Routing and Packet Scheduling in LoRaWANs-EPC Integration Network

Cheng Cheng Zhang, Kim Khoa Nguyen, Chuan Pham, Mohamed Cheriet
Lab synchromedia, École de technologie supérieure, Université du Québec,
Montreal, Canada
Email: {chengcheng.zhang.1, chuan.pham.1}@ens.etsmtl.ca, {kim-khoa.nguyen, mohamed.cheriet}@etsmtl.ca

***Abstract*—Recently, Mobile Network Operators are considering the integration of LoRaWAN in their Evolved Packet Core (EPC) to expand their business, and to improve the interoperability and multi-vendor integration in their networks. In such integration, a LoRa gateway can implement the virtual base station function of eNodeB protocol stacks to forward LoRa packets through EPC to the application servers. Unfortunately, the current integration of LoRa and the mobile access according to the 3GPP architectures does not allow the co-existence of multiple LoRa gateways, because the routing and scheduling mechanisms among them are not defined. Therefore, the LoRa gateways cannot operate together, limiting the overall performance of the integration network. In this paper, we investigate the problem of integrating multiple LoRaWANs into the EPC, which allows several LoRa gateways and sensors in various regions of LoRa signal coverage areas to access multiple network servers and application servers optimally. We propose methods to select dedicated routes in the EPC resource, and formulate the problem of optimal routing and packet scheduling to forward LoRa packets over the routes. The simulation results show our proposed solution can reduce the overall delay of the average 200 ms.**

***Index Terms*—Multiple LoRaWANs, integration, 4G/LTE, optimal routing, scheduling.**

I. INTRODUCTION

The Internet of Things (IoT) application desires to connect almost everything to the Internet. The acceleration of the deployment drives the telecommunication industry to allow new standards. The Low Power Wide Area Network (LPWAN) is the enabler to implement those IoT applications in the smart city. LoRaWAN is a prominent LPWAN technology that operates on sub-GHz frequency over the unlicensed band. LoRa leverages the modulation technique of the Chirp Spread Spectrum (CSS) which has characteristics of wide range, low bandwidth, and low battery consumption. LoRa gateway relays packets from sensors to the network server in UDP/IP without interpretation, while the network server authenticates packets and manages parameters [1].

Two main benefits have pushed the motivation for research on the integration of multiple LoRaWANs with the 4th Generation Long Term Evolution (4G/LTE) core network. Firstly, Mobile Network Operators (MNO) want to play a significant role in the smart city business to consolidate their deployed network infrastructures to extend their market over multi-vendor deployments, and to minimize the investment cost under their Operation and Maintenance (O&M) platform [2]. Secondly, the next generation RAN conducts the concept of multi-vendor integration and interoperability by running on the virtual functions of 4G/LTE on the edge computing resource, for example, LoRa gateway. The adoption of next generation RAN compliant in multi-vendor LoRa gateways will enable more scalable, cost-effective, and plug-and-play LoRaWANs to construct in anytime anywhere.

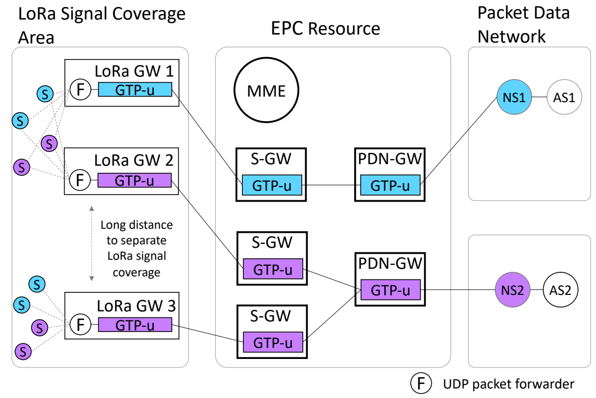

Fig. 1. A simple integreation of three multiple LoRa gateways with two pairs of the network servers and application servers

Prior work [3] [4] requires both data and control planes to integrate a single LoRa gateway with the Evolved Packet Core (EPC) resource. In the data plane, the LoRa gateway implements the eNodeB data plane protocol stack to access the EPC resource. The uplink interface of the LoRa gateway encapsulates the LoRa packets into the GTP-u tunneling packets over the EPC resource from a Serving Gateway (S-GW) to a Packet Data Network Gateway (PDN-GW). The General Packet Radio Service (GPRS) in tunneling Protocol for User plane (GTP-u) is a tunneling protocol over UDP/IP, where GTP-u can support one-to-many and many-to-many for the cascading network architecture. PDN-GW terminates GTP-u tunneling and forwards the LoRa packet to its Packet Data Network (PDN). The downlink interface of the gateway connects to LoRa sensors. The network server is master in a LoRaWAN to control many slaves of sensors and verifies LoRa packet integrity before forwarding it to the application server. In the control plane, the LoRa gateway integrates the eNodeB control plane protocol stack to call MME that is the brain in the EPC resource to set up GTP-u tunnels. The Mobility Management Entity (MME) determines the connection over mappings of GTP-u tunnels on S-GWs and PDN-GWs in the EPC resource.

Unfortunately, a single LoRa gateway cannot afford the requirements of MNOs that want to consolidate its wireless infrastructure to provide LoRaWANs for widely distributed IoT distributions. In this paper, we investigate the problem of enabling multiple LoRa gateways and sensors in distributed geographic regions to access their network servers and application servers. Fig. 1 illustrates an example [3] integrating multiple LoRaWANs with the EPC resource, which includes three domains. In the LoRa signal coverage area, all LoRa gateways listen on the same band to receive an identical copy of the LoRa packet from the sensor [6]. In the EPC resource, we need three S-GWs and two PDN-GWs to establish GTP-u tunnels. There is a network server (NS) and an application server (AS) in PDN, for instance, a public cloud on the Internet.

Prior works dealing with the integration of multiple LoRa gateways into EPC [3] [4] are still limited at the architectural level, and do not consider the operational complexity. In particular, the problems of dynamic establishment of dedicated routes, routing multiple gateways, and scheduling LoRa packets to minimize response time to access the EPC resource have not been addressed so far. In this paper, we investigate a practical implementation of integration by taking the advantages of the Home Subscriber Service (HSS) component that is a database in the EPC. Then, we propose a new optimal routing and packet scheduling method to forward data from LoRa gateways. We also carry out numerical simulations to evaluate the performance of the integration.

We summarize the contributions of this work as follows.

- We redefine the integration architecture using HSS and APN (Access Point Name) of the virtual link to establish dedicated routes for LoRa gateways to access the EPC resource.
- We propose a model of optimal routing over dedicated routes in the EPC resource.
- We propose a packet scheduling model in the LoRa gateway to encapsulate LoRa packets according to the arrival LoRa traffic and the bandwidth of the dedicated route in the EPC resource.

II. SYSTEM DESCRIPTION

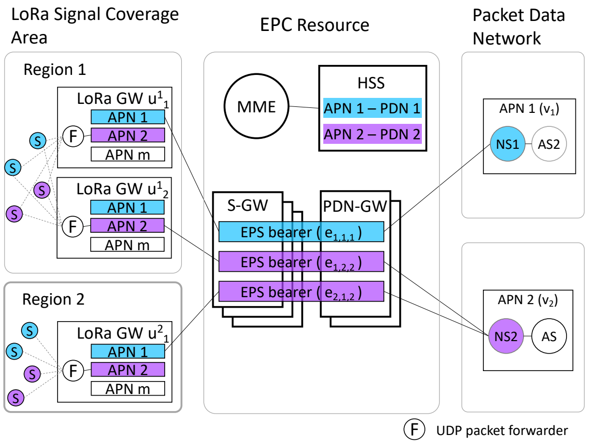

Fig. 2. Example of three LoRa gateways calling EPC procedure to establish dedicated routes of EPS bearers to connect with two pairs of network servers and the application servers.

Fig. 2 shows an example of three LoRa gateways accessing the EPC resource to connect to two pairs of NS and AS. This integration inherits the architecture presented in Fig.1 except two main differences. Firstly, we partition the entire LoRa coverage area into many regions to roll out multiple LoRa gateways with the minimum overlapping between regions. In the smart city, we assume that there are multiple service providers who intend to deploy their services of IoT applications in any given region. In this assumption, it introduces a problem that different service providers would like to rollout their exclusive LoRaWAN networks under the same region. Because the MNO wants some gateways to be spared gateway in case to replace the broken one without a replacement by an onsite visit, it requires MNO to deploy a larger number of LoRa gateways than the number of service providers. After the installation, the running gateways from different service providers working together may cause the interference. It can be solved by introducing a control of the mechanism. According to LoRaWAN specification, all gateways work the same LoRa bands over all channels [5]. For example, all gateways in Region 1 receive the same copy of the LoRa packet sent from a sensor [6]. At the LoRaWAN activation stage, a LoRa sensor uses its two fabricated keys to register with a network server, which establishes two sessions to verify the network integrity and confidentiality in a LoRaWAN. The network server filters its appropriate data. For example, the network server in APN 1 in Fig.2 will accept only packets sent from LoRa sensors colored in blue, and so does the network server in APN 2. MNO can activate gateways from the spared one connecting to NS and AS, and deactivate running gateway to the spared one. In this case, the system may provide a more flexible routing mechanism to let each LoRaWAN accessing EPC resources with optimal routing based on their cost.

Secondly, our proposed system uses APN to set up dedicated routes of EPS bearers for LoRa gateways to access the EPC resource tunnels over GTP-u tunnels. The APN represents the Virtual Private Network (VPN) to establish GTP-u tunnels to forward packets from a LoRa gateway through an S-GW and a PDN-GW to the corresponding PDN where NS and AS are located [4]. We store profiles in the HSS, which contains the mapping from the virtual link of APN to its destination PDN. For instance, in Fig. 2, we call for APN 1 to set up a tunnel to PDN of APN 1. We assume each APN has unique information identified in the EPC resource. The Evolved Packet System (EPS) bearer is an end-to-end GTP-u tunnel from a LoRa gateway to a PDN-GW. At the attachment procedure, a LoRa gateway sends a request to the MME to apply an EPS bearer to its desired PDN. The MME looks up the HSS database to set up an EPS bearer and provides EPS bearer ID to identify from other bearers. After the establishment of the EPS bearer, the gateway uses the UDP packet forwarder to forward LoRa packets to the corresponding PDN.

We model the LoRa gateways, APNs and EPS bearers by the weighted bipartite graph $G(U^i, V, E)$ to determine dedicated routes for LoRa gateways to access the EPC resource $i = 1..n.$. A NS can serve many LoRa sensors from different regions. Fig. 2 shows a set of nodes in U^i that is counted from 1 to $\left|U^i\right| \in \mathbb{Z}^+, \forall i \in \{1, n\}$. A node in V ($|V| \in \mathbb{Z}^+$) represents an APN of the PDN, which corresponds to a pair of NS and AS. An EPS bearer is denoted as an edge $e_{j^i,k}$ as the ith region, jth LoRa gateway, and kth APN. The set of edges in E represents virtual links identified by a unique APN [7].

To enable the integration of multiple LoRa gateways and applications servers through the EPC, two problems have to be addressed, namely the routing problem and the packet scheduling problem. The routing problem is to identify the optimal routes from EPS bearers connected to the gateway, and the LoRa packet scheduling problem is to minimize system response time in the individual gateways. We solved the problems by using the algorithm of Minimum-Weighted Bipartite Matching to find out the optimal routing, and by applying the various EPS bearers to calculate the response time in LoRa gateway in the same time.

III. PROBLEM FORMULATION

TABLE I
LIST OF SYMBOLS

U^i	The region set of LoRa gateways.
V	PDN set of LoRa network servers.
E	a set of edges for routes between gateways and network server.
M	Bipartite mapping.
$e_{j^i,k}$	the mapping connection table between the ith region, jth gateway, and kth network server.
$C(j^i, k)$	distance cost function between the ith region, jth gateway, and kth network server.
p_i	the ith packet size.
s	size of UDP packet.
h	size of the GTP-u header
t_i	the instance time slot of ith time.
BW	the bandwidth of EPS bearer
μ	UDP packet generating rate.

A. LoRa gateway routing model

According to the 3GPP specification [4], by the configuration of APN information on a LoRa gateway, the gateway may establish plenty of routes identified as EPS bearers in EPC resource to access all NSes in the PDN. Each EPS bearer guarantees the quality of service to specify the bandwidth that is the service rate to allow GTP-u tunnel packets passing through. EPS bearers connecting to LoRa gateways are defined with various constrains. For example, the different LoRa gateways located in the same region cannot connect to the same destination IoT application server. A network server that associates an application server can connect to multiple gateways located in different regions.

$$\exists\, M \subseteq E, \tag{1a}$$

$$\forall\, \left(u_1^k, v_1\right), \left(u_2^k, v_2\right) \in M, \tag{1b}$$

$$u_1^k \neq u_2^k, v_1 \neq v_2 \tag{1c}$$

In the equation (1a), we represent routing as a bipartite matching M that listed all the possible edges to denote every EPS bearer that connects one of APN identity in the LoRa gateway to one of the PDN domain. The matching M has to satisfy the constrain (1b) and (1c) that a LoRa gateway can only use one APN identity to connect to the corresponding PDN domain. Moreover, there are no more than two gateways in the same region that can connect to the same destination for the PDN domain. We can use a simple algorithm of the weighted bipartite graph to iterate all the possible combinations of EPS bearers from the matching function M until we find the optimal cost in minimum distance between LoRa gateway and PDN domain [7].

B. LoRa packet scheduling model

Fig. 3 shows an example in which a LoRa gateway forwards data packets through a 2 Mbps bandwidth of the EPS bearer. Based on TABLE II, the gateway generates a UDP packet for the GTP-u tunnel for every 6 ms. The value of the time slot is the duration of $t_i - t_0$ = 6 ms, where t_0 is starting at 0 ms. The LoRa concentrator interprets the LoRa frame in the signal to LoRa packets. In the time $slot_{i-1}$, the LoRa concentrator interpreted seven packets, in which three packets are from APN 1, and four packets are from APN 2. The total packet size of 1450 Bytes is smaller than the fixed UDP packet size. LoRa gateway has a UDP packet forwarder to schedule received LoRa packets into the UDP packets of the GTP-u tunnel. The loading rate [5] is depending on the maximum packet size of 250 Bytes, which is 250 Bytes per 1 ms. Therefore, 1450 Bytes of LoRa packets require 5.8 ms so that there is 0.2 ms delayed in response time. In the next time $slot_i$, the LoRa concentrator captured six packets from all sensors. The total LoRa packets have a size of 900 Bytes, less 1500 Bytes of the fixed UDP size. The loading rate is also 250 Bytes per 1 ms. Therefore, it requires 3.6 ms to load 900 Bytes so that there is 2.4 ms delayed in response time in the time of $slot_i$.

The problem here is to determine the bandwidth from optimal routing of the EPS bearer for appropriate scheduling of arrival LoRa packets [8]. We need to identify a policy to combine EPS bearers that follows the constrain of the optimal routing in the EPC resource. In this policy, we can choose randomly EPS bearers from the optimal routing or a selection of combined the lowest or highest rate of bandwidth so that we can analyze the unnecessary delay in the response time.

We formulate a flow of LoRa packets that arrive in a time interval $[t_0, t_n]$. The flow consists of n LoRa packets $p_1, p_2, \cdots, p_n$. The packet p_i in the flow generated by the LoRa RF concentrator at time t_i, where $t_i \in [t_0, t_n]$. And a LoRa packet is denoted as $P = \{(p_i, t_i)\}$, where $t_0 < t_1 < t_2 < \cdots < t_n$.

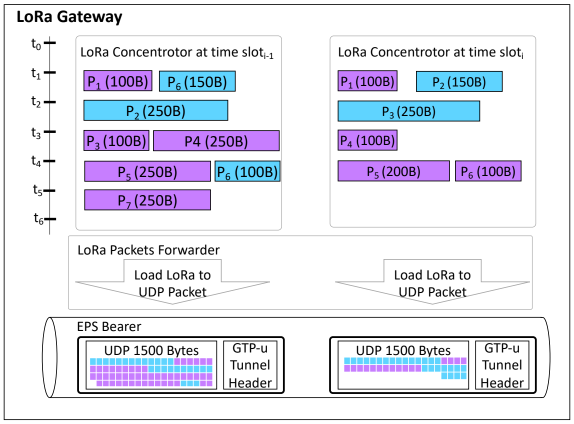

Fig. 3. The example of a LoRa gateway to schedule two-time slots of LoRa packets over a 2 Mbps bandwidth of a dedicated route of the EPS bearer

$$r = \max_{1 \leq j \leq n} \left\{ \frac{p_k}{t_k - t_{k-1}} \right\} \tag{2}$$

We propose the UDP packet loading rate model, by using k LoRa packets in the flow of LoRa traffic to fill up a UDP packet. The equation (2) that we derive in the LoRa packet forwarder shown in Fig. 3 is the shaper of the loading rate. It reshapes the LoRa packets with the maximum packet size $\max p_k$ over unit time $t_k - t_{k-1}$ to fit the maximum size of the UDP packet.

$$\mu(e_{j^i,k}) = \left\lfloor \frac{s+h}{BW(e_{j^i,k})} \times \frac{1}{1000sec} \right\rfloor \tag{3}$$

The weight function (3) is defined by the bandwidth between a LoRa gateway and a network server. We denote decision variable $e_{j^i,k}$, an EPS bearer from the j gateway in the region i to the PDN k. It is an end-to-end GTP-u tunnel through eNodeB, S-GW and PDN-GW. By LoRa specification [6], the packet size can vary from 11 Bytes to 250 Bytes. All available EPS bearers corresponding to the LoRa gateway are identified by APN names which are defined into four types of bearers, in TABLE II. We fix the UDP packet size s and header size h to simplify the system complexity. $BW(e_{j^i,k})$ denotes bandwidth which means the rate of UDP packets transmitted in the EPS bearer of $e_{j^i,k}$. The equation 3 represents the service rate μ that generates a UDP packet in the periodic duration $(s+h)/BW(e_{j^i,k})$ in ms. Therefore, we use the maximum shaping rate for every UDP packet. In the region, the LoRa gateway has its default bandwidth of the service rate to make the UDP packet. We calculate an example of the service rate based on the given function of bandwidth $BW(\cdot)$ for a specific EPS bearer $e_{j^i,k}$ in TABLE II.

C. *Optimization model*

In our formulation we solved the problem by combining the routing problem of weighted bipartite graph and the scheduling problem to minimize the system response time. The solver is executed at the beginning of the initialization [9]. Once the integrated system runs out the optimal routing and the policy of scheduling, it remains unchanged until the next periodic execution of the solver. The optimization model for our combined problem is formulated as:

TABLE II
EXAMPLE OF CALCULATION IN EPS BEARER SERVICE RATE.

Type of EPS bearers	UDP generating rate
2Mbps	1 UDP packet per 6ms of unit time
4Mbps	1 UDP packet per 3ms of unit time
6Mbps	1 UDP packet per 2ms of unit time
10Mbps	1 UDP packet per 1ms of unit time

$$\underset{e_{j^i,k} \in M}{\text{Min.}} \sum_i \sum_j \sum_k \frac{1}{\mu(e_{j^i,k})} - \frac{\sum_i p_i}{r} \tag{4a}$$

$$\text{S. t.} \quad \sum_{i=i}^{k} p_i \leq s, \forall k \ni 1 \leq k \leq n \tag{4b}$$

$$\sum_k e_{j^i,k} = 1, \quad \forall j^i \in U^i \tag{4c}$$

$$\sum_{j^i} e_{j^i,k} = 1, \quad \forall k \in V \tag{4d}$$

$$e_{j^i,k} \geq 0, \quad \forall j^i \in U^i, k \in V \tag{4e}$$

$$e_{j^i,k} \in \mathbb{Z}^+, \quad \forall j^i \in U^i, k \in V \tag{4f}$$

The objective function (4a) is to minimize the response time on each LoRa gateway in the system. The weight function of service rate $\mu(\cdot) \in \mathbb{Z}^+$ to generate UDP packet indicated by the decision variable $e_{j^i,k}$, where $j^i \in U^i$ and $k \in V$. The goal is to determine the optimal routing in the matching M minimizing the system response time. The first constrain (4b) is assumed from the LoRa Concentrator shown in Fig. 3. LoRa network server uses a minimum size of 11 Bytes that can contain a message to control LoRa Media Access Control (MAC) parameters on LoRa sensors. LoRa sensors can reply to acknowledge or transmit information in the size of the message up to 250 Bytes to IoT application. The variables $e_{j^i,l}$ are restricted to constrains of connection (4c) (4d) (4e) and the constrain (4f) of integer values.

IV. PROPOSED SOLUTION AND NUMERICAL RESULTS

A. *Algorithmic solution*

We apply the algorithm of the minimum weighted bipartite graph [10] to solve the bipartite graph of M in the objective function, which identifies EPS bearers named by APN names and the corresponding bandwidth for each LoRa gateway. This algorithm fills up the content in TABLE III and TABLE IV. We register the results into the HSS database. MME will look up the HSS database to control LoRa gateways to set up virtual links of the EPS bearer for a dedicated route between the LoRa gateway and the desired PDN.

We design a greedy algorithm [11] to control the LoRa packet arrival rate which indicates the number i of the incoming packets in $\sum_i p_i$. The greedy algorithm firstly starts from the default value, and then increases up according to the objective function. For example, at the arrival rate of 6000 LoRa packets per a second, we calculate the maximum bandwidth of EPS bearers among gateways in the region to serve a massive arrival rate of LoRa packets, and the minimum and the low arrival rate of LoRa packets.

TABLE III
CONNECTION TABLE OF GATEWAYS FOR ACCESS POINT NAMES

Index	**LoRa gateway**	**Region 1**	**Region 2**	**Region 3**
1	**Gateway 1**	APN 3	APN 2	APN 2
2	**Gateway 2**	APN 1	APN 4	APN 3
3	**Gateway 3**	APN 2	APN 1	APN 4
4	**Gateway 4**	APN 4	APN 3	APN 1
5	**Gateway 5**	APN 2	APN 3	APN 1
6	**Gateway 6**	APN 2	APN 3	APN 4
7	**Gateway 6**	APN 4	APN 1	APN 2
8	**Gateway 8**	APN 1	APN 4	APN 4
9	**Gateway 9**	APN 4	APN 2	APN 2
10	**Gateway 10**	APN 1	APN 2	APN 3
11	**Gateway 11**	APN 4	APN 1	

TABLE IV
BANDWIDTH TABLE OF GATEWAYS FOR EPS BEARERS

Index	**Region 1**	**Region 2**	**Region 3**
1	4 Mbps	2 Mbps	6 Mbps
2	10 Mbps	4 Mbps	6 Mbps
3	10 Mbps	4 Mbps	6 Mbps
4	10 Mbps	2 Mbps	2 Mbps
5	2 Mbps	6 Mbps	6 Mbps
6	4 Mbps	6 Mbps	2 Mbps
7	2 Mbps	4 Mbps	10 Mbps
8	6 Mbps	4 Mbps	6 Mbps
9	2 Mbps	10 Mbps	4 Mbps
10	4 Mbps	2 Mbps	6 Mbps
11	10 Mbps	6 Mbps	

B. Settings

Our simulation includes 32 gateways in three regions. Two regions u^1 and u^2 have 11 gateways each, and u^3 has 10 gateways. There are four LoRa network servers which require four gateways to be active at any moment of time. The remaining the gateways are standby. Each route between a gateway and a network server has a dedicated bearer service rate. Each LoRa gateway has predefined all APN names of the LoRa network servers. Each route between gateway and network server has a physical distance. To simplify the simulation, we define a fixed UDP size of 1500 Bytes. The maximum loading rate is the maximum packet size divided by the unit time to load the LoRa packets into UDP packets. The rate of LoRa packets that sensors are sending under the same region to gateways varies from 100 LoRa packets per second up to 10000 LoRa packets per second. UDP generating rates are 2 Mbps, 4 Mbps, 6 Mbps, and 10 Mbps respectively. In TABLE III, the gateways that connect to the network server 1 according to our algorithm to have the indexes of indexes 2, 8, and 10 in region 1. Their corresponding EPS bearer bandwidths are respectively 10 Mbps, 6 Mbps, and 4 Mbps, in TABLE IV. So the maximum bandwidth of 10 Mbps is used the massive flow of LoRa and 4 Mbps of the bearer established for the small flow of LoRa.

C. Results

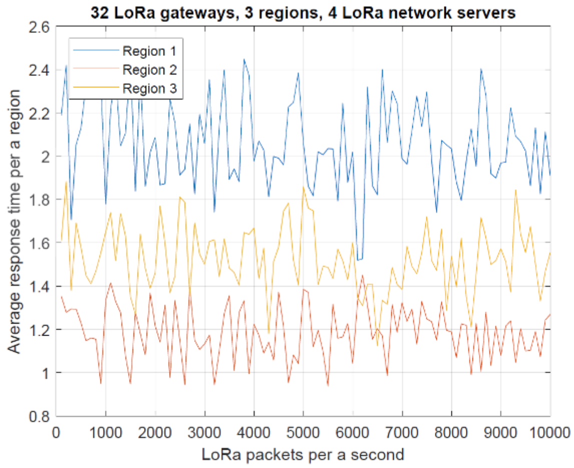

Fig. 4. The result of the response time in three regions where LoRa gateways in each region randomly select EPS bearers among all traffic of arrival LoRa packets.

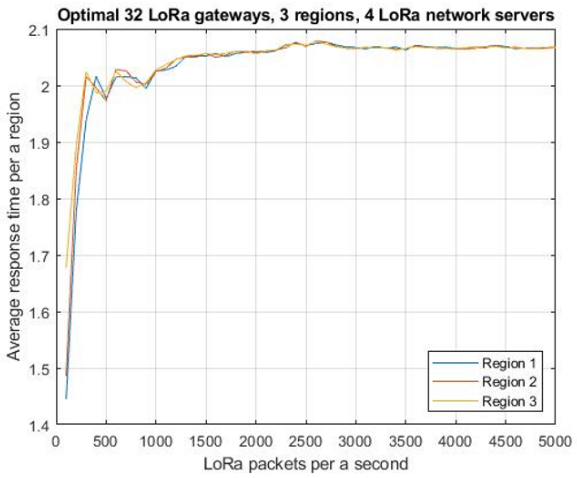

Fig. 5. The result of the response time in three regions where LoRa gateways in each region always select maximum bandwidth of EPS bearers.

We compare our greedy algorithm with a baseline algorithm that randomly selects four gateways connecting to network servers, and the gateways will call their default bandwidth of the EPS bearer in the first simulation. Fig. 4 shows the average response time resulting from the baseline algorithm for three regions, which increases according to LoRa packets rate. We use the first four gateways from all regions. In region 1, the average response time is the lowest among all regions, because the UDP service rate of the EPS bearer holds high bandwidth to access network servers. Region 3 has a moderate

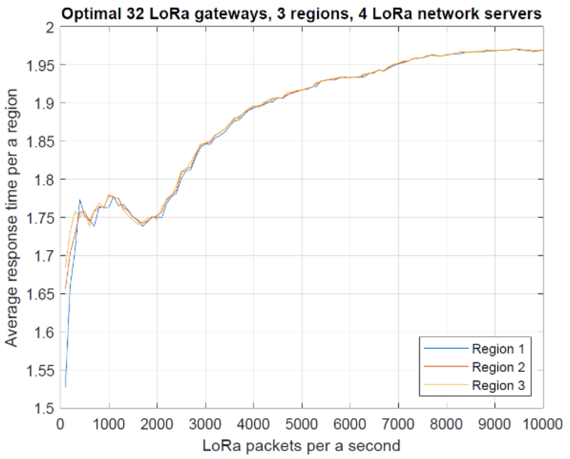

Fig. 6. The result of the response time in three regions where LoRa gateways in each region select minimum bandwidth of EPS bearers, when arrival LoRa packets are below 2000 pps, while maximum, when above 2000 pps.

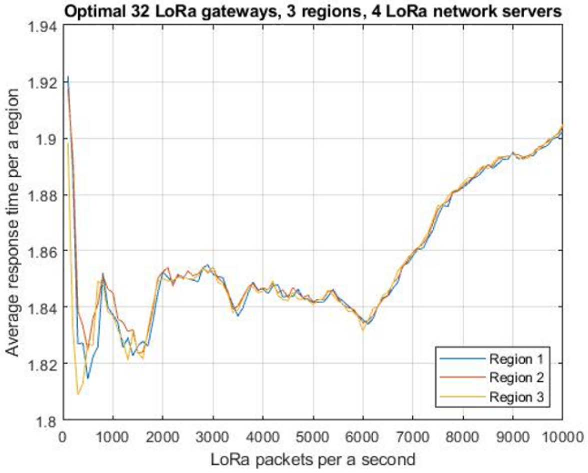

Fig. 7. The result of the response time in three regions where LoRa gateways in each region select minimum bandwidth of EPS bearers, when arrival LoRa packets are below 6000 pps, while maximum when above 6000 pps.

UDP service rate, and region 2 has a lower service rate. The fluctuation is due to the random LoRa packet size that stays in the range from 11 bytes to 250 bytes. LoRa packet requires 11 bytes to transfer the MAC command information, and the LoRa packet can extend up to 250 bytes to transfer data information. However, if we chose gateways with the highest bandwidth of its EPS bearer, Fig. 5 shows the response time of all gateways reaches 2.1 ms for any arrival rate of the LoRa packets.

Our proposed algorithm can find out the optimal routing, and we calculate the response delay on LoRa gateway by applying the various EPS bearers based on the arrival rate of LoRa packets and compare the results. Our simulation shows our algorithm can reduce 200 ms of average delay by selecting the policy of optimal routing and the scheduling mechanism to forward LoRa packets over the route in the EPC resource. The average response times shown in Fig. 6 are very similar among all regions. It is because instead of selecting a random set of gateways, we chose gateways with the lowest bandwidth of EPS bearer, when the arrival rate of the LoRa packet is less than 2000 packets per second, and the gateways having the highest bandwidth, when the arrival rate is above 2000 packets per second. The result shows that all curves fluctuate around to an average of 1.75 ms, when the arrival rate is under 2000 packets per second. Finally, all curves converge to the upper bound of 2 ms because of the limitation of the fixed UDP packet size. Fig. 7 shows the average response time we select a minimum EPS bearer bandwidth, when the arrival rate of LoRa packets is under 6000 packets per second. As shown, all the response times are at 1.84 ms on average, when the arrival rate is under 6000 packets per second, and the response time reaches 1.9 ms, when there are more than 6000 packets per second.

V. CONCLUSIONS

In this paper, we have presented problems of integration of the multiple LoRaWANs to use the existing core of 4G/LTE and GTP-u tunnels of EPS bearers in the EPC resource. We formulated the problems of dedicated routes, optimal routing and scheduling of LoRa packets, when accessing the EPC resource. Through simulation results, we showed the optimal policies to select routes in the EPC resource can reduce the overall delay of average response time.

In the future, we will apply the machine learning to analyze computational data to predict the system policy. We will also consider implementing our system over the specific deployment in 5G virtualization technologies, e.g., ORAN.

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