RESEARCH

LPWAN-Based Hybrid Backhaul Communication for Intelligent Transportation Systems: Architecture and Performance Evaluation

Taghi Shahgholi[1†], Amir Sheikhahmadi[1*†], Keyhan Khamforoosh[1] and Sadoon Azizi[2]

*Correspondence: asheikhahmadi@iausdj.ac.ir
[1] Department of Computer Engineering, Sanandaj Branch, Islamic Azad University, Iran, Sanandaj
Full list of author information is available at the end of the article
†Equal contributor

Abstract

Increased number of the vehicles on the streets around the world has led to several problems including traffic congestion in many regions. Intelligent Transportation Systems (ITSs) are a viable solution for this problem by implementing efficient use of the current infrastructures. In this paper, the possibility of using cellular-based Low-Power Wide-Area Network (LPWAN) communications, LTE-M and NB-IoT, for ITS applications has been investigated. LTE-M and NB-IoT are designed to provide wide-range, low power and low cost communication infrastructures and can be a promising option which has the potential to be employed immediately in real systems. In order to to understand the feasibility of using LPWAN for ITS, two applications with low and high delay requirements have been examined: road traffic monitoring and emergency vehicle management. Then, the performance of using LTE-M and NB-IoT for providing backhaul communication infrastructure has been evaluated in a realistic simulation environment and compared for these two scenarios in terms of end to end delay per user. Simulation of Urban MObility (SUMO) has been used for realistic traffic generation and a Python-based program has been developed. This program has the ability to exchange live data with SUMO for communication performance evaluation. The simulation results demonstrate the feasibility of using LPWAN for ITS backhaul infrastructure mostly in favor of the LTE-M over NB-IoT.

Keywords: Intelligent Transportation Systems (ITS); wireless communication; LTE-M; NB-IoT; LPWAN; Real-time traffic monitoring

Introduction

Over the last decades, an ever-increasing rise in the number of vehicles, especially in metropolitan areas, has created multiple problems including traffic congestion, massive fuel consumption, high rates of accidents, and pollution. It is anticipated that by 2030 there will be around 2 billion cars on the roads in the world [1] which can affect daily life quality in urban areas negatively. The concept of Intelligent Transportation Systems has been introduced to enhance the traffic efficiency and reduce the negative impacts of heavy traffic. Despite the significant potential of these systems and their applications, still there are very few large scale deployment of ITS around the world. Huge cost associated with providing the infrastructure on the roads to transmit data from each point to a local or global central location is a major concern in this regard.

However, recent advances in wireless technologies along with the emerging Internet of Things (IoT) , opened up a new form of low-cost and wide-range communication which can reduce the challenges of immediate implementation of the ITS application. By integration with IoT, the ITS can apply advanced technologies in the processing, storing, and wireless communication to create the Internet of Vehicles (IoV) and Road Side Elements (IoRSE) [2][3]. This allows the vehicles and the infrastructure to communicate effectively to collect the traffic data and improve the traffic conditions [4][5].

On the other hand, increasing the volume, variety, and the speed of the generated data by IoT devices, creates several challenges to collect, transfer, store, analysis, and make decisions based on the data in real world applications. For ITS applications, due to the huge amount of generated data by sensors installed on the vehicles or Road Side Units (RSUs), transferring them to cloud servers could lead to unnecessary communication overhead, high bandwidth consume, and higher response delay in sensitive traffic information. [2], [6]. Recently, to address these challenges and reduce central computing power with less required data being transferred to the central location, various computing technologies have been introduced. These technologies are employed to solve services of processing, storing, and communication for the Internet of vehicles such as: Cloud computing [7], cloudlets [8], edge computing [9], Mobile Edge Computing (MEC) [10], and fog computing.

During recent years, fog computing was introduced [11], [12] to spread the cloud processing to the network edge to provide computation, networking, and storage capabilities between vehicles and data centers. Fog devices locally process collected traffic data and present real-time services such as efficient routing of vehicles, traffic information,and safety messages. In the fog-based environment, the cloud sever is only required to process and store historical data. The Fog-processing can improve the performance of these services significantly by eliminating the huge data transfer and processing in cloud [13], [14], [15].

Considering the above-mentioned issues, in this paper a novel architecture for ITS applications is proposed which allows using the Low-Power Wide-Area Network (LPWAN) and Fog-based communication and computing. This architecture examines the possibility of using cellular-based LPWAN communications, LTE-M, and Narrow band Internet of Things (NB-IoT) for ITS applications. Moreover, the performance in the realistic simulation environment is evaluated and compared. The main contributions of this paper could be summarized as:

- A novel hybrid LPWAN-based backhaul architecture has been proposed.
- ITS applications have been selected (traffic monitoring and emergency vehicle preemption) and a large-scale realistic simulation environment has been implemented.
- The simulation environment consists of the Simulation of Urban MObility (SUMO) and a novel Python-based program for communication network performance evaluation with ability to exchange live data with SUMO.
- The large-scale simulation results demonstrate the feasibility of using LPWAN for providing backhaul infrastructure for ITS application.

The remaining paper is organized as follows: Section 1 presents related works. Section 2 provides on overview of LPWAN cellular based communication technology, LTE-M and NB-IoT. Section 4 describes our system design. Section 5 presents the resulting analysis and discussion. Section 6 presents the conclusion.

1 Related Work

Introducing LTE-M and NB-IoT technologies in ITS environments, the authors in [16] proposed an architecture based on WSN and LTE-M for gathering the data of air pollution in the ITS environment. The LTE-M was deployed in the outdoor units and public vehicles such as buses. In architecture [16] Zigbee sensors were deployed in the stations. When buses stop at the stations, LTE-Ms collect data from Zigbess and send them to the cloud computers to be analyzed.

The authors in [17] used LTE-M technology to design urban rail transit systems and elaborated the advantages and disadvantages of this technology in such systems. Also, the work in [18] employed LTE-M technology accompanied in leaky coaxial cable as the main communication solution for future urban train systems. In other work [19] assessed the performance of LTE-M for Machine-to-Machine (M2M) communication. In [20] authors studied LPWAN technology in V2X communication and employed Long Range (LoRa) and LTE-M which are LPWAN based technology in V2X communication. The simulation result show LPWAN in V2I environment works better then V2V environment. Shi et al. [21] used NB-IoT technology in smart parking systems for long battery lifetime, low deployment costs, and wide range. The work in [22] evaluated an opportunistic crowd-sensing scenario in which sensors transfer a huge amount of traffic data using NB-IoT. The work in [23] studied the performance of LTE, LTE-M, NB-IoT, and 5G to recognize gaps of LTE requirements and accessible performance to eschew analogous disagreements when 5G is deployed.

In this work, NB-IoT and LTE-M is employed in a V2I envoronment Until 5G becomes ubiquitous.

2 Cellular-Based LPWAN Communication

With advances in the wireless communication systems, vehicles and infrastructures will be equipped with short-range radio technologies such as Dedicated Short-Range Communication (DSRC) and Long-range radio technology such as LTE. In terms of cost, the LTE is more expensive due to high power consumption, high deployment costs and complex protocols. On the other hand, the DSRC technology is limited in the range communication. The IoT technology in vehicles, traffic lights and other elements of road side needs to be simple, reliable, and accessible everywhere at any time; also, uses as less power as possible. One of the wireless communication solutions is LPWAN which is designed with target long battery lifetime and wide area coverage. LPWAN includes cellular (licensed band) and non-cellular (unlicensed) approaches [24], [25], [26]. NB-IoT and LTE-M are both LPWAN cellular-based communication technologies which are designed to reduce the device cost, increase the cell capacity, lessen the power, and widen the range to transmit/receive small amounts of data using lower bandwidth. [27], [28], [29] and [30].

Increased requirements to improve power consumption and signal coverage, Vehicles, traffic lights and other elements of roadside like RSU, Base Stations (BSs), that collecting real-time data related to traffic and air pollution, can be equipped with LPWAN and be not limit in energy consumption. The LPWAN can be one of the promising ways in next-generation communications of the ITS. The low power consumption, Low-cost hardware, and long-range communication are the major requirements for emerging ITS solutions.

The LTE-M is known as eMTC (enhanced Machine-Type Communication) created by 3GPP to IoT applications in long-range communications. This technology can improve the functions of roadside devices in terms of delay, and battery lifetime. The low power consumption of LTE-M enhances the battery up to 10 years. The bandwidth of LTE-M devices is 1.08MHz, which is equal to 6 LTE Physical Resource Blocks (PRBs). The cost of LTE-M systems is less than 2G/3G/4G technologies due to the reduced complexity of IoT road side elements. LTE-M can be used everywhere that LTE is used because, that is a transfiguration of LTE [31], [32], [19].

In the LTE-M considered Coverage Enhancement (CE) Modes A and B. In each two CE Modes repetition techniques for data channels and control channels are used.

CE Mode A is the default mode of LTE-M devices and networks and are used when moderate coverage enhancement and high data rates are needed such as voice call possibility and connected mode mobility.

CE Mode B is optional and can even further enhance coverage at the expense of throughput and delay, and it was mainly designed to provide deep coverage within buildings. Hence, Mode B is intended more for stationary or pedestrian speeds applications that require limited data rates and less data per month. The maximum coverage Mode B provides is highly configurable by the MNO (from 192 to 2048 repeats).

NB-IoT is another low power wide area similar to LTE-M that stands NB-IoT and, focuses on higher coverage, less energy consumption, and lower cost. However, the bandwidth of NB-IoT devices is 180 kHz (one PRB of LTE) [22], [33]. The geographical coverage in NB-IoT is better than LTE-M. Table 1 describes difference between LTE-M and NB-IoT.

3 Methods

In this work, we proposed a novel hybrid architecture, ITS- Fog-based communication and computing, which uses the LPWAN cellular-based communication technology (NB-IoT and LTE-M) with target reduce cost, higher cell capacity, and wide area coverage to transmit/receive small amounts of data using lower bandwidth. We evaluated the performance of using LTE-M and NB-IoT for providing backhaul communication infrastructure in a realistic simulation environment and compared for two applications with low and high delay requirements: road traffic monitoring and emergency vehicle management and preemption in terms of end to end latency per user.

To achieve this goal, first we have provided the proposed system architecture alongside with mathematical modeling for the Data Transmission Delay (DTD) from vehicle to the traffic lights and from there to the cloud. Then, We have developed a realistic traffic simulation environment using SUMO simulator and a Python-based program with the ability to live data exchange with SUMO for communication

Table 1: DIFFERENCE BETWEEN LTE-M AND NB-IoT.

Specifications	LTE-M	NB-IoT
Bandwidth	1.4 MHz	180 KHz
Maximum Number of RBs	6 PRBS in DownLink/UpLink	One RB
Coverage	155.7 dB	164 dB
Downlink Physical layer	OFDMA, 15 KHz tone spacing, turbo code, 16QAM, 1 Rx	OFDMA, 15 KHz tone spacing, TBCC, 1 Rx
Uplink Physical layer	SC-FDMA, 15 KHz tone spacing, Turbo code, 16QAM	• Single tone, 15 KHz and 3.75 KHz spacing • SC-FDMA, 15 KHz tone spacing • Turbo code
Deployment	In Band LTE	In Band, Guard Band LTE and Standalone
Number of Antennas	1	1
Transmit Power (UE)	20 dBm	23 dBm

performance evaluations. We have calculated and compared the DTD for both LTE-M and NB-IoT and the simulation results illustrate the feasibility of using LPWAN for ITS backhaul infrastructure where it was in favor of the LTE-M over NB-IoT.

4 System Design

Fig. 1 illustrates the proposed system architecture which includes vehicles, Traffic lights (TLs), several RSUs, and Cellular BS or evolved Node B (eNodeB). Following section provides information and assumptions about each element.

- *Traffic lights (TLs)* referred to a fixed element installed in intersections. Each TL controls in/out flow on roads with intersection with changing traffic signals [34], [35]. We assumed TLs are edge-node and able to process small amount of data with low complexity.
- *Road Side Unit (RSU):* RSU is a fixed element that is located in a different geographic location with the (x, y) coordinates on the road. RSUs have IEEE 802.11p/DSRC communication device to communicate with On-Board Units (OBUs) installed on vehicles and LPWAN communication devices to communicate with TLSs and LPWAN Base Station (BS). In proposed architecture, RSUs are equipped with basic processing, storing and communication functionality acting as a fog node.
- *LPWAN BS:* The BS (e.g. eNodeB) installed on road similar to RSUs in a geographic location with the (x, y) coordinates. BSs have a much broader communication range than DSRC.
- *Vehicles:* The vehicle is a dynamic node that is equipped with OBU, computing and networking resource. An OBU is a transceiver which can be mounted on a vehicle. Vehicles know their position using GPS and can communicate with other vehicles (Vehicle-to-Vehicle communication), traffic lights and RSUs (Vehicle-to-Infrastructure communication).

Sensors installed on vehicles generate huge amounts of data. If generated data transfer to RSU or Cloud using DSRC/LTE, it could take very long. Also, huge backhaul communication is required which accompanies with high installation and ongoing costs. Thus, the proposed architecture divides the whole city map into several sub road networks called areas. One RSU is required in each area. We assume RSUs as fog nodes that can pre-process traffic data or temporally store reiterative information. Moreover, there is one LPWAN (BS) able to communicate with LTE network, equipped with LTE-M/NB-IoT with communication range of R_c, able to cover several areas. In each area, there are several TLs equipped with the same LTE-M/NB-IoT module. TLs are considered as edge nodes.

The RSU has high capabilities relative to TL and can offer services such as helping the vehicles with navigation. TLs can process traffic data in its own intersections in order to reduce transformation of data to LPWAN BS. In our architecture, each TL has the capability of processing traffic data related to its own intersection. Each intersection can be linked to several roads, R_i as input roads and R_o output roads, as well as each road having minimum one lane L_r. The processed data by TL is sent to RSU at a lower volume (small size) with the same LTE-M/NB-IoT module. Therefore, we use LPWAN for communication between RSUs and TLs that has much lower cost, complexity and delay compared to DSRC. To assign TL to RSU we use the lowest distance which is calculated using Euclidean metric as

$$D = \sqrt{(TL_x - BS_x)^2 + (TL_y - BS_y)^2}$$

The fixed and historical data store on cloud servers. The historical data sent to cloud (core network) by LPWAN BS, and the fixed data such as the speed and capacity of roads are stored by transportation engineers and become updated at certain times.

In summary, in the proposed architecture system , the generated data by sensors installed on vehicles transfers to the nearest traffic light using DSRC communication in an area. Each traffic light in the same area processes the congestion of its own intersection to reduce the data transfer to LPWAN RSU. Then, traffic lights send the processed data to RSU by LPWAN, LTE-M or NB-IoT communications. Each RSU has exact detailed information of intersections in its own area. There are different functionalities that RSUs may perform such as: processing the traffic status of area, performing re-routing, proposing routes to vehicles in the area, emergency vehicle exemption, and broadcasting road information. This architecture can support early implementation of the backhaul for the intelligent transportation system. In the next section, we have performed the modeling for the proposed architecture with focus on end to end latency.

4.1 Modeling

In this section, we explain the latency from vehicles to the Traffic Management Center (TMC (remote servers)) on our scenarios.

4.1.1 Data Transmission Lelay (DTL)

Fig. 2 shows a diagram of end to end latency from vehicle to cloud in an ITS scenario. The expected total DTL from a vehicle to traffic light, traffic light to RSU, and from RSU to cloud can be expressed by

$$\begin{aligned} DTL(t) = {} & \alpha.PD^{V}(t) + \beta.\left(PD^{TL}(t) + TD^{V2TL}(t)\right. \\ & \left.+PgD^{V2TL}(t)\right) + \zeta.\left(PD^{TL2RSU}(t)\right. \\ & \left.+TD^{TL2RSU}(t) + PgD^{TL2RSU}(t)\right) \\ & + \theta.\left(PD^{RSU2Cloud}(t) + TD^{RSU2Cloud}(t)\right. \\ & \left.+PgD^{RSU2Cloud}(t)\right) \end{aligned} \tag{1}$$

where α, β and ζ defined as binary variables assigned for existence of the each communication delay i.e. DSRC, LTE-M, and cloud and $\alpha + \beta + \zeta + \theta = 1$. Also, $PD^{V}(t)$ defined as the processing delay happens at the vehicle v, where $PD^{TL}(t)$, $PD^{RSU}(t)$ and $PD^{RSU2Cloud}(t)$ denotes the delay for processing in the traffic light, RSU and cloud respectively.

$TD^{V2TL}(t)$, $TD^{TL2RSU}(t)$ and $TD^{RSU2Cloud}(t)$ are data transmission delay from a vehicle v to the traffic light with DSRC communication technology, from the traffic light to RSU with LTE-M/NB-IoT, and from the RSU to cloud with LTE respectively. $PgD^{V2TL}(t)$, $PgD^{TL2RSU}(t)$ and $PgD^{RSU2Cloud}(t)$ denote propagation delay from the vehicle v to the traffic light with DSRC communication technology, from the traffic light to RSU with LTE-M/NB-IoT, and from the RSU to cloud with LTE respectively.

$TD^{TL2RSU}(t)$ consists of the reception of downlink control information (DCI), transmission of data, and transmission or reception of the acknowledgment. We formulate the data transmission delay in the downlink (DL) and the uplink (UL) transmission as follows [36]:

$$\begin{aligned} TD^{TL2RSU}_{DL}(t) = {} & (PDCCH_{dur} + t_{D} + PDSCH_{dur} + t_{DUS}+ \\ & ULACK_{dur} * \lceil \frac{DataLen}{TBS(MCS;RBU)} \rceil \Big) \end{aligned} \tag{2}$$

$$\begin{aligned} TD^{TL2RSU}_{UL}(t) = {} & (PDCCH_{dur} + t_{DUS} + PUSCH_{dur} + t_{UDS}+ \\ & DLACK_{dur} * \lceil \frac{DataLen}{TBS(MCS;RBU)} \rceil \Big) \end{aligned} \tag{3}$$

Communication latency in LTE-M/NB-IoT depends on the Transport Block Size (TBS) and the number of repetitions, N_R. In Equs. (2) and (3), $\dfrac{DataLen}{TBS(MCS;RBU)}$ is the total number of transport blocks needed to transmit the traffic light data to RSU. TBS is the transport block size that depends on MCS and the allocated RB per user (RBU). $DataLen$ is the data size per use Where The transmission latency per transport block depends on Physical Uplink Shared Channel (PUSCH), Physical Downlink Control Channel (PDCCH) duration, and Physical Downlink Shared Channel (PDSCH). Reader can find more details here [36]. PDCCH duration equals $N_R * TT_{CF}$. Here TT is the transmission time needed to transmit the control information and PDSCH, and PUSCH duration are equal to $N_R * TT_{TBS}$. TT_{TBS} is the transmission time needed to transmit one transport block on PDSCH and PUSCH, respectively. DLACK and ULACK are Downlink acknowledgement and uplink acknowledgement respectively. The values of number of repetitions depend on maximum coupling loss (MCL). t_D is the cross sub-frame delay, t_{DUS} and t_{UDS} are the radio frequency (RF) tuning delay for switching from DL to UL and UL to DL channels, respectively. For simplicity, we assume that there are no repetitions in DCI and $N_R = 0$. t_{UDS} and $DLACK_{Dur}$ are set to zero. Therefore, we can rewrite Equs. (2) and (3) as follows like the work in [36],

$$TD_{DL}^{TL2RSU}(t) = \left(t_D + PDSCH_{Dur} + * \lceil \frac{DataLen}{TBS(MCS;RBU)} \rceil \right) \tag{4}$$

$$TD_{UL}^{TL2RSU}(t) = \left(t_{DUS} + PUSCH_{Dur} * \lceil \frac{DataLen}{TBS(MCS;RBU)} \rceil \right) \tag{5}$$

The total latency in LTE-M / NB-IoT is

$$TD^{TL2RSU}(t) = TD_{UL}^{TL2RSU}(t) + TD_{DL}^{TL2RSU}(t) \tag{6}$$

For simplicity, we considered $\alpha = 0$, $\beta = 0$, $\zeta = 1$ and $\theta = 0$. Consequently, the delay for one RSU area RSU_r can be expressed by

$$DTL^{RSU_r} = \sum_{TL_{n=1}^i}^{TL_N^i} TD^{TL2RSU}(t) \tag{7}$$

The latency in the road network can be expressed by

$$D_{Total}^{Net} = DTL^{RSU_1} + DTL^{RSU_2} + ... + DTL^{RSU_R} = \sum_{r=1}^{R} DTL^{RSU_r} \tag{8}$$

5 Results And Discussion

In this paper, a novel architecture for backhaul communication for ITS application based on LPWAN has been proposed. In previous section, we have defined the architecture and demonstrated a mathematical modeling for latency as one of the important aspects of the backhaul communication. In this section, the latency performance of the architecture in two realistic ITS applications has been evaluated. The architecture in a network simulator has been implemented and a traffic simulator to generate realistic environment for validations has been used. Next section provides details about the simulation setup.

Table 2: CHARACTERISTIC OF THE USED MAP.

Map	Total number of intersections	Total lane length(km)	Total number of vehicles
New York	2104	163.54	1000
Toronto	4140	356.63	2000

5.1 Simulation Setup

In order to evaluate the performance of the proposed architecture, realistic maps of New York city and Toronto has been used with the characteristics summarized in Table 2.

To perform the simulation, microscopic traffic simulator SUMO [37] has been used with its built-in client/server architecture, Traffic Control Interface (TraCI). TraCI acts as a communication medium between SUMO and any external software. SUMO generates a realistic traffic simulation and the external software acts as the client with the capability of impacting the simulation, movements and speed of the cars, and etc. [38].

In this paper, a new Python-based program has been developed to simulate the wireless network environment which is able to interact with SUMO . In our program, the traffic and movement of the cars are generated with SUMO, but the wireless network and characteristics are prepared externally. We also employed open source PyLTE library [39], which is able to emulate the LTE network with User Equipment (UE) and Base Station (BS). In our developed program, the vehicles are defined as UE and are able to communicate with traffic lights and RSUs. In addition, traffic lights have wireless communication with RSUs and LTE base station.

In order to define RSUs in SUMO, the method used in [3] has been employed. The dimensions are extracted from the map, then RSUs are added manually with a unique ID and coordinates of (x , y). RSUs have a virtual radius drawing within the map with the size equal to 1000. RSUs are assumed to be equipped with LTE-M or NB-IoT device. LTE-M and NB-IoT are implemented based on PyLTE.

We implemented two realistic ITS application for evaluation of the performance: traffic monitoring scenario and emergency vehicle preemption. In each scenario, we divided the map of New York city to seven area, where a RSU located in each area and it includes several traffic lights. Table 3 summarizes the total number of TLs in each RSU area.

Table 3: THE NUMBER OF TLS IN EACH RSU's AREA.

ID	RSU_0	RSU_1	RSU_2	RSU_3	RSU_4	RSU_5	RSU_6	RSU_7
Total number of TL (NewYork)	10	31	11	217	22	213	5	40
Total number of TL (Toronto)	101	48	25	13	241	89	32	11

5.2 Traffic Monitoring

In the first scenario, it is considered that each traffic light collects traffic data of its own intersection. The broadcasting data from the vehicles including the speed, direction, acceleration, location, and vehicles' ID are delivered to the traffic lights.

Afterwards, considering these information, the traffic lights perform a basic analysis and compute (count) the number of the vehicles on each street to recognize the congestion happening at the intersection. After pre-processing the traffic data, it sends the outcomes and important traffic information of its own intersection to RSU using LTE-M or NB-IoT module.

Using the described simulation tools, we developed a program that runs a realistic simulation which generates the traffic information of vehicles traveling on the map of New York city and Toronto. Then, each vehicle broadcasts data to traffic lights and the traffic lights send the data to RSUs using the LTE-M or NB-IoT. A sample snapshot of realistic maps of city of New York city and Toronto has been shown in Fig. 3.

Algorithm 1 THE ALGORITHM OF THE FIRST SCENARIO (TRAFFIC MONITORING).

```
1: BS_list ← All RSU, BSs and locations
2: TL_list ← Retrieval all traffic lights
3: LTE ← Create One Base Station network
4: LTE-M/NB-IoT← Create Several Base Station network
5: Insert Traffic Light as User Equipment (UE) to Network
6: Connect RSU To The Nearest BS
7: Connect Traffic Lights to The Nearst RSU
8: while SIMULATION do
9:     if Simulation Time % 600 s == 0 then
10:        PauseSimulation
11:        for all vehicle in Road Network do
12:            Get Position of vehicle
13:            Insert vehicle as UE with x,y,and id
14:        end for
15:        Connect Vehicle To the Nearest Traffic Light
16:        Calculation The Number of vehicles in each area of traffic light
17:        Calculation Latency
18:    end if
19: end while
```

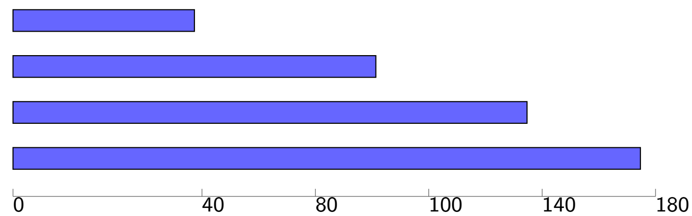
During the simulation, in each 600s, we list the vehicles that are on the road network and receive the position of vehicles. Then we insert vehicles as UE with indicators of x,y,and id. Vehicles connect to the nearest traffic light and we calculate the number of vehicles in the area of traffic light in addition to the number of cars that the light will have in every 600s N_{user}. In lines 16 and 17, delays of each area is calculated.

Using 1000 vehicles and map of city of New York, plus 2000 vehicles and map of city of Toronto, two simulations are performed using LTE-M and NB-IoT as the backhaul. Also, the total end to end latency is calculated and summarized in Figs. 4 and 5 for 8 RSUs. In this scenario, each traffic light calculates the congestion and sends results as a message to RSU. As can be seen in the figures, the LTE-M outperform the NB-IoT in all of the RSUs. In Fig . 4, LTE-M has shown a better performance in all areas. For instance, in RSU 4, End to End up link latency of the LTE-M is less than End to End up link latency of the NB-IoT. Also, In Fig . 5, LTE-M has shown a better performance in all areas. For example, in RSU 4, End to End up link latency of the LTE-M is less than End to End up link latency of the NB-IoT.

In addition to the latency, we examined another parameter. One of the most important parameters is Block Error Rate (BLER). BLER is referred to the ratio

Table 4: EMERGENCY VEHICLE SCENARIO IN NEW YORK CITY AND TORONTO.

Type	Num. of TL in vehicle's path	Total E2E latency (Sec.)
LTE-M (NewYork)	6	34.62
NB-IoT (NewYork)	6	61.632
LTE-M (Toronto)	14	85.325
NB-IoT (Toronto)	14	137.954



of the number of erroneous blocks to the total number of blocks transmitted over the wireless channel. In order to evaluate BLER, we performed a new simulation in the NB-IoT NPUSCH BLER simulation has been done for a number of Signal-to-noise ratio (SNR) points. SNR is the signal-to-noise ratio of the given signal. Fig. 6 shows results for NB-IoT NPUSCH BLER simulation for various SNR {-20, -18, -15, -12.5, -10, -6.4, -3.5, 0.7, 2} using LTE Toolbox of Matlab. The simulation length is 5 UL-SCH transport blocks for a various SNR points in different repetitions {2, 16, 64}.

5.3 Emergency Vehicle Preemption

We also perform another simulation to understand the possibility of using the LP-WAN for backhaul in safety critical application and evaluate the performance. In this paper, we selected emergency vehicle preemption application. As can be seen in Fig. 7, in this scenario, an emergency vehicle wants to travel from point A to point B which includes several intersection and traffic lights. The vehicle can broadcast its own information include its location, speed, the route it is going to take, ID, etc. to the first TL in its path. Then, the first TL can changes the status to green for emergency vehicle to allow it pass the intersection. Meanwhile, TL sends information of emergency vehicle to neighbouring traffic light where they can also take similar action to change their status to green for emergency vehicle and they provide a "green wave" for it.

We have developed a program that can run the scenario in realistic environment. We used the same structure of simulation explained in the previous section and used the map of New York city and the implementation procedure is summarized in algorithm 2. In this algorithm, the lines 1-13 is similar to the algorithm 1 for traffic monitoring. In line 16, emergency vehicle communicate to the nearest traffic light, and then emergency vehicle's delay has been calculated in line 17. In line 18, traffic light calculate the latencys to the neighbour traffic light (line 19).

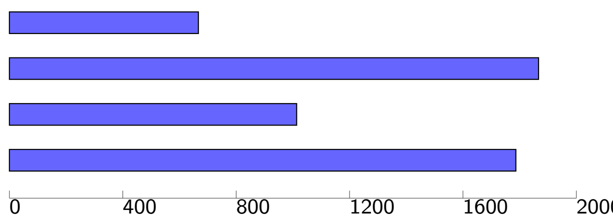
Similar simulation scenarios with 1000 vehicles in the city of New York has been performed and 50 emergency vehicles have been added with a route of 5 km as a sample path which includes 6 traffic lights. Then, the average communication delay has been calculated for these 50 vehicles both in LTE-M and NB-IoT which is summarized in Table 4. Also, the end-to-end delay has been calculated between traffic lights on the UL in comparison with NB-IoT illustrated in Table 5. In this scenario, each traffic light changes the signal to green, then sends a message to its

Algorithm 2 THE ALGORITHM OF THE SECOND SCENARIO (EMERGENCY VEHICLE).

```
BS_list ← All BSs and locations
TL_list ← Retrieval all traffic lights
LTE ← Create One Base Station network
LTE-M/NB-IoT← Create Several Base Station network
Insert Traffic Light as User Equipment (UE) to Network
Connect LTE-M/NB-IoT To The Nearest LTE
Connect Traffic Lights to The Nearst LTE-M/NB-IoT
while SIMULATION do
    if Simulation Time % 600 s == 0 then
        PauseSimulation
        for all vehicle in Road Network do
            Get Position of vehicle
            Insert vehicle as UE with x,y,and id
            List Traffic Lights in vehicle's path
        end for
        Connect Emergency Vehicle To the Nearest Traffic Light
        Calculation Latency Emergency to Traffic light
        Connect Traffic Light To Neighbour Traffic Light
        Calculation Latency Traffic Light To Neighbour Traffic Light
    end if
end while
```

Table 5: TOTAL ROAD NETWORK END TO END DELAY IN NEW YORK CITY AND TORONTO.

Type	Total E2E in Road Network
LTE-M (NewYork)	659.69
NB-IoT (NewYork)	1804.64
LTE-M (Toronto)	924.16
NB-IoT (Toronto)	1.665.866



neighbour traffic light to provide the green wave. Despite the fact that the LTE-M performs better in terms of delay compared with NB-IoT, the average delay in TLs communications might not be perfect for emergency vehicle exemption. The proposed architecture could provide basic functionality for emergency vehicles management to help with first step ITS applications. However, it can be replaced with other applications in future.

6 Conclusion

In this work, a new architecture has been proposed which can be used for ITS applications using the LPWAN technology. This architecture can help with early implementation of the ITS applications in real world cases in close future. To do so, LTE-M and NB-IoT have been studies as cellular-based LPWAN communication technologies. The performance of LTE-M and NB-IoT for ITS in two scenarios has been evaluated: traffic monitoring, and emergency vehicle exemption, in terms of end to end delay. The city map has been divided to several areas with the possibility of vehicles sending their own collected traffic data to traffic lights. Then traffic lights compute congestion of their own intersection and send the results to RSU. Therefore, the size of the required data being transferred to RSU has been reduced.

The results of the simulation demonstrate that LTE-M performs better compared with NB-IoT. These technologies can help to solve the big data challenge in ITS and provide early implementation.

7 Abbreviations

ITS: Intelligent Transportation System; LPWAN: Low-Power Wide-Area Network; IoT: Internet of Thing; IoV: Internet of Vehicle; IoRSE: Road Side Element; RSU: Road Side Units; TMC: Traffic Management Center; MEC: Mobile Edge Computing; NB-IoT: Narrow band Internet of Thing; M2M: Machine-to-Machine; LTE: Long Term Evolution; DSRC: Dedicated Short-Range Communication; BS: Base Stations; eMTC: enhanced Machine-Type Communication; PRB: Physical Resource Blocks; CE: Coverage Enhancement; eNodeB: evolved Node B; TL: Traffic lights; OBU: On-Board Units; DTD: Data Transmission Delay; DCI: downlink control information; DL: downlink; UP: uplink; DLACK: Downlink acknowledgement; ULACK: uplink acknowledgement; RBU: RB per user; PUSCH: Physical Uplink Shared Channel; PDCCH: Physical Downlink Control Channel; PDSCH: Physical Downlink Shared Channel; MCL: maximum coupling loss; RF: radio frequency; SUMO: Simulation of Urban MObility; TraCI: Traffic Control Interface; UE: User Equipment;

8 Availability of data and materials

The data sets used and analyzed during the current study are available from the corresponding author on request.

9 Competing Interest

The authors declare that they have no competing interests.

10 Funding

11 Authors Contribution

The authors have contributed equally to the paper. The authors read and approved the final manuscript.

12 Acknowledgements

The authors acknowledged the anonymous reviewers and editors for their efforts in valuable comments and suggestions.

Author details

[1] Department of Computer Engineering, Sanandaj Branch, Islamic Azad University, Iran, Sanandaj. [2] Department of Computer Engineering and Information Technology, University of Kurdistan, Iran, Kurdistan.

References

1. Sperling, D., Gordon, D.: Two billion cars: transforming a culture. TR news (259) (2008)
2. Rezaei, M., Noori, H., Rahbari, D., Nickray, M.: Refocus: a hybrid fog-cloud based intelligent traffic re-routing system. In: 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI), pp. 0992–0998 (2017). IEEE
3. Rezaei, M., Noori, H., Razlighi, M.M., Nickray, M.: Refocus+: Multi-layers real-time intelligent route guidance system with congestion detection and avoidance. IEEE Transactions on Intelligent Transportation Systems (2019)
4. Al-Otaibi, B., Al-Nabhan, N., Tian, Y.: Privacy-preserving vehicular rogue node detection scheme for fog computing. Sensors **19**(4), 965 (2019)
5. Khamforoosh, K., Rahmani, A.M., Sheikh Ahmadi, A.: A new multi-path aodv routing based on distance of nodes from the network center. In: 2008 Mosharaka International Conference on Communications, Propagation and Electronics, pp. 1–5 (2008)
6. Ning, Z., Huang, J., Wang, X.: Vehicular fog computing: Enabling real-time traffic management for smart cities. IEEE Wireless Communications **26**(1), 87–93 (2019)
7. Jeong, J., Jeong, H., Lee, E., Oh, T., Du, D.H.: Saint: Self-adaptive interactive navigation tool for cloud-based vehicular traffic optimization. IEEE Transactions on Vehicular Technology **65**(6), 4053–4067 (2016)
8. Verbelen, T., Simoens, P., De Turck, F., Dhoedt, B.: Cloudlets: Bringing the cloud to the mobile user. In: Proceedings of the Third ACM Workshop on Mobile Cloud Computing and Services, pp. 29–36 (2012). ACM
9. Khan, W.Z., Ahmed, E., Hakak, S., Yaqoob, I., Ahmed, A.: Edge computing: A survey. Future Generation Computer Systems **97**, 219–235 (2019)
10. Zhang, J., Letaief, K.B.: Mobile edge intelligence and computing for the internet of vehicles. arXiv preprint arXiv:1906.00400 (2019)
11. Rezazadeh, Z., Rezaei, M., Nickray, M.: Lamp: A hybrid fog-cloud latency-aware module placement algorithm for iot applications. In: 2019 5th Conference on Knowledge Based Engineering and Innovation (KBEI), pp. 845–850. IEEE
12. Nath, S.B., Gupta, H., Chakraborty, S., Ghosh, S.K.: A survey of fog computing and communication: current researches and future directions. arXiv preprint arXiv:1804.04365 (2018)
13. Darwish, T.S., Bakar, K.A.: Fog based intelligent transportation big data analytics in the internet of vehicles environment: motivations, architecture, challenges, and critical issues. IEEE Access **6**, 15679–15701 (2018)
14. Zhang, Y., Wang, C.-Y., Wei, H.-Y.: Parking reservation auction for parked vehicle assistance in vehicular fog computing. IEEE Transactions on Vehicular Technology **68**(4), 3126–3139 (2019)
15. Huang, C., Lu, R., Choo, K.-K.R.: Vehicular fog computing: architecture, use case, and security and forensic challenges. IEEE Communications Magazine **55**(11), 105–111 (2017)
16. Jamil, M.S., Jamil, M.A., Mazhar, A., Ikram, A., Ahmed, A., Munawar, U.: Smart environment monitoring system by employing wireless sensor networks on vehicles for pollution free smart cities. Procedia Engineering **107**, 480–484 (2015)

17. Tang, T., Dai, K., Zhang, Y., Zhao, H., Jiang, H.: Field test results analysis in urban rail transit train ground communication systems of integrated service using lte-m. In: 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 2017–2021 (2016). IEEE
18. Wang, H.F.R.Y., Jiang, H.: Modeling of radio channels with leaky coaxial cable for lte-m based cbtc systems. In: IEEE Communications Letters, pp. 1038–1041 (2016). IEEE
19. Dawaliby, S., Bradai, A., Pousset, Y.: In depth performance evaluation of lte-m for m2m communications. In: 2016 IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 1–8 (2016). IEEE
20. Li, Y., Yang, L., Han, S., Wang, X., Wang, F.-Y.: When lpwan meets its: Evaluation of low power wide area networks for v2x communications. In: 2018 21st International Conference on Intelligent Transportation Systems (ITSC), pp. 473–478 (2018). IEEE
21. Shi, J., Jin, L., Li, J., Fang, Z.: A smart parking system based on nb-iot and third-party payment platform. In: 2017 17th International Symposium on Communications and Information Technologies (ISCIT), pp. 1–5 (2017). IEEE
22. Petrov, V., Samuylov, A., Begishev, V., Moltchanov, D., Andreev, S., Samouylov, K., Koucheryavy, Y.: Vehicle-based relay assistance for opportunistic crowdsensing over narrowband iot (nb-iot). IEEE Internet of Things journal **5**(5), 3710–3723 (2017)
23. Lauridsen, M., Gimenez, L.C., Rodriguez, I., Sørensen, T.B., Mogensen, P.E.: From lte to 5g for connected mobility. IEEE Communications Magazine **55**(3), 156–162 (2017)
24. Noori, H., Valkama, M.: Impact of vanet-based v2x communication using ieee 802.11 p on reducing vehicles traveling time in realistic large scale urban area. In: 2013 International Conference on Connected Vehicles and Expo (ICCVE), pp. 654–661 (2013). IEEE
25. Ismail, N.L., Kassim, M., Ismail, M., Mohamad, R.: A review of low power wide area technology in licensed and unlicensed spectrum for iot use cases. Bulletin of Electrical Engineering and Informatics **7**(2), 183–190 (2018)
26. Chen, M., Miao, Y., Jian, X., Wang, X., Humar, I.: Cognitive-lpwan: Towards intelligent wireless services in hybrid low power wide area networks. IEEE Transactions on Green Communications and Networking **3**(2), 409–417 (2018)
27. Lauridsen, M., Kovács, I.Z., Mogensen, P., Sorensen, M., Holst, S.: Coverage and capacity analysis of lte-m and nb-iot in a rural area. In: 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall), pp. 1–5 (2016). IEEE
28. Ratasuk, R., Mangalvedhe, N., Ghosh, A., Vejlgaard, B.: Narrowband lte-m system for m2m communication. In: 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall), pp. 1–5 (2014). IEEE
29. Boulogeorgos, A.-A.A., Diamantoulakis, P.D., Karagiannidis, G.K.: Low power wide area networks (lpwans) for internet of things (iot) applications: Research challenges and future trends. arXiv preprint arXiv:1611.07449 (2016)
30. Jörke, P., Falkenberg, R., Wietfeld, C.: Power consumption analysis of nb-iot and emtc in challenging smart city environments. In: 2018 IEEE Globecom Workshops (GC Wkshps), pp. 1–6 (2018). IEEE
31. Ratasuk, R., Mangalvedhe, N., Bhatoolaul, D., Ghosh, A.: Lte-m evolution towards 5g massive mtc. In: 2017 IEEE Globecom Workshops (GC Wkshps), pp. 1–6 (2017). IEEE
32. Ksairi, N., Tomasin, S., Debbah, M.: A multi-service oriented multiple access scheme for m2m support in future lte. IEEE Communications Magazine **55**(1), 218–224 (2016)
33. Ratasuk, R., Vejlgaard, B., Mangalvedhe, N., Ghosh, A.: Nb-iot system for m2m communication. In: 2016 IEEE Wireless Communications and Networking Conference, pp. 1–5 (2016). IEEE
34. Noori, H., Fu, L., Shiravi, S.: A connected vehicle based traffic signal control strategy for emergency vehicle preemption. In: Transportation Research Board 95th Annual Meeting (2016)
35. Noori, H.: Modeling the impact of vanet-enabled traffic lights control on the response time of emergency vehicles in realistic large-scale urban area. In: 2013 IEEE International Conference on Communications Workshops (ICC), pp. 526–531 (2013). IEEE
36. El Soussi, M., Zand, P., Pasveer, F., Dolmans, G.: Evaluating the performance of emtc and nb-iot for smart city applications. In: 2018 IEEE International Conference on Communications (ICC), pp. 1–7 (2018). IEEE
37. Behrisch, M., Bieker, L., Erdmann, J., Krajzewicz, D.: Sumo–simulation of urban mobility: an overview. In: Proceedings of SIMUL 2011, The Third International Conference on Advances in System Simulation (2011). ThinkMind
38. Wegener, A., Piórkowski, M., Raya, M., Hellbrück, H., Fischer, S., Hubaux, J.-P.: Traci: an interface for coupling road traffic and network simulators. In: Proceedings of the 11th Communications and Networking Simulation Symposium, pp. 155–163 (2008). ACM
39. Slabicki, M., Grochla, K.: Pyltes—python lte evaluation framework for quick and reliable network optimization. In: 2016 39th International Conference on Telecommunications and Signal Processing (TSP), pp. 64–67 (2016). IEEE

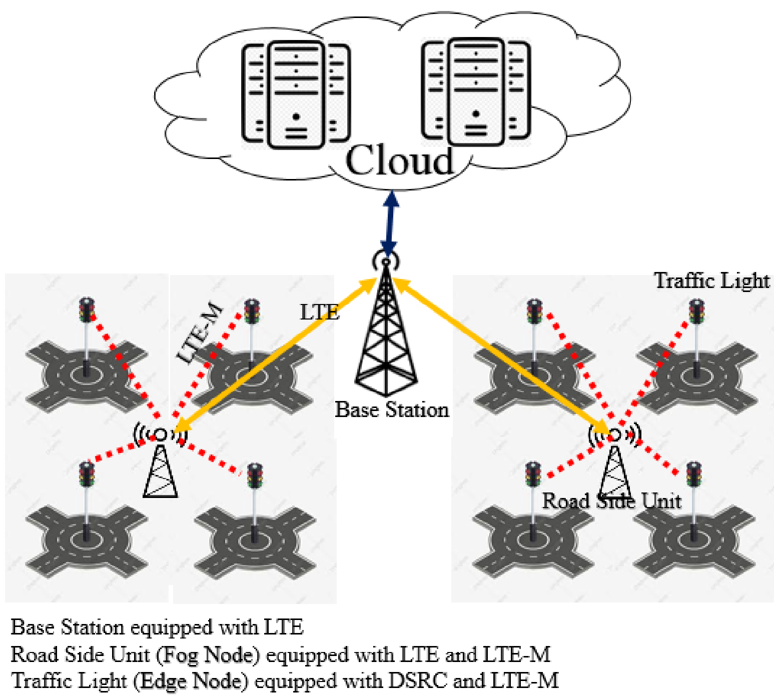


Figure 1: Proposed System Architecture

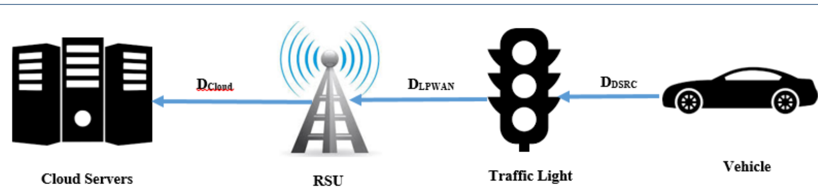
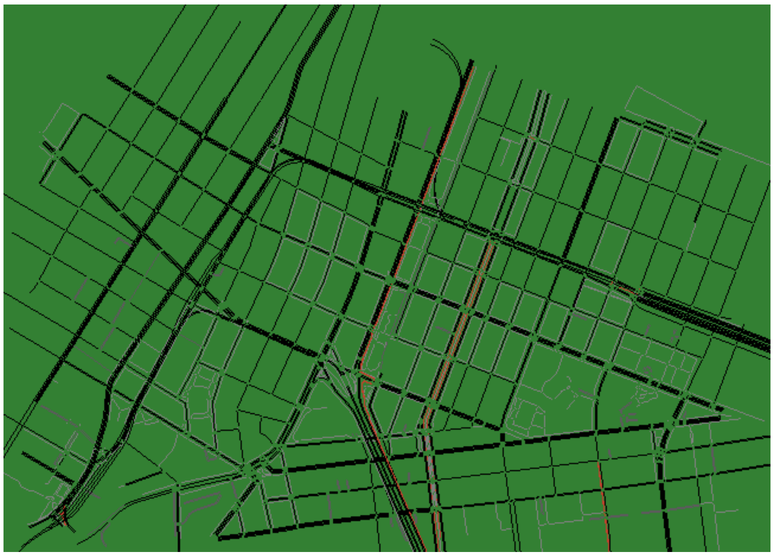
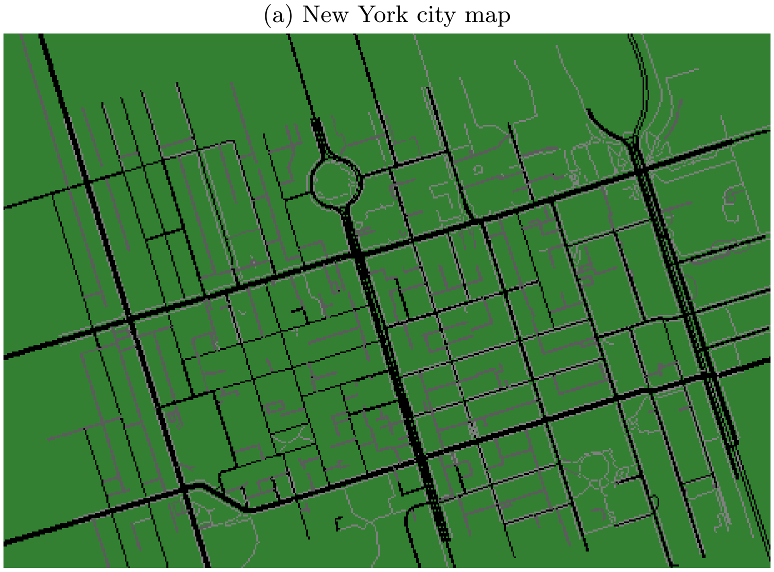


Figure 2: End-to-End Latency From Vehicle to Cloud.



(a) New York city map



(b) Toronto city map

Figure 3: A Sample Snapshot of the Realistic Maps Used in the Simulations

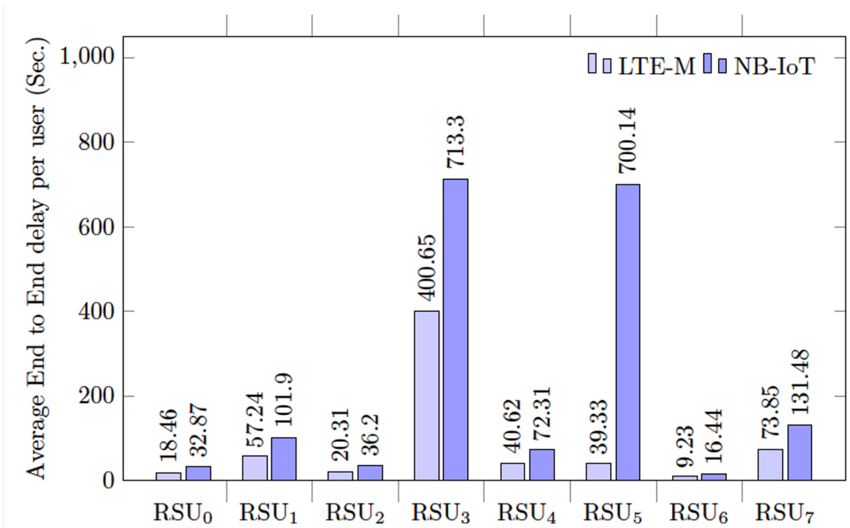


Figure 4: Average End to End Latency Per User in Traffic Monitoring Scenario (Newyork).

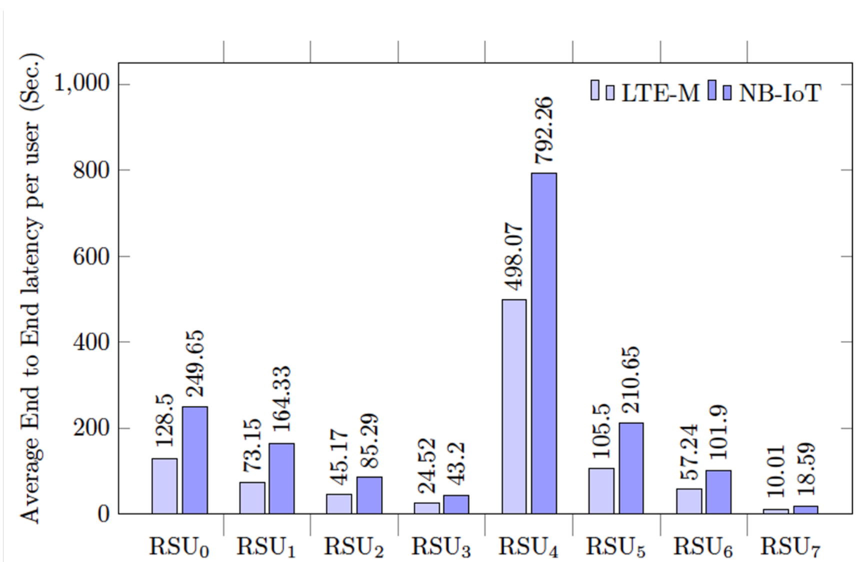


Figure 5: Average End To End Latency Per User In Traffic Monitoring Scenario (Toronto).

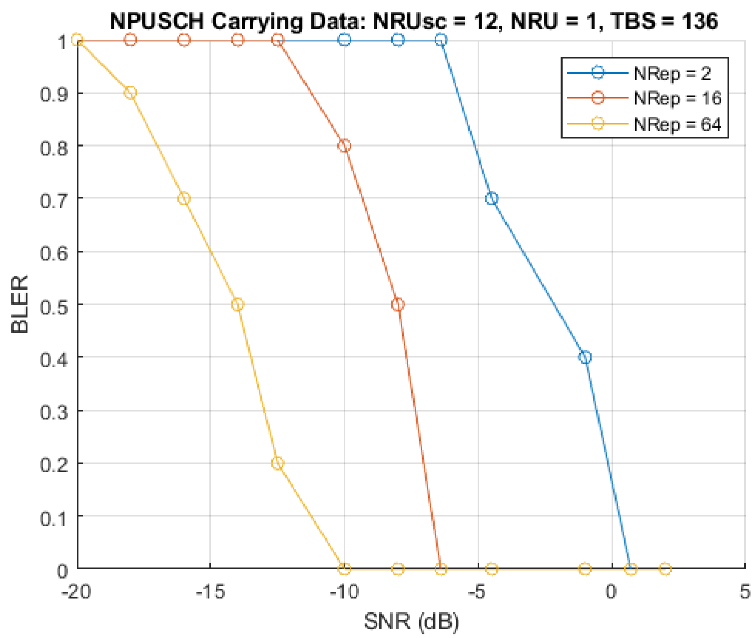


Figure 6: NB-IoT NPUSCH BLER Vs. SNR

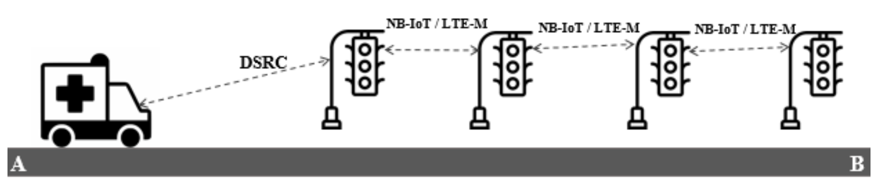


Figure 7: Emergency Vehicle Scenario