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A review of Next Generation 5G Device-to-Device (D2D)

Kumar Shanu[1] and Aman Saraf[2]
[1]Research Scholar, Department of Electronics and Communication, Radharaman Institute of Technology and Science, Bhopal (Madhya Pradesh), INDIA
[2]Assistant Professor, Department of Electronics and Communication, Radharaman Institute of Technology and Science, Bhopal (Madhya Pradesh), INDIA

(Corresponding author: Kumar Shanu)

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ABSTRACT: The Proliferation of heterogeneous devices connected through large-scale networks is a clear sign that the vision of the Internet of Things (IoT) is getting closer to becoming a reality. Many researchers and experts in the field share the opinion that the next-to-come fifth generation (5G) cellular systems will be a strong boost for the IoT deployment. Device-to Device (D2D) appears as a key communication paradigm to support heterogeneous objects interconnection and to guarantee important benefits. In this paper, we thoroughly discuss the added-value features introduced by cellular/no cellular D2D communications and its potential in efficiently fulfilling IoT requirements in 5G networks. State-of-the-art solutions, enabling radio technologies, and current standardization activities for D2D communications are surveyed and their pros and cons with reference to manifold IoT use cases pointed out. Future research directions are then presented towards a fully converged 5G IoT ecosystem.

Key words: fifth generation, D2D communications, Wi-Fi Direct, energy consumption.

I. INTRODUCTION

The Internet of Things (IoT) holds the promise to improve our lives by introducing innovative services conceived for a wide range of application domains: from industrial automation to home appliances, from healthcare to consumer electronics, and many others facing several societal challenges in various everyday-life human contexts [1]. Currently we have 10 billion IoT devices connected and 24 billion to 50 billion total connections expected within the next five years [2]. The vision of a "Smart world" where our everyday furniture, food containers, and paper documents accessing the Internet is not a mirage anymore [3] The IoT growth is sustained by the constant increase in the number of devices able to monitor and process information from the physical world and by their decreasing costs. Most of them operate through their virtual representations within a digital overlay information system that is built over the physical world. The majority of current IoT solutions, indeed, require Cloud services, leveraging on their virtually unlimited capabilities to effectively exploit the potential of massive tiny sensors and actuators towards a so-called Cloud of Things [4]. Despite all the conditions seem to be very favorable, still much remains to do before reaching well-working, reliable and efficient IoT ecosystem. In [5] the current situation of the IoT arena is compared to the "Wild West" of a couple of centuries ago with its vast, mostly unexplored territories, without clear borders, where all current technologies can play a role, and where ad hoc solutions are often the norm. For instance, the high heterogeneity of devices, technologies, and interaction modalities (machine-to-machine, machine-to-human, and machine-to-cloud) involved poses severe challenges concerning the communication process. Multiple-antenna technology is a rich area of research.[20]Whether for future military wireless networks, soldier radios, autonomous sensors, or robotics, the demand for improved performance may be met with multiple antenna communication links and the advanced technology making those links effective. In this view, a wide variety of low-power short-range wireless technologies, such as IEEE 802.15.4, Bluetooth Low Energy, IEEE 802.11ah, have been designed to provide efficient connectivity among IoT devices and to the Internet. Recently, also long-range cellular networks are being considered as promising candidates to guarantee the desired internetworking of IoT devices, thanks to the offered benefits in terms of enhanced coverage, high data rate, low latency, low cost per bit, high spectrum efficiency, etc. [3].

In this context, the Third Generation Partnership Project (3GPP) has introduced novel features to support machine-type communications (MTC) [6] by accounting for the intrinsic battery-constrained capabilities of IoT devices and the related traffic patterns (e.g., small data packets). At the same time, the efforts of academic, industrial and standardization bodies are pushing towards the fulfillment of IoT requirements through the next-to-come fifth generation (5G) wireless systems [7]. 5G will not only be a sheer evolution of the current network generations but, more significantly, a revolution in the information and communication technology field [8] with innovative network features [9].

In Recent year, the wireless communication industry is facing new challenges due to constant evolution of new standards (2.5G, 3G and 4G). Wireless systems are expected to require high data rates with low delay and low bit-error-rate (BER). In addition, high data rate transmission and high mobility of transmitter and/or receivers usually result in frequency-selective and timeselective,i.e., doubly selective, fading channels for future mobile broadband wireless system. The rapidly growing IP data traffic cost-effectively and to improve cell-edge performance, [19] 3GPP is working on the evolution of LTE called LTE-Advanced. Among these we can mention: (i) native support of MTC, according to which ad-hoc transmission procedures are defined to efficiently handle the cellular transmission of small packets by reducing latency and energy consumption; (ii) small-cell deployments, envisaging femto, pico and relay cells massively deployed to extend coverage and capacity and to reduce energy consumption; (iii) interoperability, i.e., seamless integration between 3GPP and non-3GPP access technologies to enhance reliability and coverage; (iv) optimized access/core segments, achieved through novel paradigms such as softwarisation and virtualization of network entities and functionalities, respectively. In this direction go the initiatives of GSM Association towards embedded-sim (esim) solutions [10], to overcome the classic concept of physical cellular sim, which could be a serious limitation for large-scale tiny IoT device (e.g., sensors). The e-sims will allow "over the air" provisioning of network connectivity and possibility to subscribe to multiple operators. In the evolutionary scenario depicted so far, a new device-to-device (D2D) will play an undoubted key role in the IoT/5G integration [11]. D2D communications refers to the paradigm where devices communicate directly with each other without routing the data paths through a network infrastructure. In wireless scenarios this means bypassing the base station (BS) or access point (AP) and relaying on direct inter-device connections established over either cellular resources or alternative over WiFi/Bluetooth technologies. This approach has recently gained momentum as a means to extend the coverage and overcome the limitations of conventional cellular systems. The main benefits it can introduce are [12]: (i) high data rate transmissions supported also by devices remotely located from the BS/AP; (ii) reliable communications also in case of network failure, as may be the case of disaster scenarios; (iii) energy saving since devices in close proximity can interact at a lower transmission power level; (iv) traffic offloading that reduces the overall number of cellular connections; (v) heterogeneous connectivity accounting that direct communications among devices does not only rely on cellular radio interface, but can be established through alternative radio technologies; (vi) instantaneous communications between a set of devices in the same way that walkie-talkies are used for emergency services. Needless to say, these same features make D2D a very appealing solution to satisfy also the exacting requirements imposed by IoT in emerging 5G network scenarios (a possible IoT internetworking scenario is depicted in Fig.1).

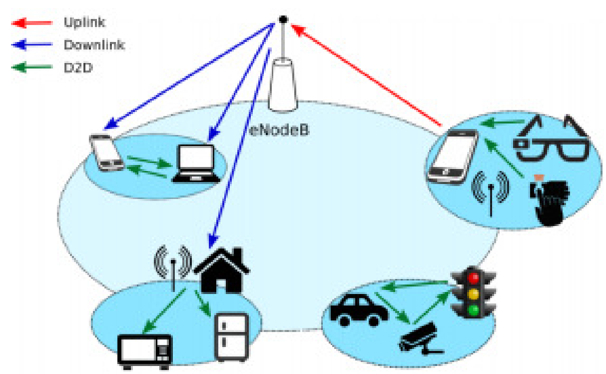

Fig. 1. D2D communications in 5G IoT networks.

The numerous initiatives conducted by mobile and wireless communication leading enablers of the twenty-twenty information society (such as METIS European project [13], 5G-PPP association [14], Networld2020 platform [15], etc.), confirm the role of D2D in various scenarios such as vehicle-to-vehicle communications, national security and public safety, cellular network offloading, or service advertisement. Nonetheless, when considering the possibility of D2D-based interconnection of IoT devices in cellular environment, severe challenges still need to be faced, such as efficient device discovery in heterogeneous environment, optimized link selection for highly dynamic multi-tenant networks. Device-to-Device Communication: Approaches, Enabling Technologies, and Standards. D2D communications aim to boost the performance of conventional cellular networks (in terms of metrics, such as power consumption, spectrum efficiency, throughput, etc.) by exploiting direct interaction between devices in proximity.

Several solutions have been investigated in the literature, and different classifications have been provided. A good taxonomy of D2D communications is given in [7], where a first distinction is made based on the spectrum adopted for D2D communications. This can be either cellular licensed spectrum, like for cellular communications (i.e., in band communication), or unlicensed bands such as Wi-Fi (i.e., out band communication). The in band solution, can be further classified in (i) underlay in band D2D mode [8] and (ii) overlay in band D2D mode. In the former, D2D and cellular communications share the same licensed cellular spectrum; in such a case, the main issue is the mitigation of the interference between D2D and cellular communications. In the latter, a portion of the cellular resources is dedicated to D2D communications for avoiding interference problems; in this case, the resource allocation becomes the key issue to address to avoid wasting precious spectrum resources. The out band solution aims to eliminate the interference between D2D and cellular link,. The coordination between radio interfaces is either controlled by the BS/AP, i.e., controlled mode, as illustrated in Figure 2 (a), or by the users, i.e., autonomous mode, as illustrated in Figure 2(b). Hence, the studies on out band D2D involve both aspects of power consumption and inter-technology architectural design.

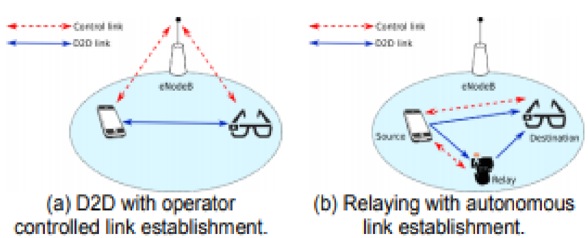

Fig. 2. Possible approaches for D2D link establishment.

Radio Technologies for D2D Communications From what said so far, any technology supporting the direct communication between devices can enable D2D communications. In the following, some details are given on those mainly considered to this purpose. In particular, notions about Wi-Fi Direct, Bluetooth, Radio Frequency Identification (RFID) and IEEE 802.15.4 are given, before going into the details of the cellular D2D technology (named LTE-Direct) and the 3GPP standardization achievement concerning D2D technology (named LTE-Direct) and the 3GPP standardization of the available technologies for D2D communications. Wi-Fi Direct Wi-Fi Direct [5] allows mobile devices (e.g., smart phones, tablets) to directly connect over unlicensed bands and transfer content or share applications anytime and anywhere. Although the idea of supporting direct links was already found in the original IEEE 802.11 standard through the ad-hoc mode, the lack of efficient power saving and enhanced QoS support has limited the market penetration of this functional mode [2]. Wi-Fi Alliance has recently certified Wi-Fi Direct to support peer-to-peer (P2P) communications between 802.11 devices by jointly exploiting the potentialities of ad-hoc and infrastructure modes. Wi-Fi Direct allows devices to implement the role of either a client or an access point (AP), and hence to take advantage of all the enhanced QoS, power saving, and security mechanisms typical of the infrastructure mode. Wi-Fi Direct devices can connect for a single exchange, or they can retain the memory of the connection and link together each time they are in proximity. Data communication is accomplished by creating a P2P group, where a device with a role of P2P group owner (P2P GO) can allow a cross-connection of devices belonging to its P2P group to an external network (e.g., a 3GPP network). The vision of next generation 5G wireless communications lies in providing very high data rates (typically of Gbps order), extremely low latency, manifold increase in base station capacity, and significant improvement in users' perceived quality of service (QoS), compared to current 4G LTE networks. Ever increasing proliferation of smart devices, introduction of new emerging multimedia applications, together with an exponential rise in wireless data (multimedia) demand and usage is already creating a significant burden on existing cellular networks. 5G wireless systems, with improved data rates, capacity, latency, and QoS are expected to be the panacea of most of the current cellular networks' problems. In this survey, we make an exhaustive review of wireless evolution toward 5G networks. We first discuss the new architectural changes associated with the radio access network (RAN) design, including air interfaces, smart antennas, cloud and heterogeneous RAN. Subsequently, we make an in-depth survey of underlying novel mm-wave physical layer technologies, encompassing new channel model estimation, directional antenna design, beam forming algorithms, and massive MIMO technologies. Next, the details of MAC layer protocols and multiplexing schemes needed to efficiently support this new physical layer are discussed. We also look into the killer applications, considered as the major driving force behind 5G. In order to understand the improved user experience, we provide highlights of new QoS, QoE, and SON features associated with the 5G evolution. For alleviating the increased network energy consumption and operating expenditure, we make a detail review on energy awareness and cost efficiency.

As understanding the current status of 5G implementation is important for its eventual commercialization, we also discuss relevant field trials, drive tests, and simulation experiments. Finally, we point out major existing research issues and identify possible future research directions.

Mobile wireless communications were initiated with the first generation, voice-only systems. Over the last couple of decades the world has witnessed gradual, yet steady evolution of mobile wireless communications towards second, third and fourth generation wireless networks. Introduction of digital modulations effective frequency reuse, penetration of packet-based Internet and rapid advancement in physical layer technologies, like WCDMA, OFDMA, MIMO, HARQ etc. have significantly contributed towards this gradual evolution. Besides this, with the ever increasing popularity of smart devices, currently all IP based fourth generation LTE networks have become a part of everyday life. As a result, a set of new, user-oriented mobile multimedia applications, like mobile video conferencing, streaming video, e-healthcare and online gaming are coming up. These new applications are not only satisfying users' requirements, but also opening up new business horizons for wireless operators to increase their revenue.

A quick look into recent wireless network statistics reveal that global mobile traffic experienced around 70% growth [1] in 2014. Only 26% smart phones (of the total global mobile devices) are responsible for 88% of total mobile data traffic [1]. Cisco's Visual Networking Index (VNI) forecasts that mobile networks will have more than half of connected devices as smart devices by 2019. Increasing Smartphone usage is resulting in an exponential growth in mobile video (multimedia) traffic. In fact, since 2012 video traffic is more than half of the global mobile traffic [10]. An average mobile user is expected to download around 1 terabyte of data annually by 2020 [12]. Moreover, researchers are exploring new applications in directions of augmented reality, Internet of Things (IoT), Internet of vehicles (IoV), Device to Device (D2D) communications, ehealthcare, Machine to Machine (M2M) communications and Financial Technology (FinTech). Supporting this enormous and rapid increase in data usage and connectivity is an extremely daunting task in present 4G LTE cellular systems. For example, with a theoretical 150 Mbps maximum downlink data rate, traditional LTE systems, with 2 × 2 MIMO can support only up to (150/4) simultaneous full HD (@ 4 Mbps rate) video streaming. Furthermore, while standard LTE networks were originally designed to support up to 600 RCC-connected users per cell [3-4], M2M communications and IoT requires supporting of tens of thousands of connected devices in a single cell. LTE cellular network is exploring avenues of different research and development, like, MIMO, small cells, Coordinated Multi-Point (CoMP) transmission, HetNets and multiple antennas to enhance capacity and data rates. However, it is unlikely to sustain this ongoing traffic explosion in the long run [18]. Hence, the primary concern is to satisfy the exponential rise in user and traffic capacity in mobile broadband communications.

II. CONCLUSIONS

Wireless connectivity, almost exponential increase in wireless data (multimedia) usage and proliferation of feature-rich smart devices are gradually setting the stage for next major cellular evolution towards 5G. Next generation 5G wireless systems are already promising a manifold increase in data rate, connectivity and QoS. A plethora of new applications, like IoT, smart grids and IoV are expected to be supported under the umbrella of 5G systems. In this survey we provide a comprehensive review of cellular evolution towards 5G networks. We begin with pointing out the new architectural paradigm shift, associated with the design of radio network layout, air interfaces, smart antennas like D2D and M2M communications, IoT, Vehicular communications and Healthcare applications form the major driving force behind 5G. We digress into the details of these killer applications to understand the associated impact on the cellular evolution. In order to realize the current state of the implementation, we also look into the major 5G field trials, drive tests and simulations. Finally, we point out major existing research challenges and identify possible future research directions. We believe that our survey will serve as a guideline for major future research works in 5G wireless communications

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