Innovative Platform for Resource Allocation in 5G M2M Systems

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Abstract. One of the major drivers of cellular network evolution towards 5G systems is the communication between devices, also known as Machine-to-Machine (M2M) communications. M2M mobile connections will reach an estimated 3.2 billion devices and connections by 2020, which will pose a challenge as the state-of-the-art cellular and wireless networks were designed keeping in mind Human-to-Human (H2H) communication. A massive amount of M2M devices create overload problems with a significant impact on the radio access and core network of the cellular system leading to what are known as the problems of RAN overload and CN overload. The paper presents a proof-of-concept hardware implementation of novel resource allocation algorithms in 4G cellular communication systems. The proof-of-concept thus, will enable lab-scale analytical and experimental studies for validating theoretically developed algorithms with the focus being on validating the scheduling and admission control algorithms for M2M scenarios. The platform will be based on an LTE-A eNodeB implemented using a software defined radio (SDR) platform and a UE simulator that enables simulating a large number of UEs sharing the same spectrum. The platform will be complemented by field-programmable gate array (FPGA) devices that enable the hardware implementation of the analytically developed resource allocation algorithms.

Keywords: Wireless networks · Machine-to-Machine · 5G
Resource allocation

1 Introduction

Scheduling and resource allocation are essential components of wireless data systems and they tend to be a very complex problem [1,2]. This is because different variables have to be taken into account like the user radio conditions, the user's traffic pattern or the user Quality of Service (QoS) and the allocation of radio resources has to be optimized from the whole system point of view. Essentially, one has to decide when and how the available resources in a cell are assigned to each of the users, where the resources depend on the access method.

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For users in an LTE or LTE-Advanced system, the users are allocated Physical Resource Blocks (PRBs). This has led to a great deal of interest in the research community on scheduling and resource allocation algorithms [1].

However, most scheduling and admission control algorithms remain at the stage of theoretical development. There are few testbeds which have been developed for evaluating resource allocation. One such testbed has been developed by Toshiba in 2011 [3]. However, the authors used a pair of laptops to mimic Femto-UE communication, as the transmission was done via Wi-Fi cards. Another testbed for reconfigurable, multi-layered communication systems is ASGARD [4] which is a "software tool for the implementation of Cognitive Radio communication systems over Software Defined Radio equipment". Although the platform is modular and flexible, it lacks implementation of resource allocation algorithms and it is mostly software-based for higher layer protocols experimentation. It is, however, available for using under an open source license. OpenLTE [5] provides an open source implementation of the 3GPP LTE specifications suitable for implementing it on a Software-Defined Radio platform with GNU Radio [6] applications available.

Additionally, it is foreseen [7] that M2M mobile connections will reach more than 26 percent of total devices and connections by 2020. This poses a challenge as the state-of-the-art cellular and wireless networks were designed keeping in mind Human-to-Human communication. In the light of M2M scenarios, present-day mobile networks face challenges of [8,9]:

- **variation of QoS requirements** as M2M devices have QoS requirements that vary depending on different purposes of data delivery;
- **different traffic patterns** as some M2M devices may transmit data at large time intervals (hours, months) while others may transmit data continuously.

Therefore, there will be the need to differentiate between M2M, M2H, H2H traffic in wireless cellular communications [10]. Researchers have been studying resource allocation (packet scheduling and admission control) algorithms for 4G (LTE-Advanced) wireless communication systems. In particular, the main author has developed a number of scheduling algorithms for carrier aggregation systems, using a convex optimization approach, that take into account the existence of multiple component carriers, and optimizes the allocation of radio resources in LTE-Advanced systems. The developed algorithms have been proven to outperform existing traditional scheduling algorithms. Also, we have developed novel admission control algorithms for 4G systems that, together with already developed scheduling algorithms, form the basis of new resource allocation algorithms. The algorithms take also into account the existence of different QoS requirements and are suitable candidates to be employed in next-generation cellular communication systems with different possible applications such as differentiating between M2M, H2H and M2H traffic. The results have been published in a number of papers [11–15] and part of the results therein constituted the main author's PhD thesis [16].

Starting from the developed scheduling and admission control algorithms and examples mentioned above, together with existing 3GPP standards, the paper proposes a proof-of-concept hardware implementation of the theoretically-developed scheduling and resource allocation algorithms. The proof-of-concept is to be designed to work in different scenarios such as different types of traffic and different types of devices in order to validate key performance indicators (KPIs) of the theoretical algorithms.

The present paper is organized as follows. Section 2 presents the resource allocation algorithms that form the basis of the proposed platform, while Sect. 3 presents a preliminary architecture for such a testbed. The impact the proposed platform would have is outlined in Sect. 4, while Sect. 5 draws the conclusions.

2 Resource Allocation Algorithms

LTE Rel. 10 specifies the aggregation of up to 5 LTE Rel. 8 carriers, also known as component carriers (CCs), in order to achieve an overall bandwidth of 100 MHz. The main author has proposed [11] an algorithm which enables the best user allocation over any number of CCs, with the objective of maximising the total user throughput, and maintaining QoS requirements. The algorithm is based on solving an optimisation problem for the best use of network resources. The following Profit Function is proposed in order to maximize the total throughput of the cell [13]:

$$\sum_{c=1}^{N_c}\sum_{u=1}^{N} w_{cu}x_{cu} \tag{1}$$

where x_{cu} is the allocation variable and wcu is a normalized metric. Also N_c is the number of configured component carriers (CCs) in the cell and N is the number of users attached to the cell. The allocation variable x_{cu} is defined as:

$$x_{cu} = \begin{cases} n, & \text{if } n \text{ PRBs are allocated to user } u \text{ on component carrier } c \\ 0, & \text{if no PRBs are allocated to user } u \text{ on component carrier } c \end{cases} \tag{2}$$

The normalized metric w_{cu} is defined as:

$$w_{cu} = \frac{T_u}{R_u} \tag{3}$$

where T_u is the current estimated throughput for user u and R_u is the average received throughput for user u.

Therefore, the values of x_{cu} that maximize the proposed profit function have to be found taking into account allocation and bandwidth constraints. This is called the Multi-Carrier Scheduling Algorithm (MCSA) algorithm. An enhanced version of the algorithm (called Enhanced MCSA - E-MCSA) was developed and presented in [13] taking into account a variable upper bound on the user allocation constraint. Because of this, an admission control algorithm had to be developed [13], otherwise, the optimization problem could have become unbounded or unfeasible.

The algorithms were validated in comparison with traditional scheduling algorithms (Round Robin, Proportional Fair) and in a scenario with different types of users (macro cell, femto cell, with QoS, without QoS) [16]. The *general conclusion* regarding the developed scheduling algorithms is that convex optimization used for resource allocation in a Carrier Aggregation system has better performances than existing state-of-the-art algorithms (as seen in Figs. 1 and 2). In particular, MCSA is more suited in a mixed scenario of both LTE and LTE-A users, but, if we consider that there are mainly QoS users that are LTE-Advanced capable, E-MCSA would be a better choice.

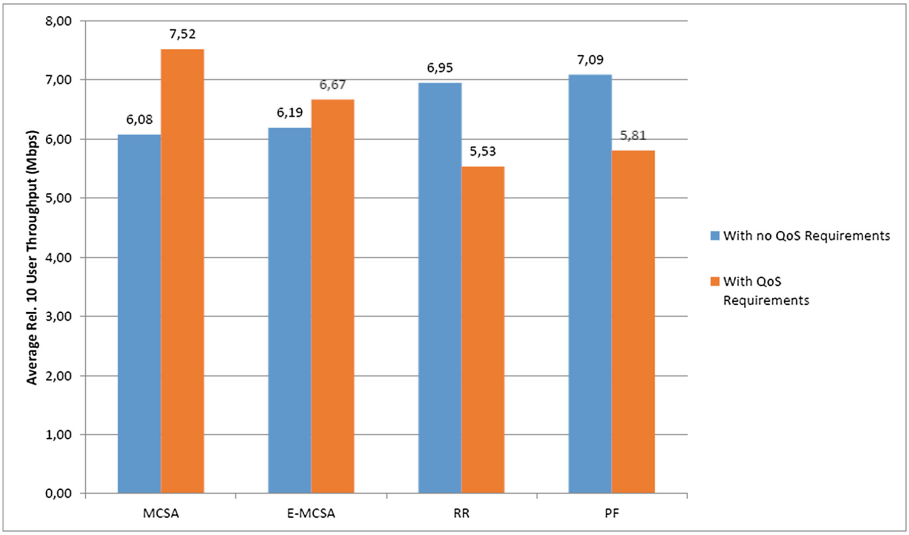

Fig. 1. Average Rel. 10 user throughput

With theoretical validation achieved, comes the next step and that is the physical implementation of the developed algorithms. Therefore a hardware and software architecture is needed in order to physically implement the algorithms.

3 Preliminary Architecture

We take a *bottom-up approach* in which the emphasis is laid on first, deriving the mathematical models for radio resource scheduling and admission control algorithms for massive M2M access in future 5G systems, then designing the software framework for validation through simulation and emulation. This is to be done by considering different approaches, for instance, applying the concepts of convex optimization, identifying constraints for M2M massive access and formulating a convex optimization problem for determining the radio resource

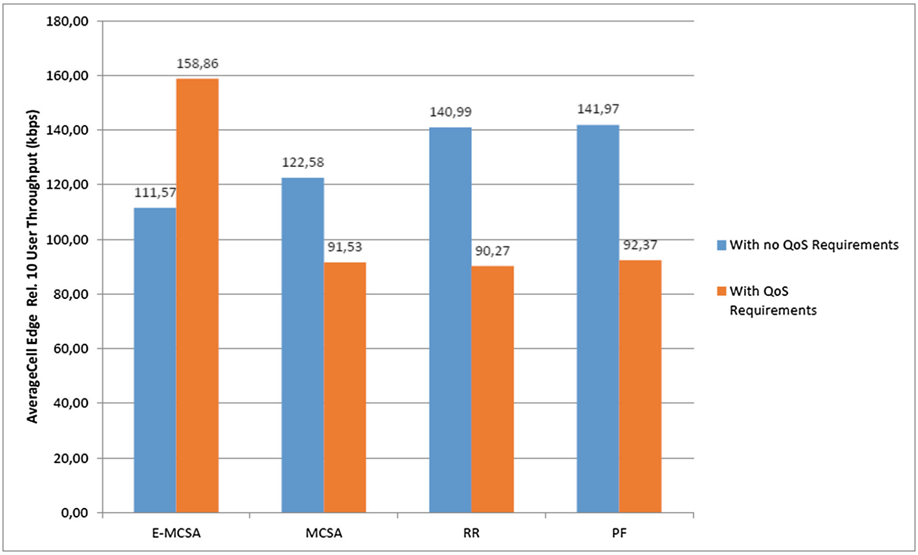

Fig. 2. Average Rel. 10 cell edge user throughput

allocation matrix in an M2M scenario. Other approaches can be taken into consideration such as clustering techniques, machine learning, game theory, or a combination thereof.

The work is then taken to developing a plugin for a network emulator able to handle M2M communications in an LTE network, based on existing standards such as NB-IoT[1] and also modifying the source code of the simulator for implementing the mathematical model of the resource allocation algorithms. The development of the resource allocation algorithms is to be done according also to the simulator/emulator constraints, and they will be evaluated and compared to existing state-of-the-art algorithms using the developed software framework. The need for an emulator is justified by the fact that there is physical equipment that is not readily available (Massive M2M gateway) and an emulator serves to connect simulated devices and network elements to existing physical infrastructure. Figure 3 illustrates a conceptual architecture of the experimental simulation/emulation platform to be developed.

The simulation platform has a two-fold purpose: first it should enable the validation of new resource allocation algorithms specifically designed for M2M therefore serving as a validation platform including also for other interested parties. Second, it should serve as the bridge for a physical implementation of the algorithms. The algorithms can be extensively tested before starting a physical implementation, therefore eliminating any limitations from the theoretical point of view.

[1] http://www.3gpp.org/news-events/3gpp-news/1785-nb_iot_complete.

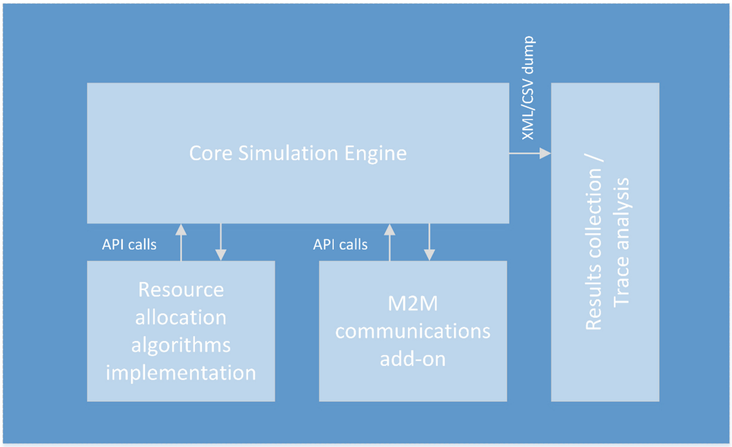

Fig. 3. Conceptual architecture of the experimental emulation platform

After emulation comes the physical implementation. This will be done, first, via hardware development of the LTE-Advanced Radio Access Network with an eNodeB implemented via OpenLTE and USRP B210 SDR platform and the UEs are emulated via an UE simulator that can emulate tens of UEs and is connected to an USRP N210 platform. The enhancement of the existing resource allocation algorithm will be done according to the identified hardware constraints, and they will be evaluated and compared to the original theoretical algorithms using the developed proof-of-concept. Figure 4 presents the envisioned proof-of-concept architecture.

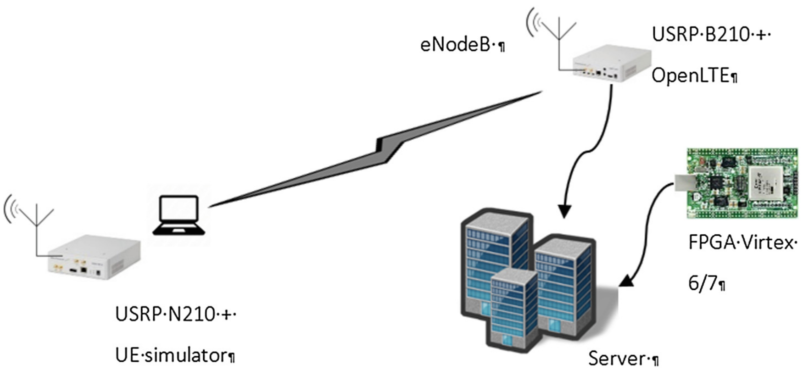

Fig. 4. Envisioned proof-of-concept architecture

4 Impact

Considering the rapid growth of the M2M data traffic in mobile networks and the continuous increase of the radio resources demand, the proposed proof-of-concept aims to provide solutions for efficient massive M2M access to the cellular network. Thus, it can be viewed as contributing to solving the challenges of the M2M paradigm in future wireless communication network. The M2M access will play a vital role in future 5G systems, both as an enabler of potential disruptive paradigms (Smart City) and as potential challenges that it might pose to the communication network services. Aside from traditional enhancements such as increased data rate and increased user and system energy efficiency, 5G will be required to provide minimal latency for critical services and to support massive M2M services, without degrading the Quality of Service of the so-called conventional services (voice, video streaming, web browsing etc.).

There are some major impacts of the proposed platform as follows:

- economic growth by enabling new applications to be developed that benefit from a richer awareness of the surrounding environment, enabling the concept of Smart City; these include applications ranging from e-Health to vehicle tracking and public safety;
- the development of technologies that are considered to be effective in 5G networks;
- the promotion and facilitation of new business models for operators by solving the challenges brought by the massive M2M ecosystem. Mobile operators and users may deploy a plethora of nodes that can connect to their network and have minimal impact on the human-originated data or voice traffic;
- improving the quality of life of the individuals by enabling the paradigms of smart home, connected home and smart city.

By designing, developing and validating new radio resource allocation algorithms for massive M2M communications, the envisioned platform is expected to promote future radio access technology and resource management methods that consider the key features of M2M networks that have massive connectivity, explosive traffic, various applications with diverse QoS and reliability features. As more and more devices become connected, the operators' networks will be subject to increasing overload, therefore hindering the Quality of Service of their human users, but also affecting the reliability of M2M devices. Thus the results obtained by using the proposed platform in the perspective of the future 5G communication networks can become a significant engine for network efficiency for mobile operators.

5 Conclusions

As presented throughout the article, the main objective of the proposed platform is to provide means of implementing resource allocation algorithms for massive M2M access.

The M2M paradigm will be a major pillar of the future 5G systems and numerous challenges related to it will occur. The proposed platform is to serve as a stepping stone towards more optimized massive M2M access.

Therefore, even though the proposed platform is not entirely implemented, based on results obtained from our preliminary analysis made and their innovation in specific areas, we can state that our proposed architecture will enable its users to create efficient M2M systems.

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