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Resource Optimization for M2M fleet Management Communications in 5G Networks

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***Abstract*—The fifth generation of mobile networks is expected to include Internet of Things (IoT) as an important innovative kind of accessibility. Various Machine to Machine (M2M) services will be provided through this type of connectivity. Requirements of these services are various mainly in term of security and quality of service. Some of these services, such as fleet management, are time sensitive and generate a considerable amount of signaling messages. In this paper, we propose an innovative framework in order to optimize the quality of service for fleet management M2M communications through the reduction the signaling overhead.**

***Keywords*—Resource management, Fleet tracking, Fifth generation (5G).**

I. Introduction

The fifth generation 5G is expected to have the ability to support the continuously growing traffic generated by the most innovative services which characterize the novel Internet of Things (IoT) paradigm. It will be built up around a ultra broadband core network and will be characterized by the integration of high capacity heterogeneous access networks.

Traffic generated by vehicular networks and the related applications will increase and become more and more adapted to mobile user needs for a plethora of services such as fleet management, cargo tracking, route planning, and vehicle diagnostics among others [1]. Actually, vehicular networks still have several limitations: limited spectrum resource, incapable on-board devices, and inefficient system management [2]. Moreover, this kind of application generate a significant amount of signaling messages and this impacts severely mobile cellular networks in term of load and overhead.

In general, vehicular M2M applications generate higher signaling overhead both on the UpLink (UL) and the DownLink (DL) due to the mobility of devices and to the frequent updates of the location, in fact, this is a consequence of a change in network radio conditions as a result of mobility which often generates successive handovers and hence, extra signaling. In addition, high signaling is required in 5G in order to manage the heterogeneity of access networks and to cope with the autonomy of the attached nodes. It is expected that high signaling overhead would occur with increased mobility speeds due to rapid cell crossing.

In particular, fleet management – which falls onto the category of vehicular applications – is associated with some specific real time needs related to traffic reporting, resource consumption, and incidents' management amongst other tasks.

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The need for adequate models dealing with the optimization of the signaling activity, real time event reporting, and network updating is then justified. Another important factor is related to the analysis of the effects of the expected very high number of M2M communications on the network resource allocation.

In this paper, we propose an innovative framework in order to optimize the quality of service for large fleet management M2M communications through the reduction the signaling overhead over a 5G network allowing the fleet to be real time monitored. More precisely, we propose: (i) a signaling reduction technique (ii) the development of a real time mobility management technique for fleet management (iii) the evaluation of the impact of an increased number of M2M connections on the total load of the network. In particular, the following issues will be addressed: (a) a model for temporary identification of fleet entities coping with the relative density of the fleet, the entity mobility, and the volatility of M2M connections is provided; (b) a model for the provision and the prediction of resources needed for the signaling activity is proposed; and (c) a technique to build efficient signaling interoperation is presented. Finally, the scalability of the proposed models is measured through real data.

The rest of the paper is organized as follows: in Section 2 we present and discuss the state of the art, in Section 3 we formulate the problem of resource reservation in M2M fleet communications and in Section 4, we present our proposed approach for resource optimization for M2M communications in 5G enabled environments. Then, in Section 5, we present and discuss the simulation results, and finally, in Section 6, we conclude with suggestions and future work.

II. Related Work

Several research efforts have been investigating M2M communications support for vehicular networks. Few of them focused on resource management issues in 5G environments.

Authors of [2] propose a new paradigm for vehicular networks in a 5G communications environment which aims to support data-heavy applications, such as augmented-reality applications. In the proposed scheme authors formulate the resource allocation problem as a non cooperation matrix game and solve it through a nonlinear concave optimization approach. In [3], authors consider scenarios of vehicular communications for vehicle-to-infrastructure, and they derive the handoff rate and the overhead ratio in order to evaluate the mobility performance in 5G cooperative MIMO small-cell networks considering co-channel interference.

A reduced M2M signaling communications framework in 3GPP LTE and future 5G cellular Networks is proposed in [4]. In this work, authors propose a new Random Access-based Small IP packet Transmission (RASIPT) procedure for M2M UEs small data transmissions. The work presented in [5]

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describes the evolution of resource reservation mechanisms for machine type communication over broadband networks. Besides, authors introduce a novel solution for supporting resource management for M2M over wireless devices based on customization and grouping and propose cached based resource reservation and event notification mechanisms.

Authors of [6] present a pricing model based on option pricing and auction that aims at guaranteeing the required QoS in the reserved resources. Authors also introduce the concept of Total Payment that refers to the price paid by the device when entering a M2M network. Furthermore, they suggest the optimal value of Total Payment and its corresponding optimal range of strike price based.

Massive deployment of M2M communications is investigated in [7]. Authors of this paper explore the principles of attaching M2M devices to LTE to adapt them in the cases of massive deployments. Moreover, they discussed solutions that depend on including special SIM types in machine type communication devices.

Different research works present in the literature address resource reservation for M2M communications and for vehicular networks without dealing with real time and heterogeneity issues. To the best of our knowledge none of them have investigated the integration of Vehicular M2M communications through Low Power Wide Area Network (LPWAN) and cellular M2M communications. In this work we address these issues and we propose an innovative framework for LPWAN – cellular M2M interoperability and we present a novel signaling and resource optimization scheme accordingly.

III. Problem Formulation

In this section the problem of resource reservation for M2M fleet management communications over 5G enabled access networks is presented and discussed.

A. *Vehicular Communications*

In a vehicular network, vehicles can either communicate with other vehicles (Vehicle-to-Vehicle (V2V)) or with an infrastructure (Vehicle-to-Infrastructure (V2I)). For fleet management configuration, we opted for a hybrid architecture for which a part of the architecture is made up of V2V communications and the other part is made up of V2I communications. The fleet network studied in this work is composed of vehicles, amongst which some gateways equipped with two interfaces ensure the role of a gateway. In addition some road side devices (on the bus stops for example) may be used by the vehicle to communicate.

B. *Fleet Management in 5G*

Future 5G networks will have the ability to handle mobile applications such as autonomous cars, real-time vehicle fleet management, smart utilities, and e-health monitoring,etc. For 5G, the challenge is that different applications will have different requirements. For example, health monitoring and video surveillance will require low-latency M2M communications while requirements of some other applications like such as smart energy meters are less stringent.

5G will also be the key technology to support vehicle fleet management, including vehicle localization, vehicle status monitoring, and traffic reporting. As an application of this service, smart buses, for example, will be able to avoid traffic congestion by choosing 'smart routes', or by skipping out bus stops that have no passengers waiting. In addition useful information about passengers or the traffic can be reported.

C. *System Architecture*

To meet the increasing needs of connected devices in term of higher data rates and in order to raise the network capacity in 5G networks, different techniques are used. One of these techniques consists in diversing in terms of access networks, reducing the cell sizes (and increasing the spectral efficiency consequently) and using a high capacity cloud network. In particular, the system will allow M2M establishment between vehicles and road side devices.

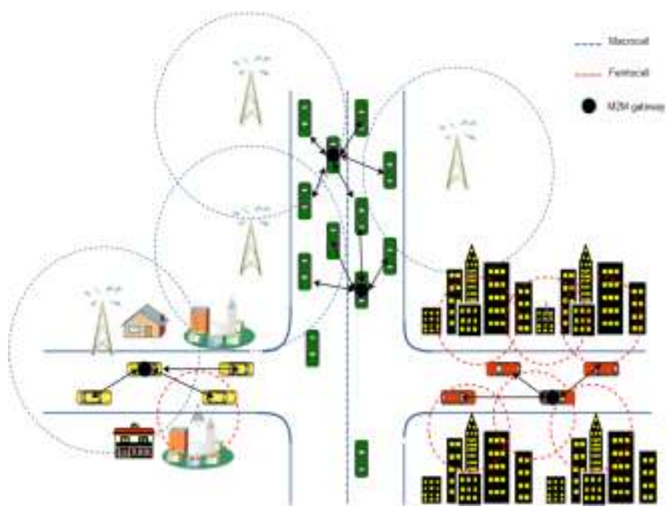

Figure 1. M2M vehicular communication architecture

The proposed system architecture is made up of a set of access networks including LTE networks. Vehicular networks are connected to the network either through macrocells or femtocells. This architecture is presented in figure1.

IV. The proposed Resource Management Scheme

This section proposes a novel resource reservation concept, which is based on the dynamic allocation of resource blocs in the communication frame. This allocation is based on:

- The density of the fleet in a particular geographic zone.
- The negotiation of the quality of service on both the LPWAN radio link and the access network radio link.
- The cost of the LPWAN radio link.

We assume that the system is made up of two types of M2M communications. Cellular M2M communications trough usual access networks (2G/3G/4G) and M2M yhrough

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LPWAN. Vehicles are moving in a zone covered by a 5G network where different types of broadband access networks coexist. Some vehicles have the role of gateway and are called “G-vehicles”. Normal vehicles communicate with G-vehicles through LPWAN. G-vehicles communicate with the network though cellular acces networks. In order to be able to communicate in both sides, G-vehicles are equipped with two interfaces.

A. *Signaling scheme*

In our M2M fleet management scheme, tracking needs to be real time or near real time and this requires a significant amount of signaling messages. The introduction of a new intermediate gateways further increases the total amount of signaling messages. In the folllowing subsections, we introduce a new signaling scheme for vehicles attachment and resource negociation through the G-vehicles. This scheme is based on three types of signaling messages:

1) *First Access signaling*

As presented earlier in this paper, a G-vehicles is a mobile node that plays the role of gateway. It is equipped with two interfaces and communicates using two diffrent ranges of frequencies. A vehicle that needs to communicate with the M2M platform must start by establishing a communication channel with the G-vehicle (or a road side device). These G-vehicles broadcast messgages in the LPWAN bands with a range that can reach some kilometers and can hence reach a considerable amount of vehicles. In order to get access to the network, vehicles listen the messages broadcasted by the G-vehicles and send their attachment requests in free resource blocks.

Based on the attachement request received by a G-vehicle during a particular period of time called “discovery phase”, this latter can estimate the number of vehicle in its coverage zone and estimate the signaling load accordingly.

Once vehicles are attached to the G-vehicle, they initiate a negociation process during which they announce their needs in term of QoS (bandwidth in particular) and during which the G-vehicle executes an evaluation process based on his own capacities and the eventual extra amount of resources that could be negociated with the network on the other side.

We assume that the traffic that is sent by vehicles is video traffic. So, in order to guanratee a certain level of QoS for this kind of traffic, we assume that VBR connection requests have the priority compared to best effort connections. So, even if a vehicle is connected in best effort, his connection is ended if there is a lack of resources for the video sessions.

The different steps of the negociation process are presented hereafter. We notice however that in this algorithm the G-vehicle can be replaced by a road side device.

Let:

- b_{v_i} be the individual bandwidth needed by vehicle i,
- b_{Gv} the bandwidth available at the G-vehicle,
- $b_{Gv_{extra}} < b_{Gv}$ the bandiwidth that could be allocated to the vehicles attached to the G-vehicle,
- $b_{Gv_{neg}}$ the bandwidth obtained after a negociation with the based station of attachment.
- n the number of gateways in the fleet.

Negiciation process

1. For $i \in \{1,..,n\}$, vehicle i annouces its own needs in terms of bandwidth b_{v_i},
2. The G-vehicle estimates the total amount of bandwidth $Tb_n = \sum_{i=1}^{n} b_{v_i}$ resquested by all vehicles,
3. The G-vehicle compares its own extra bandwidth $b_{Gv_{extra}}$ to the total amount of bandwidth requested by all vehicle under his coverage zone,

if

$b_{Gv_{extra}} \geq Tb_n$, then the G-vehicle admits all the vehicles,

Else

The G-vehicle negociates an extra amount of resources with the base station,

if $b_{Gv_{extra}} + b_{Gv_{neg}} \geq Tb_n$, then the G-vehicle admits all the vehicles,

Else

The G-vehicle admits vehicles based on first in first out logic and allocates them the resources they resquested,

Endif

One can notice that the higher n is the more important the bandwidth negociated will be. Due to the increased capacities the 5G networks offer, the limit value of this bandwidth is as high as total capacity of the radio link connecting the G-vehicle, which is quite important. The number of vehicles is supposed to be limited to a maximum value in order to guarantee the quality of service for VBR traffic. After this negociation phase, all vehicles whose needs could be statisfied initiate an attachment process with the G-vehicle.

Another kind of signaling messages, which is specific to the fleet, is the identification signaling. The particularity of fleet identifiers is that they are doubly needed. There is a unique identity within the fleet and the unique identity within the network. The first is the identifier of the attaching machine and the second is the identifier of the attached machine. In our case, we assume that the identication signaling objective is to concatenate the two identifiers in a single one. We will also assume that during a handover, data arriving to the left behind machine will be deleted and that it is the duty of the moving machine to resume.

2) *Periodic signaling*

During this phase vehicles admitted are all connected and they are sending and receiving data. The objective of this kind of signaling is to maintain the attachement of all these vehicles through the broadcasting of a number of relevant signaling messages that help vehicles in making the decision of keeping the connection or intiating a handoff process. The messages

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are related namely to the quality of service of the radio link, the cost of the connection, the status of the vehicles in the fleet, and the traffic beeing exchanged in both ways. The spacing time separating the broadcast message should be as large as possible to reduce the number of messages per time slot.

3) Decision signaling

The goal of the decision signaling messages is to inform the vehicles about whether they could be accepted to the network or not. It is also used by the vehciles in order to accept or reject the connection to that particular network based on the cost of the LPWAN proposed by the G-vehicle in comparison with its paying capacity.

The attachement to the G-vehicle is not accepted by the vehicle i only if $C_{Gv}^{i} \leq C_{pay}^{i}$, where:

- C_{Gv}^{i} is the cost proposed by the G-vehicle to the vehicle i,
- C_{pay}^{i} is the paying capacity of vehicle i.

Once the connection is accepted in both sides, the G-vehicle initiates a frame adaption phase.

B. Frame Adaptation

In M2M fleet management, the Uplink load is often greater than the downlink, especially when the vehicles are equipped with cameras and provide live streaming to the monotoring plateform. This is why, in this paper, we address the uplink optimization.

In our proposed scheme, resource reservation is made dynamically depending on the requirements of vehicles in term of bandwidth. Let us assume that the G-vehicle has X resource blocs for its own communication and X_{extra} is the number of resource blocs reserved for communications of other vehicles. In each frame, and based on the results of the negociation phase, each vehicle is allocated a cerain number of resource bloc dynamically proportionnally to the bandwidth allocated.

C. Resource Optimization

In order optimize the use of radio resources, to reduce the frequency of signaling messages, and to increase the overall capacity of the system, we introduce two novel concepts: the first is called the “virtual frame” and the second is the signaling profiling.

1) Virtual frame

The concept of virtual frame consists in reorganizing the way data is sent and received in order to support the transmission of high amounts of data (particularly in the uplink). This is done by spreading data that have to be sent in the uplink over multiple frames instead of only one frame. With virtual frame new concept, the size of the typical frame is multiplied by N, where N depends on the amount of data that a machine has to send and/or relay.

2) Traffic profiling

The technique we propose in order to reduce signaling for fleet vehicles is to carry out a profiling technique, which consist in grouping signaling messages for a set of vehicles located in a limited geographic area and having the same behaviour. This is based on prediction which takes into account the velocity of vehicles, the traffic sent and received, etc. For simplicity reasons, these prediction techniques will not be adressed in this work.

V. Performance evaluation

In this section, we present and evaluate the efficiency of our proposed resource management model. We defined our simulation scenario based on a typical example of fleet which is smart buses and we use real data in order to prove the effectiveness of our approach. Our objective is to observe the influence that a certain number of parameters can have on the performance of the system and to test the feasibility of our method.

A. Scenario configuration

Our proposed scenario is based on a fleet made up of smart buses, which are controlled and monitored remotely by a provider through an automatic monitoring system. The parameters of this scenario are presented hereafter:

TABLE I. FLEET SCENARIO CONFIGURATION

Number of vehicles within the fleet	*Payload for signaling messages*	*Maximum distance from de G-vehicle*
8000	248 bytes	500 m

We assume that for our system, vehicles are connected to 5 different G-vehicles, which handles the traffic in both ways (Uplink and Downlink). In figure 2, we represent the daily evolution of the signaling traffic for the fleet M2M traffic and the siez of signaling messages that we obtain using the profiling technique previously described.

Through this figure, we can observe the presence of a significant amount of peaks of signaling at every quarter or half hour, that are generated automatically for different kind a signaling messages. Depending on the profiling technique that is used, the overall signaling overhead can be significantly reduced. In our case, we used a profiling technique is based on velocity and geographic proximity.

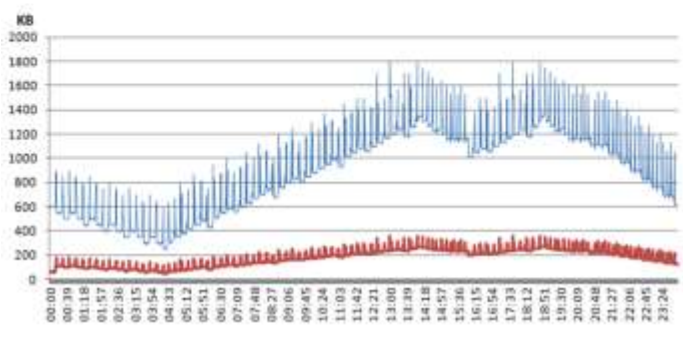

Figure 2. Signaling traffic evolution

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The evolution of the signaling traffic is directly tied with the evolution of the traffic sent and received by vehicles within the fleet. This traffic is relatively low during the night hours (after midnight) and the maximum is reached during the working hours. The maximum peaks are reached during the rush hours.

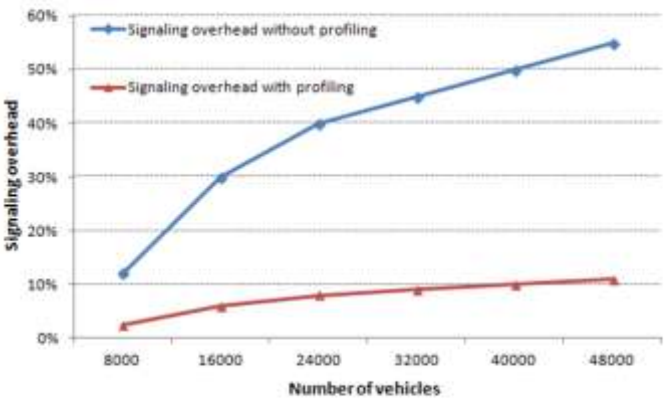

Figure 3. Signaling overhead in function vehicles number

Results obtained show that by using the profiling techniques, the signaling traffic is reduced by 60% as an average. The best performance enhancement was observed during the rush hours (up to 80% of decrease in the signaling overhead).

Another factor which directly impacts the signaling overhead is the number of vehicles in the fleet. Our simulation where conducted with 8000 vehicles, but when this number increases, the signaling overhead increases accordingly. In figure 3, we show that without traffic profiling the signaling overhead goes from 12% with 8000 vehicles till 55% for 48000 without profiling. With traffic profiling the previous values are reduced by 80% as an average. This proves that our proposed technique can efficiently optimize the system capacities used both for signaling and for data transmission.

VI. Conclusion

In this paper we have proposed a new scheme for resource optimization in M2M fleet management communications in 5G enabled environments. We have introduced new categories of signaling messages and we have proposed the new concept of virtual frame in order to meet the increasing needs of dense vehicular fleets. We have proven by simulations that our approach enhances the system performances and reduces the total load generated by M2M fleet management communications.

In the future, we will address the impact of mobility on the signaling scheme and we will propose a technique for managing extra signaling messages.

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