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Virtual code resource allocation for energy-aware MTC access over 5G systems

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ABSTRACT

The enormous traffic of machine-type communications (MTC) expected over 5G exacerbates the limitations of access schemes currently under investigation in the literature. This scenario becomes more challenging when considering smart city environments, which introduce further issues due to the heterogeneity in the level of residual battery energy of involved machines. Novel solutions are, therefore, required, which aim at drastically reducing the collision probability of devices with critical level of residual battery energy. In this paper, we propose a virtual code resource allocation (VCRA) approach which extends the code-expanded strategy to support a high number of devices simultaneously accessing the system. Besides, a virtual resource allocation scheme to guarantee energy-priority in the access procedure is introduced. The idea behind our proposal is the definition of different access levels that exploit disjoint sets of access codewords, properly tailored to guarantee high capacity for each access level. Simulation results show to the effectiveness of our scheme in terms of (*i*) reducing the collision probability of machines with limited battery capabilities also in scenarios with very high cell load and (*ii*) enhancing the efficiency with respect to legacy code-expanded strategy.

1. Introduction

A field of keen interest for network providers is the deployment of effective solutions allowing *smart city* to become a new complex ecosystem with innovative applications [1,2] by simultaneously supporting different traffic types with unique features over next-to-come fifth generation (5G) systems [3]. An example of smart city environment is depicted in Fig. 1.

In this scenario, a key role will be played by *machine-type communications (MTC)*, which represent a novel transmission paradigm where machines (such as smart meters, cameras, remote sensors) send data without (or with minimal) human intervention [4]. MTC are expected to offer unprecedented opportunities and business models to telco operators in different fields (e.g., city transport and logistics, smart power grids, e-health, home and building remote surveillance) [5] and, consequently, have promising economic and strategic value for 5G wireless networks.

The effective management of MTC opens up different research scenarios, such as ad-hoc cellular-compliant network architecture [6] and data transmission procedures, currently under investigation by industries and standardization bodies [7]. In particular, being machines battery-constrained devices, they usually try to send data as quickly as possible to save battery; this dictates for the definition of an adequate access scheme [8] able to support the huge number of MTC devices expected to operate over

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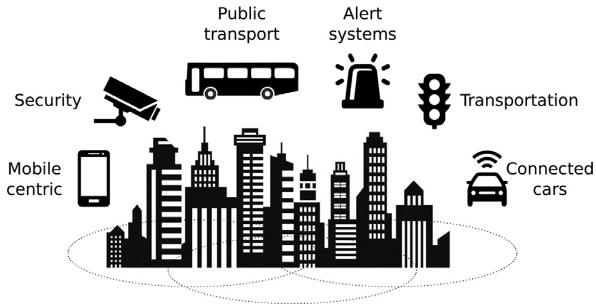

Fig. 1. Example of application scenarios for 5G smart city.

5G networks [9]. Furthermore, the expected high load offered by MTC devices has to be properly managed to avoid a negative impact on the QoS offered to human traffic [10].

To the end, the 3rd Generation Partnership Project (3GPP) standardized the contention-based random access channel (RACH) mechanism [11], where devices waits for a random access (RA) slot to send a randomly chosen orthogonal preamble; if two (or more) devices select the same preamble, then a collision occurs and preamble transmission has to be re-accomplished. Due to the limited set of available preambles (and, thus, associated access codewords), the 3GPP RACH suffers in terms of *capacity* when the number of devices accessing the network increases. This implies high delays and battery consumptions for both human and machine devices, as highlighted in [6]. Several works have been presented in the literature aiming at overcoming the limitations of 3GPP RACH [8]. Among them, virtual resource allocation [12] and code-expanded strategies [13] have been designed to achieve access prioritization and higher capacity, respectively. The former approach addresses a split of RA resources (i.e., preambles) into different sets to guarantee access separation to devices with different priorities, while the latter introduces a logical extension of the access method according to which devices send multiple preambles over multiple RA slots. Nevertheless, these schemes suffer from two main drawbacks. The virtual resource allocation may require a high ratio of preambles for high-priority level(s) to guarantee low collision probability; this obviously may jeopardize the number of preambles for low-priority level(s) with a consequent performance degradation. The code-expanded approach introduces a novel negative phenomenon, known as phantom codes: since the access codeword is composed of multiple preambles, the base station hears different preambles in each RA slot and, consequently, the number of codewords computed by the base station (referred in the paper as ‘decoded codewords’) is basically the combination of preambles received in each slot. This means that the number of decoded codewords is higher than the number of codewords effectively transmitted by devices. This may involves high inefficiencies due to the fact that the management of phantom codes (i.e., codes not transmitted by accessing devices) requires a large amount of resources by the base station and this, as a consequence, increases the delay of the RA procedure.

In this paper, we deal with an aspect not adequately investigated in the literature, i.e., the design of an energy-aware access scheme. As also highlighted in [3,7,8], the set of machines populating a smart city and accessing 5G systems is expected to be heterogeneous, even in terms of differentiated levels of residual battery energy. It is enough to think about roadside units and vehicles with almost no energy consumption issues, compared to energy-constrained hand-held devices through which citizens access the offered services, to wireless sensors scattered across the smart cities characterized by very stringent energy consumption constraints. In this direction, special care has to be reserved for those devices for which RACH collisions will involve a consumption of their already drastically low battery energy level. By extending the virtual resource allocation and code-expanded approaches, the idea behind our proposal is to define different energy-based access levels and to split the set of available preambles into different subsets, each one associated to one access level. In so doing, we can set the number of access levels, as well as the number of associated codewords, according to the measured cell load and the expected levels of residual battery charge. Our proposal, named *virtual code resource allocation (VCRA)*, outperforms the ones in the literature in that it guarantees a different collision probability for each access level, with a keen attention to devices with critical residual energy. With respect to 3GPP and the virtual resource allocation schemes, our proposed strategy increases the access capacity and, consequently, avoids human traffic degradation caused by MTC. With respect to legacy code-expanded, the use of different sets of access codewords, at the basis of our approach, reduces the side effects (i.e., latency and resource consumption) of phantom codes.

The remainder of this paper is structured as follows. Section 2 illustrates the related work, while Section 3 depicts the considered system model and analyzes the approaches considered as benchmark. Section 4 presents our proposal, whose effectiveness is testified through simulation results in Section 5. Section 6 draw the conclusions of this our research work and discusses about the possible future activities.

2. Related work

The design of access procedures able to support the simultaneous access of both human- and machine-type devices is currently considered as one of the most challenging issue for 5G systems in smart city environments [8]. In this scenario, the reference scheme is represented by the 3GPP RACH [11], a contention-based RA mechanism which consists of a four-message handshake between the accessing devices and the base station. The RA procedure is performed in the following situations:

- Upon *initial access* to the network.
- To receive/transmit new data in case the device is *not synchronized*.
- Upon transmission of new data if *no scheduling request resources* are configured on the uplink control channel.
- During *handover* (i.e., change of associated BS) to avoid a session drop.
- For *connection re-establishment* after a radio link failure.