84–91, Oct. 2016.

[7] R. Sanchez-Iborra and M.-D. Cano, "State of the art in LP-WAN

Fig. 3. Speed of the monitored car in the UDP-based experiment.

solutions for industrial IoT services," *Sensors*, vol. 16, no. 5, p. 708, 2016.

[8] A. Ghose, P. Biswas, C. Bhaumik, M. Sharma, A. Pal, and A. Jha, "Road condition monitoring and alert application: Using in-vehicle Smartphone as Internet-connected sensor," in *IEEE International Conference on Pervasive Computing and Communications Workshops*, 2012, pp. 489–491.

[9] R. Dhall and V. K. Solanki, "An IoT based predictive connected car maintenance approach," *Int. J. Interact. Multimed. Artif. Intell.*, vol. 4, no. 3, pp. 16–22, 2017.

[10] J. Herrera-Tapia *et al.*, "Evaluating the use of sub-gigahertz wireless technologies to improve message delivery in opportunistic networks," in *14th IEEE International Conference on Networking, Sensing and Control, (ICNSC 2017)*, 2017.

[11] LoRa-Alliance, "A technical overview of LoRa and LoRaWAN," *White Pap.*, 2015.

[12] IETF, "LPWAN Static Context Header Compression (SCHC) and fragmentation for IPv6 and UDP," 2017.

[13] IETF, "LPWAN Static Context Header Compression (SCHC) for CoAP," 2017.

[14] P. Weber, D. Jackle, D. Rahusen, and A. Sikora, "IPv6 over LoRaWAN," in *3rd International Symposium on Wireless Systems within the Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS)*, 2016, pp. 75–79.

[15] S. Thielemans, M. Bezunartea, and K. Steenhaut, "Establishing transparent IPv6 communication on LoRa based low power wide area networks (LPWANS)," in *Wireless Telecommunications Symposium (WTS)*, 2017, pp. 1–6.

[16] K. Q. Abdelfadeel, V. Cionca, and D. Pesch, "LSCHC: Layered Static Context Header Compression for LPWANs," in *CHANTS Workshop - ACM MobiCom Conference'17*, 2017.

[17] J. Petäjäjärvi, K. Mikhaylov, M. Pettissalo, J. Janhunen, and J. Iinatti, "Performance of a low-power wide-area network based on LoRa technology: Doppler robustness, scalability, and coverage," *Int. J. Distrib. Sens. Networks*, vol. 13, no. 3, p. 155014771769941, Mar. 2017.

[18] IETF, "LPWAN Static Context Header Compression (SCHC) for ICMPv6," 2017.

[19] T. Lagos, "No Title." [Online]. Available: https://github.com/tlagos1/LoRA_IPv6_implementation. [Accessed: 01-Sep-2017].

[20] Semtech, "AN1200.22. LoRa™ modulation bsics," 2015.