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

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Abstract

Vehicles around the world rapidly growing which causing worldwide congestion. The solution to these issues could making efficient use of the current infrastructure using current technological advances by implementing Intelligent Transportation Systems (ITSs). We proposed and explored the possibility of using cellular-based Low-Power Wide-Area Network (LPWAN) communications, LTE-M and NB-IoT, for ITS applications. LTE-M and NB-IoT are designed to provide long-range, low power and cost communication infrastructure and can be a viable promising option for immediate implementation in the real world. In order to understand the feasibility of using LPWAN for ITS, we investigated two applications with low and high delay requirements: road traffic monitoring and emergency vehicle management and preemption. 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 latency per user. SUMO simulator has been used for realistic traffic generation and a Python-based program with the ability to live data exchange with SUMO has been developed for communication performance evaluations. The simulation results demonstrate the feasibility of using LPWAN for ITS backhaul infrastructure where it was 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

1 Introduction

During the last decades, the rapid growth in the number of vehicles specially in the major cities around the world, creating the numerous issues including congestion, huge fuel consumption, accidents, emissions, etc. It is predicate that by 2030 there will be around 2 billions vehicles traveling on the world [1] which can have significant negative impacts on daily life quality in urban area. With advanced in various technologies, the concept of Intelligent Transportation System (ITS) has been introduced to help in increasing the traffic efficiency and reducing the negative impacts of the traffic. Despite the potential extensive positive impact of implementing the Intelligent Transportation System and its applications, still there are very few large scale deployment of ITS happened around the world and it is facing challenges. One the important issues which preventing the immediate implementation of the ITS applications is the huge cost associated with providing the infrastructure in all roads of a city for transmitting data from each point in city to a local or global central location for data processing and analysis.

The recent advanced in wireless technologies along with emerging Internet of Things (IoT) technologies, opened up a new form of low cost and long range communication which can help with the raised issue and immediate implementation of the ITS application in real world. 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] and allows the vehicles and infrastructures communicate to effectively collect the traffic data to improve the traffic conditions [4].

On the other hand, increases in the volume, variety, and the speed of the generated data by IoT devices, creates several challenges to collect, transfer, store, analysis, and make decision based on the data for real world applications. For ITS applications, due to the huge amount of generated data, by sensors installed on vehicles or Road Side Units (RSUs), transferring them to cloud servers could lead to unnecessary communication overhead, high bandwidth consume, increased response delay in sensitive traffic information, etc. [2], [5]. Recently, considering these challenges and to reduce central computing power and reduce the amount of required data transfer to central location, various computing technologies have been introduced to solve services of processing, storing, and communication for the Internet of vehicles such as: Cloud computing [6], cloudlets [7], edge computing [8], Mobile Edge Computing (MEC) [9], and fog computing.

In recent years, fog computing was introduced [10], [11] 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 a real-time services such as efficient routing of vehicles, traffic information, safety messages, etc. In this fog-based environment, the central or cloud sever only required to process and stored historical data and Fog-processing can improve the performance of these services significantly by eliminating the huge data transfer and processing in cloud [12], [13], [14].

Considering the mentioned issues, in this paper we propose a novel architecture for ITS applications which uses the Low-Power Wide-Area Network (LPWAN) network and Fog-based communication and computing. The architecture explore the possibility of using cellular-based LPWAN communications, LTE-M and Narrow band Internet of Things (NB-IoT), for ITS applications and evaluate and compare the performance in the realistic simulation environment. The main contribution of this paper is

- 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 a traffic simulator (SUMO) and a novel Python-based program for communication network performance evaluations with ability of live data exchange 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 2 presents related works. Section **??** provides on overview of LPWAN cellular based communication technology, LTE-M and NB-IoT. Section 4 describes our system design. Section 5 present the resulting analysis and discussion. Also, Section 6 presents the conclusions.

2 Related Work

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 like Long Term Evolution (LTE). The cost of LTE is expensive due to high power consumption, high deployment costs and complex protocols. The DSRC technology is limit in range communication. The IoT technology in vehicles, traffic lights and other elements of road side needs to be simple, reliable everywhere at any time, and use as little power as possible. One of wireless communication solution is LPWAN which designed with target long battery lifetime and wide area coverage. LPWAN includes cellular (licensed band) and non-cellular (unlicensed) approaches [15], [16], [17]. NB-IoT and LTE-M are a LPWAN cellular-based communication technology designed with target reduce device cost, higher cell capacity, Low power, and wide range to transmit/receive small amounts of data using lower bandwidth [18], [19], [20] and [21].

The increasing requirements to improve power consumption and signal coverage, Vehicles, traffic lights and other elements of roadside like Road Side Units (RSU), Base Stations (BSs), that collect 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 improves the functions of roadside devices in term of latency, and battery lifetime. The low power consumption of LTE-M leads to the battery can last 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. Because reduced complexity of IoT road side units. LTE-M can be used everywhere that LTE be used. Because, that is a transfiguration of LTE [22], [23], [24].

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

CE Mode A is the default mode of LTE-M devices and networks and uses where moderate coverage enhancement and higher data rates are needed like voice call possibility and connected mode mobility.

CE Mode B is optional and can even further coverage enhancement at the expense of throughput and latency and it was mainly designed to provide coverage deep within buildings. Hence, Mode B is intended more for stationary or pedestrian speeds applications that require limited data rates and limited volumes of 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 like LTE-M that stands Narrow Band Internet of Things and focuses on higher coverage, lower-energy consumption, and cost. But, the bandwidth of NB-IoT devices is 180 kHz (one PRB of LTE) [25], [26]. The geographical coverage in NB-IoT is better than LTE-M. Table 1 describes difference between LTE-M and NB-IoT.

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 Down-Link/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

Introducing LTE-M and NB-IoT technologies in ITS environments, the authors in [27] proposed an architecture based on WSN and LTE-M for gathering the data of air pollution in the ITS environment. The LTE-M deployed in the outdoor units and public vehicles such as buses. In architecture [27] Zigbee sensors deployed on the stations. When buses stop on the stations, LTE-Ms collect data from Zigbess and send data to the cloud computers for analyzed.

The authors in [28] employed LTE-M technology in design of urban rail transit system and provide the advantages and disadvantages of this technology in such system. Also, the work in [29] employed LTE-M technology accompanied in leaky coaxial cable as the main communication solution for future urban train systems. In other work [24] assessed performance of LTE-M for Machine-to-Machine (M2M) communications. The work in [30] studied LPWAN technology in V2X communication and employed LoRa and LTE-M which are LPWAN based technology in V2X communications. The simulation result show LPWAN in V2I environment is better then V2V environment.

Shi et al. [31] used NB-IoT technology in smart parking system for long battery lifetime, low deployment costs and long wide range. The work in [25] evaluated an opportunistic crowd-sensing scenario that sensors transfer a huge amount of traffic data using NB-IoT.

The work in [32] 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. The authors suggested 5G improve the radio signal availability.

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

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 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 illustrate the proposed system architecture which includes Vehicles, Traffic lights (TLs), several RSUs, and Cellular Base Station (BS) or evolved Node B (eNodeB). Following section provide information and assumptions about each element.

- *Traffic lights (TLs)* referred to a fixed element that deploy in intersections. Each TL controls in/out flow on roads of intersection with changes traffic signals [33], [34]. 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 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 device to communicate with TLSs and LPWAN Base Station (BS). In proposed architecture, RSUs are equipped with basic processing, storing and communications functionality and act as a fog node [35].
- *LPWAN BS:* The BS (e.g. eNodeB) installed on road similar the RSU 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 and 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), and with traffic lights and RSUs (Vehicle-to-Infrastructure communication).

pic.png

Figure 1: **Our System Architecture**

Sensors installed on vehicles generate huge amounts of data. If generated data transfer to RSU or Cloud using DSRC/LTE, could takes very long time and need huge backhaul communication which can come with huge installation and ongoing cost. Thus, the proposed architecture divides the whole city map into several sub road network as area. Within each area, there is one RSU in each area. We assume RSUs as a fog node that can pre-process traffic data or temporally store reiterative information. Also, there is one LPWAN (BS) able to communicate with LTE network, equipped with LTE-M/NB-IoT with communication range of R_c, and possible coverage several area. In each area, there are several TLs equipped with the same LTE-M/NB-IoT module. TLs considered as a edge node.

The RSU has high capabilities relative to TL and can presents services such as helping the vehicles with navigation. TLs can process traffic data in its own intersections in order to reduce the transfer of data to LPWAN BS. In our architecture, each TL has the capability of the process of traffic data related to own intersection. Each intersection can has several roads, R_i as input road and R_o as output road, as well as each road has minimum one lane, L_r. The processed data by TL send to RSU at a lower volume (small size) with the same LTE-M/NB-IoT module. Hence, we use LPWAN for communication between RSUs and TLs that has much less cost, complexity and delay compare to DSRC. To assign TL to RSU we use lowest distance which distance calculates 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 send to cloud (core network) by LPWAN BS and the fixed data like the speed and capacity of roads store by transportation engineers and update at one certain time.

To summarized, in the proposed system architecture, the generated data by sensors installed on vehicles transfer to the nearest traffic light using DSRC communication in one area. Each traffic light in the same area processes the congestion of it own intersection in order to reduce the transfer of data to LPWAN RSU. Then, traffic lights send the processed data to RSU by LPWAN, LTE-M or NB-IoT, communications. Each RSU has exact detail information of intersections in its own area. There are different functionality that RSUs may perform such as: processing the traffic status of area, performing re-routing and proposes route to vehicles in the area, emergency vehicle preemption, broadcasting road information, etc. 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 TMC (remote servers) on our scenarios.

[]Delay.png

Figure 2: **End-to-End Delay From Vehicle to Cloud.**

4.1.1 Data Transmission Delay (DTD)

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

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

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 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 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.

$TD^{TL2RSU}(t)$ is consists 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) transmissions as follows [36]:

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

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

Communication latency in LTE-M/NB-IoT depends on Transport Block Size (TBS) and 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 user. 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), the 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. 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. Hence, 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 delay 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 is for one RSU area RSU_r can be expressed by

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

The delay in the road network can be expressed by

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

5 Results And Discussion

In this paper, a novel architecture for backhaul communication for ITS application has been proposed which is based on the LPWAN. In previous section, we have defined the architecture and proposed a mathematical modeling for one of the important aspect of the backhaul communication, latency, in our architecture. In this section, we evaluate the latency performance of the architecture in two realistic

ITS applications. We implemented the architecture in a network simulator and we have used a traffic simulator to generate realistic environment for validations. Next section provide details about the simulation setup.

5.1 Simulation Setup

In order to evaluate the performance of the proposed architecture, realistic map of New York city has been used with characteristics summarized at Table 2. To

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

perform the simulation, a microscopic traffic simulator SUMO (Simulation of Urban MObility [37]) in a client/server architecture by employing SUMO built-in interface, Traffic Control Interface (TraCI). TraCI plays as a connection between SUMO and other software SUMO generate realistic traffic simulation and external software act as client and can influence the simulation, movements, etc. [38].

In this paper, we have developed a new Python-based program to simulate the wireless network environment and it 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 characteristic is done 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 defined as UE where they 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 definition of RSUs in sumo, we employed from used method in [3]. We get the dimensions of map and then added RSUs manually with an unique ID and coordinates of (x , y). RSUs have a virtual radius drawing within the map with size = 1000. We assumed RSUs equipped to LTE-M or NB-IoT device and based on PyLTE, we implemented LTE-M and NB-IoT.

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	10	31	11	217	22	213	5	40

5.2 Traffic Monitoring

In the first scenario we consider that each traffic light collects traffic data of its own intersection. The collected data will be deliver from the vehicle broadcasting their information such as speed, direction, acceleration, location, vehicles' ID, etc.

Then, considering these information, the traffic lights perform a basic processing and computes (count) the number of vehicles at each street and so it can realize the congestion happening at the intersection. After pre-processing the traffic data, it sends the outcomes and important traffic information of own intersection to RSU using LTE-M or NB-IoT module.

Using the described simulation tools, we developed a program that can run a realistic simulation where at first it generates the traffic of vehicles traveling at map of New York city. Then, each vehicle broadcast a data to traffic lights and traffic light send the data to RSUs using the LTE-M or NB-IoT. The algorithm 1 summarizes the steps happening in the programming.

At the first step, we get the location of all traffic lights from SUMO and list them all along with added RSUs and Base Stations (lines 1 and 2). In sumo, we need to manually create virtual RSU and BS within the map using radius. BSs and RSUs distribute based on the communication range and the dimensions of the road network (map) and each BS has unique ID. We used TraCI and add RSU and BS externally. Then, we create one BS network to send historical data to cloud (lines 3) and as well as create several RSU network (LTE-M/NB-IoT) with capability long range communication (lines 4) and in line 6 it connects RSU to the nearest BS. In line 5, we insert traffic lights as UE to network and in line 7 connect traffic lights to the nearest RSU.

Figure 3: **Average end to end Up Link latency per user in traffic monitoring scenario.**

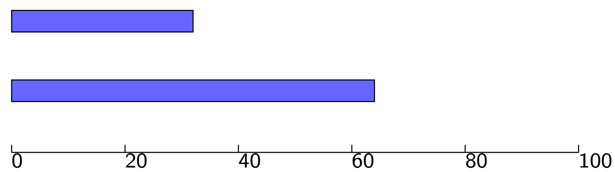
Algorithm 1 THE ALGORITHM OF THE FIRST SCENARIO (TRAFFIC MONITORING).

```
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 Delay
18:    end if
19: end while
```

During the simulation, in each 600s, we list vehicles those are in the road network and we get the position of vehicles. Then we insert vehicles as UE with attributes of

Table 4: EMERGENCY VEHICLE SCENARIO.

Type	Num. of TL in vehicle's path	Total E2E latency per user (Sec.)
LTE-M	6	34.62
NB-IoT	6	61.632



x,y,and id. Vehicles connect to the nearest traffic light and we calculate the number of vehicles in each area of traffic light and each traffic light every 600s will have N_{user}. In lines 16 and 17, we calculate delay for each area.

Using 1000 vehicles and map of city of New York, we have performed two simulations one using LTE-M and the other with NB-IoT as the backhaul and we calculated the total end to end latency and summarized it in Fig. 3 for 8 RSUs. In this scenario, each traffic light calculated the congestion and send result as a message to RSU. As can be seen in the figure, the LTE-M outperform the NB-IoT in all the RSUs. Also, it can be concluded that using LTE-M and the proposed architecture for the backhaul for ITS application can be realistic and feasible and it can cause limited latency in data transfer which can be acceptable in non-safety critical applications such as the proposed traffic monitoring

5.3 Emergency Vehicle Preemption

We also perform another simulation to understand the possibility of using the LPWAN 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. 4, 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.

Figure 4: **Emergency Scenario**

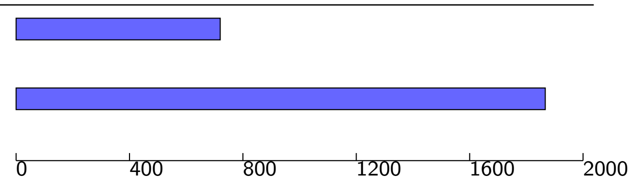
We have developed a program that can run the scenario in realistic environment. We used the same structure of simulation explained in the previous section and used the map of New York city and the implementation procedure is summarized in algorithm 2. In this algorithm, the lines 1-13 is similar to the 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 delays to the neighbour traffic light (line 19).

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 Delay Emergency to Traffic light
        Connect Traffic Light To Neighbour Traffic Light
        Calculation Delay Traffic Light To Neighbour Traffic Light
    end if
end while
```

Table 5: TOTAL ROAD NETWORK END TO END UP LINK LATENCY.

Type	Total E2E in Road Network
LTE-M	65.87
NB-IoT	180.64



We have perform the similar simulation scenarios with 1000 vehicle in city of New York and added 50 emergency vehicles with a route of 5 km as a sample path which includes 6 traffic lights. Then, we calculated the average communication latency happened for these 50 vehicles both in LTE-M and NB-IoT and summarized it in Table 4. Also, we calculated the end-to-end latency between traffic lights on the UL in compared NB-IoT and illustrated it in Table 5. In this scenario, each traffic light changes signal to green and then send message to neighbour traffic light to provide the green wave. Despite the fact that the LTE-M perform better in terms of delay compare to NB-IoT, however the average delay happened in TLs communications might not be perfect for emergency vehicle preemption. The proposed architecture could provide basic functionality for the preemption, as a early implementation to help with first step ITS application, but it can be replace with other application in future.

6 Conclusion

In this work, we proposed a new architecture which can be used for ITS application using the LPWAN technology. This architecture can help with early implementation of the Intelligent Transportation System (ITS) application in real world in near future. To do so, we study LTE-M and NB-IoT those are cellular-based LPWAN communication technology. We evaluate performance of LTE-M and NB-IoT for ITS in two scenario: for traffic monitoring, and emergency vehicle preemption, in term of end to end latency. We divide the city map to several area and vehicles send its own collected traffic data to traffic lights. Then traffic lights compute congestion of own intersection and send result to RSU. Hence, we reduced the size of data that should transfer to RSU. The result of the simulation shows LTE-M has good result in compared with NB-IoT. These technologies can help to solve big data challenge in ITS and help with 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; 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; 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.

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11 Authors Contribution

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