Controlled Emission Zone Pollution Resource Management in 5G C-ITS

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Abstract: An innovative pollution resource management scheme is proposed to tackle air pollution. The scheme introduces a novel concept of a pollution grant, a centralised pollution grant scheduler and accompanying pollution grant signalling between the scheduler and controlled polluting vehicle or a stationary source in a co-operative ITS environment. The scheme is analysed and discussed qualitatively as it can be effectively applied to controlled emission zones in cities and as a result, can improve the pollution control fairness, effectiveness and efficiency. The scheme can be implemented as a new pollution resource management function in 5G wireless base station within MEC architecture to leverage its low latency capabilities in parallel to its traditional radio resource management role.

1 INTRODUCTION

Air pollution from vehicles has been one of the most challenging aspects of the urban transport systems. Toxic gaseous and particulate matter emissions from vehicle internal combustion engines such as carbon oxides, nitrogen oxides, particulate matters etc. contribute a significant part to the urban atmospheric pollutants. To protect public health, the total amount of generated pollution is controlled by the legislation. E.g. the hourly NO_2 concentrations in the air are regulated by EU and UK legislations. The soft concentration limit is 200μg/m^3 measured hourly and the hard concentration limit is less than 18 excesses per year (Air Quality Expert Group, 2004).

Local city authorities are required to meet air pollution regulations to ensure the city air quality. Traffic pollution charge schemes are introduced with the aim of reducing tailpipe emissions. The schemes are typically based on a simplified version of 'pay as you pollute' principle. A typical example is London Low Emission Zone (LEZ) (Transport for London, retrieved 2017. Watkiss, 2003. Chapman, 2010). Such LEZs are currently common across Europe and beyond (European Commission, retrieved 2017. Weinmann, 2014. Transport and Travelling Research Ltd., 2006). London authority has even stepped up the measure by introducing Ultra Low Emission Zone (ULEZ) (Transport for London, retrieved 2017) in the most polluted city centre. The zone itself is a geographically defined area where access by certain polluting vehicles is restricted or deterred with the aim of improving the air quality. Only vehicles not conforming to higher emission standard (e.g. EURO 4 for lorries) are charged. Other vehicles not covered by the scheme enter the zone for free.

The amount of vehicle generated pollutants in a controlled emission zone like LEZ mainly depends on:

- Distance travelled in the zone
- Time spent in the zone
- Vehicle speed in the zone
- Alternative engine power source used (for hybrid vehicles) in the zone.

Existing controlled emission zone traffic pollution charge schemes are not based on accurate amount of the actually generated vehicle emissions. This limitation is mainly caused the by the lack of efficient methods to directly control actual emissions from every vehicle accurately. The charging model based on a flat fee when entering the LEZ fee is not linked to the actually generated vehicle pollution and as a result, it could be argued that the charging model is not fair. Therefore, a more efficient traffic pollution control approach to fairly implement "pay

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as you pollute" model is required in such controlled emission zones like LEZ.

In this paper, we propose a new scheme of Pollution Resource Management (PRM) for controlled emission zones which can be used to improve the fairness, efficiency and effectiveness of such controlled emission zones.

The remaining of the paper is organised as follows: section two specifies the proposed PRM scheme in details; section three gives some alternative implementations of the scheme; and in the last section we discuss the scheme and provide conclusions.

2 SPECIFICATION OF THE PRM SCHEME

PRM defines pollution as a controllable and shareable common user resource by using regulatory limits in space and time, i.e. the difference between regulatory pollutant limit and actual mass of pollutant per cubic meter at precise location during predefined period of time. It aims to improve the controlled emission zone scheme by leveraging Cooperative Intelligent Transport Systems (C-ITS) architecture (European Telecommunications Standards Institute, retrieved 2017). Each polluting vehicle, or other stationary pollution source, is a C-ITS Station supporting proposed PRM functionalities. Each active vehicle in the controlled emission zone is continuously supervised by a centralised scheduler. The vehicle reports its emission characteristics status and corresponding data to the scheduler, and in turn is informed about the current environmental pollution level in the predefined space and time unit and how much pollutant it can emit in this unit (i.e. pollution grant). The scheme is implemented by a feedback loop between the vehicle and the scheduler, enabling dynamic data sharing and permitted emission scheduling. The communication between the controlled C-ITS station and the pollution scheduler is facilitated by a complete pollution grant signalling message set (request/response) implemented by a wireless technology.

2.1 High-Level Overview

The three pivotal components of PRM are centralised pollution scheduler, dynamically adapted pollution grant and reliable low latency pollution grant signalling. Figure 1 illustrates a typical example how the PRM scheme works, incorporating the three pivotal components. A vehicle equipped with a C-ITS station travelling in the controlled emission zone is granted the pollution allowance. It communicates with the centralised pollution scheduler all the time during its presence in the zone. Figure 2 presents the data flow diagram with more details of the system implementing the proposed scheme.

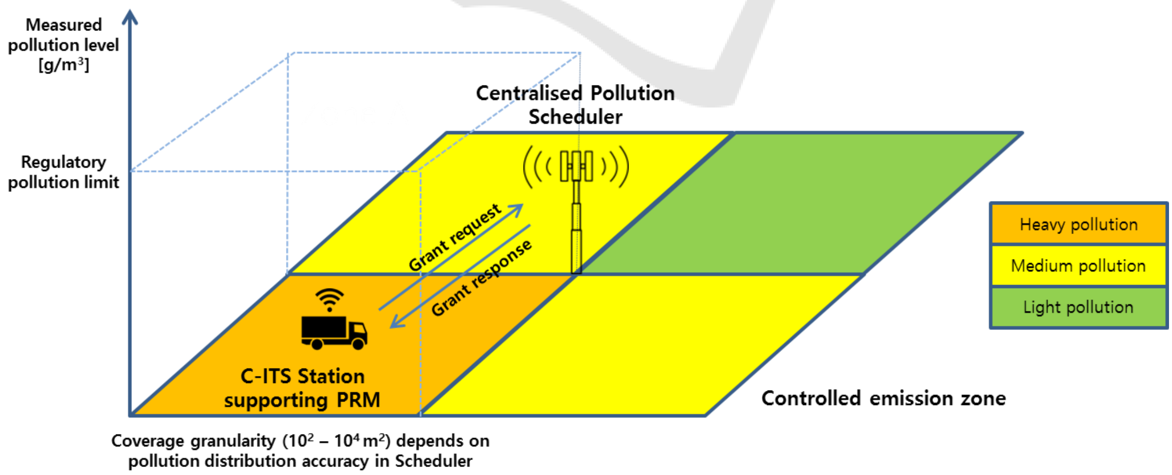

Figure 1: Example scenario showing pollution scheduler, grant signalling and pollution resource.

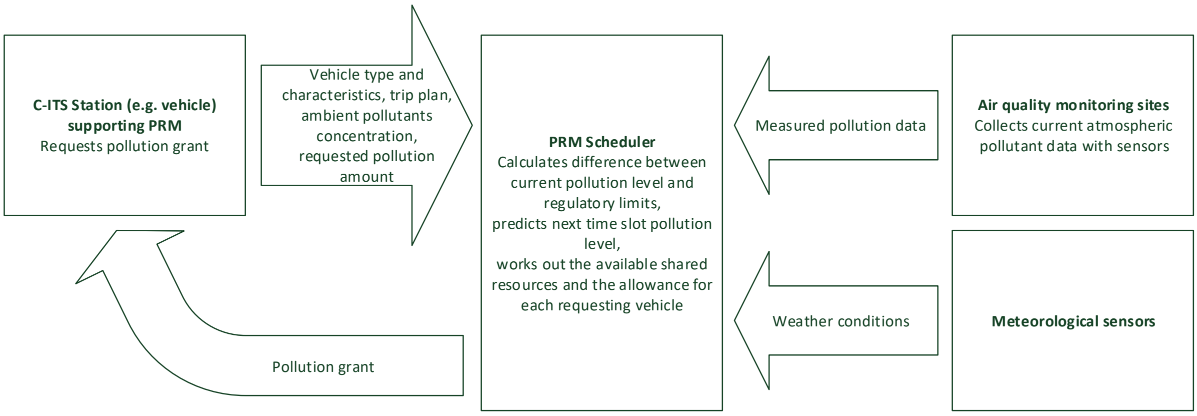

Figure 2: Detailed flow of data in a system implementation of PRM.

2.2 Pollution Scheduler

The centralised PRM scheduler is similar to frequency/time resource scheduler in the LTE mobile telecommunication network entity eNB (base station). The PRM Scheduler periodically receives pollution related information (ideally in real time), from various sources in different locations using wireless communication (e.g. high throughput low latency communication may be required for almost real time pollution information exchange e.g. provided by 5G systems):

- Generated pollution (e.g. [g] or [g/s]) - vehicles, power stations, business premises, households, and other sources
- Pollution measurements (e.g. concentration limit [g/m^3]) - from available pollution sensors in the zone (e.g. reusing pollution stations in cities or pollution sensors integrated with pollution sources i.e. vehicles)
- Weather conditions – factors impacting pollution dispersion (e.g. wind direction and strength, temperature)

Based on the received feedback aggregated from all sources, PRM Scheduler could build a precise pollution concentration map [g/m^3] in spatial domain and model the pollution dispersion in time domain (e.g. caused by the wind) and use the interpolation where the information is not available. Scheduler tracks pollutant concentration changes in a spatial domain, possibly with a cubic meter used as a concentration unit mapped to a square meter on the map to render the isometric representation (see Figure 1), and compares it with the regulatory limit (concentration limit per second rather than hour or similar needs to be defined). The main goal of the scheduler is to keep the actual mass of the pollutant per cubic meter (or similar unit) at the precise location during a predefined period of time below the regulatory pollutant limit (soft or hard) while ‘fairly’ sharing the observable difference i.e. [g] or [g/s] between the users of the common resource by using pollution grants. The actual definition of fairness in this context could be an implementation specific and could be related to the communicated characteristics of the pollution source (see pollution grant and signalling described in next sections for more details).

2.3 Pollution Grant

PRM controls the amount of generated pollution in a spatial domain by scheduling pollution grants to pollution sources (e.g. vehicles or other stationary objects). Pollution grant controls how much pollution (mass) the source could generate per spatial unit or air volume (in cubic meters) in its location to keep the concentration level below the limit. Scheduling decision frequency may depend on the frequency of received pollution feedback (in seconds or tens of seconds). Scheduling grant could be communicated to sources by a wireless communication technology (e.g. cellular, V2X). The communication does not necessarily need to happen in the controlled emission zone. It can be initiated by a vehicle outside of the zone to facilitate the trip planning when in the zone. If inside the zone, every pollution source after receiving the grant continuously monitors its emissions and makes sure its pollution emission does not exceed the grant to avoid consequential penalty from the local environment authority (enforcement).

The pollution source takes into account its characteristics and adapts its behaviour to use the grant efficiently to reduce emissions:

- Mobile vs. static source - Vehicle will receive different grant as it moves to different location in the zone, while power stations will receive updated grant as time proceeds
- Behaviour change - Vehicle limits maximum speed, reduces engine power (e.g. switches off some engine cylinders), switches to electric or alternative power source (hybrid)

Pollution grant validity could be limited by

- a configurable timer
- mobile pollution source (vehicle) leaving predefined area (location based)
- new grant received from the pollution scheduler (update)

2.4 Pollution Grant Signalling

Pollution grant signalling is based on a request message(s) from the pollution source (grant request) and response message(s) from the pollution scheduler (grant approval). Figure 3 illustrates the corresponding message sequence diagram.

Pollution Request Message could be sent when the current pollution grant was used (grant invalid) or periodically and could include parameters which the scheduler takes into account:

- Measured ambient pollutant concentration at source area location (if available). Source area location size could vary (meters to hundreds of meters) depending on the granularity of the pollution resource definition in PRM Scheduler (increased granularity may increase amount of exchanged data and as a result, high performance wireless communication providing high throughput and low latency may be required e.g. based on 5G system)
- Amount of planned emitted pollution requested to be approved by the scheduler, e.g. based on other in zone trip related factors
  - current location
  - distance to be travelled in the zone
  - planned time spent in the zone
  - average speed
  - capability to temporarily reduce emissions (e.g. alternative engine power source, reduced engine power)

Scheduler Response Message based on the knowledge of pollution resource usage in current location (pollution emission amount-mass to stay below the regulatory limit) may grant either

- a full pollution amount requested by the source or
- a reduced pollution amount (local pollution high or close to the limit) to keep the overall concentration below the limit

Overriding pollution scheduler grant decision (generating more pollution than approved) is possible but

- must be communicated back to the scheduler (by using another message or piggybacked on the next grant request message from the vehicle) to make sure the scheduler controls the overall pollution
- may generate additional charging fee (“pay as you pollute” principle etc.)

3 ALTERNATIVE IMPLEMENTATIONS

3.1 Distributed Pollution Scheduler within MEC Architecture

Pollution scheduler can be implemented in a distributed architecture – centralised pollution scheduler controlling predefined geographical area can communicate (e.g. wirelessly) with other schedulers in the neighbourhood geographical areas to share information and coordinate the pollution level changes at the boundaries (i.e. due to the wind impact). This makes PRM a suitable use case for Mobile Edge Computing (or Multi-access Edge Computing, MEC) (ETSI, Multi-access Edge Computing, retrieved 2017). MEC has a primary use case of Active Device Location Tracking (Huawei et al. 2014). PRM can be integrated with the MEC use case using the location service. Figure 4 illustrates an example of the PRM implementation within the MEC network architecture. The example assumes a 5G network deployment scenario, to leverage superior 5G capability, where the PRM can be regarded as a user scenario of massive Machine Type Communication (mMTC). The PRM application may be also using 4G LTE or 3G UMTS technologies for communication.

To allow continuous and almost real time information exchange (low latency), the pollution scheduler functionality can be implemented as a new application integrated into cellular base station architecture (5G gNB or 4G LTE eNB) in parallel to its normal radio resource management function

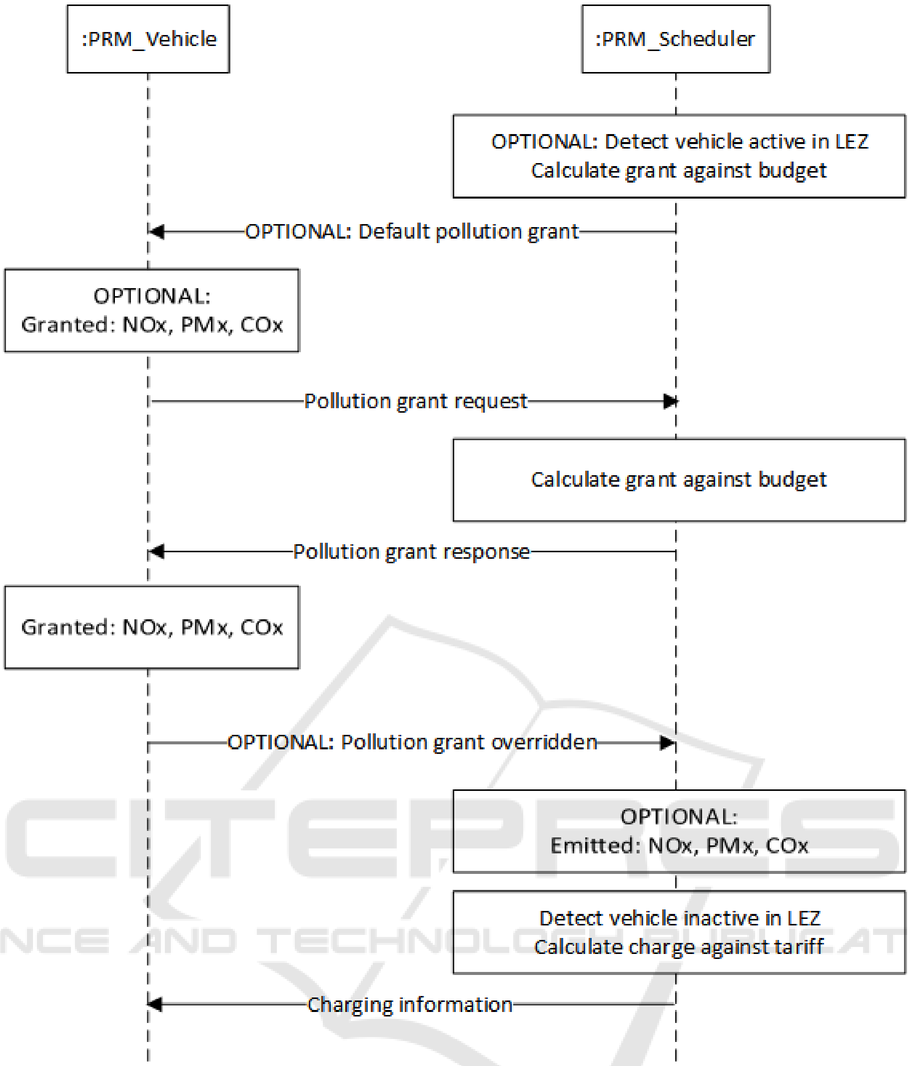

Figure 3: Pollution grant signalling scenario example.

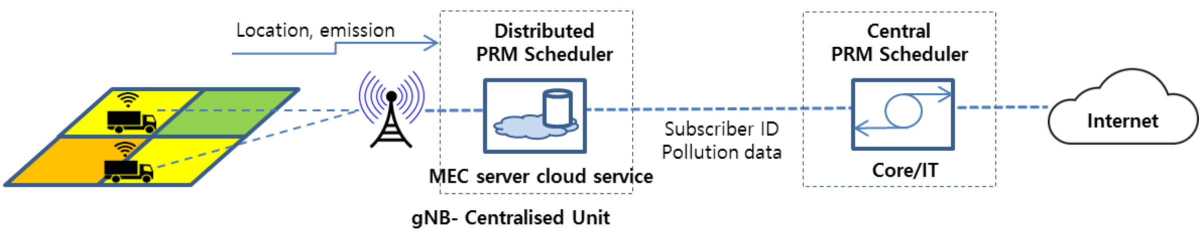

Figure 4: Example of PRM implementation within MEC network architecture.

supported by high performance wireless communications. The new application is denoted as PRM Scheduler in Figure 4. It will use the cloud resources centralised and provided at gNB-Centralised Unit (gNB-CU, or Baseband Unit, BBU) in a typical 5G Centralised Radio Access Network (or Cloud RAN, C-RAN). On the vehicle side, each 5G User Equipment (UE) is also a C-ITS Station, communicating directly with a Distributed Unit (gNB-DU, or Remote Radio Head, RRH).

Periodically, the vehicle will send its location and polluting emission information to the gNB and the data is centralised and locally pre-processed at the gNB. It is worth also noting, although not depicted in Figure 4, that the sensed atmospheric environmental pollution data can also be collected in the same way as the vehicle data is done.

The controlled emission zone supported by a low latency radio access and the PRM application available at the network edge coincides with the 5G small cell network deployment in a geographical sense, providing a great potential for highly efficient pollution controlled scheme in the local neighbourhood of the small cell. Depending on the PRM deployment policy and the controlled emission zone granularity, the small cells can be aggregated or divided to be mapped into each controlled zone. The benefit of this mapping is that the pollution resource quota can be allocated to each distributed PRM scheduler residing on the gNB-CU. The scheduler monitors the pollution level in its local zone and schedules the grants to each vehicle in the zone, under the coordination of the central PRM service, which is located in the Core network.

The gNB edge processed information is then filtered and the much reduced refined information is exchanged with the central PRM service, which will coordinate the whole controlled wider area emission zone entailing all the distributed PRM scheduler controlled zones. The information between the C-RAN and Core Network central service comprises of the subscriber ID of the vehicle, pollution data in the controlled emission zone and other environmental information. That information will be logged into and updated at the central service user account and zone database. In the opposite direction, the central service will coordinate the pollution resource grant and synchronise all the distributed user data all over the zone. To summarise, the 'centralised unit' of gNB centralises all the resources in the 5G C-RAN, whilst PRM schedulers are distributed into each C-RAN, under the coordination of the central service.

3.2 Pollution Grant Signalling

It is also possible that the same default pollution grant value is first automatically broadcasted to all users (e.g. this may be implemented as part of the system information broadcast messaging typically used in the mobile cellular networks if the pollution scheduler is integrated with the 5G base station, gNB) and then an additional amount is only requested by those users who found the grant insufficient for their use (see Figure 3).

The proposed pollution grant signalling can be then implemented in a new pollution supporting protocol running between the base station scheduler application and corresponding applications integrated with the pollution sources. This may be realized in the future Internet of Things / Smart City architectures by the broader integration of the pollution monitoring and control network (sensors and monitoring stations) with the communication infrastructure (cellular wireless network).

4 DISCUSSION AND CONCLUSIONS

PRM defines the pollution as a controllable and shareable user resource by using regulatory limit in space and time. The difference between the regulatory pollutant limit and the actual mass of the pollutant per cubic meter at a precise location during a predefined period of time is viewed as the pollution resource. If the pollutant concentration is under the limit, then the resource is available and the air can be polluted in a controllable manner with PRM. If the concentration is above the limit, then the resource is in deficit and as a result, immediate measure should be taken with PRM.

PRM Scheduler provides proactive continuous pollution emissions management based on the central entity which aims to minimise the difference between a regulatory pollutant limit and the actual mass of the pollutant per cubic meter at a precise location during a predefined period of time.

PRM provides continuous proactive control and sharing of the pollution resource to be used between users in a fairer way by means of the pollution grant. Each vehicle or polluting source equipped with communication capabilities and PRM functionalities contributes to the fairer pollution management and charging scheme. The flat charging will be replaced with a "pay as you pollute" approach with an accurate customised charging. According to the vehicle type, the polluting grant is adjusted and allocated fairly to each vehicle / source.

PRM signalling is based on a user asking for the pollution emission allowance in advance (grant request message) and receiving the pollution grant (response). The polluting vehicle may be informed about the possible consequence of travelling through the the controlled emission zone at the trip planning stage even before it enters the zone.

In summary, there are three novel elements proposed in this paper related to the pollution:

- Grant - defining pollution as a controllable and shareable user resource by using

regulatory limit in space/time (i.e. difference between regulatory pollutant limit and the actual mass of the pollutant per cubic meter at a precise location during a predefined period of time)
- Scheduler - proactive continuous pollution emissions management based on the central entity which aims to keep the difference between regulatory pollutant limit and the actual mass of pollutant per cubic meter at a precise location during a predefined period of time
- Signalling - based on a user asking for the pollution emission allowance in advance (grant request message) and receiving the pollution grant (response).

Furthermore, the other innovative aspect is the continuous, proactive and dynamic control of the pollution in the controlled emission zone (e.g. in a large city) based on the current air quality, weather forecast and polluting sources status. The dynamic control through the interaction between the polluting source (e.g. vehicle) and the centralised PRM scheduler is achieved by restricting the pollution allowed for each vehicle. This can be enforced by charging users extra for overusing the grant and causing excessive tailpipe emissions. Instead of unfairly punishing some fraction of the vehicles in the zone (typically heavy goods vehicles or buses), every polluting source is involved in the scheme, which takes the environmental awareness to a new level. Although th proposed PRM scheme may require some infrastructure investments, it can improve the fairness, effectiveness and efficiency of the controlled emission zones in cities. Finally, the proposed scheme extends the 5G communications technology application to the new vertical domain of the pollution control by leveraging the capabilities of 5G to provide the continuous air pollution control in the future Internet of Things and Smart Cities environments.

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