Towards Device Driven 5G: Radio Resource Allocation Perspective

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***Abstract*—**5G cellular network is the next revolutionary wireless network system that is anticipated in the next few years with exceptional capabilities to achieve the IMT 2020 requirements. The 5G network will introduce a high level of flexibility, user centric, ultra reliable and low latency communications with a plethora of novel applications. Introduced in the LTE advanced system, carrier aggregation technology was one of the major milestone in radio resource management, significantly increasing the overall network performance.

5G will be a collision of networks tiers of various transmit powers, sizes, different radio access technologies, backhaul connections, and unprecedented number of heterogeneous and smart devices. Device to Device (D2D), Massive Machine Communication (MMC), enhanced carrier aggregation along with other technologies proposed in 5G such as energy harvesting and wireless network virtualization will introduce complexity of the resource scheduling.

While the network design is envisioned to overcome the fundamental challenges of the existing and previous mobile networks, there are some clearly unprecedented challenges that can be foreseen. A survey of recently proposed resource allocation strategies for 5G, design aspects, issues and the likely challenges to be encountered in the resource allocation for the multi-tier architecture of this device driven network are presented.

***Keywords*—**5G, IMT 2020, Radio Resource, Allocation Strategies, Future Networks, D2D Communication

I. Introduction

In the recent days, the world has demonstrated considerable dynamism in the usage of wireless and cellular communication through development trends in emerging applications and rapid demand of high speed internet, with massive interconnected wireless devices such as machines, smart cities, sensors and tablets. Fifth generation (5G) mobile network is expected to revolutionise the user experience, giving infinite capacity to the user, as opposed to the previous networks that focussed primarily on transmission efficiency of particular services such as voice and video streaming. The mobile networks will be expected to sustain manifold wireless requirements in different use cases under 5G. To sustain these emerging applications with diverse traffic characteristics, an entire engineering paradigm shift is vital in the development of the 5G mobile network.

Through Internal Mobile telecommunications 2020 (IMT-2020) also known as 5G, the International Telecommunications Union Radiocommunications Standardisation Sector (ITU-R) outlined manifold design goals for user experienced data rate, peak data rate, connection density, area traffic capacity, mobility and latency, with potential for future evolution [1]. In achieving these goals, a sufficient 5G radio access network system will be required, having to integrate the revolved and evolved multiple radio access technologies of previous mobile network generations. In meeting the requirements and the needs of 5G service landscape, three main 5G Service types, also known as scenarios are considered.

Massive Machine to machine (M2M) communications (mMTC) will be offered in the 5G New Radio (NR), requiring wireless connectivity for up to tens of billions of devices in the world that are network enabled. Here, wide area coverage, scalable connectivity for the growing number of devices per cell and deep indoor are the main priorities.

Extreme Mobile BroadBand (xMBB), also known as enhanced mobile broadband (eMBB), demands both low latency communication and extremely high data rates, and reliable broadband access over large coverage areas.

Ultra-reliable Machine type communications (uMTC), also known as ultra-reliable and low latency communications (URLLC), related to mission critical industry control, vehicle to anything (V2X) communications, and smart grid, among others.

The Fig. 1 indicates the three key service types or scenarios introduced for 5G network, together with the requirements for the scenarios in terms of performance parameters such as latency, area traffic capacity and connection density.

Depending on services offered and propagation conditions best suitable access technology (or combination of access technologies in the case of coordinated Multi points CoMP), multiple connectivity or load sharing can be assigned through optimised selection schemes of multiple radio access technology [2]. In integrating all these technologies and features in 5G, agile radio resource management is required to ensure optimised network performance is achieved. To achieve low latency and ultra-reliable communication in 5G system, we need to understand the tools appropriate for design of radio resource allocation under the limitations of availability, reliability and delay. On the other hand, D2D communication introduced in 5G offers various resource management problems [2] [3] [4] [5]. This research paper first introduces 5G architecture briefly, enabling technologies, and then carries out a survey of the studies done recently on resource allocation in D2D enabled 5G networks.

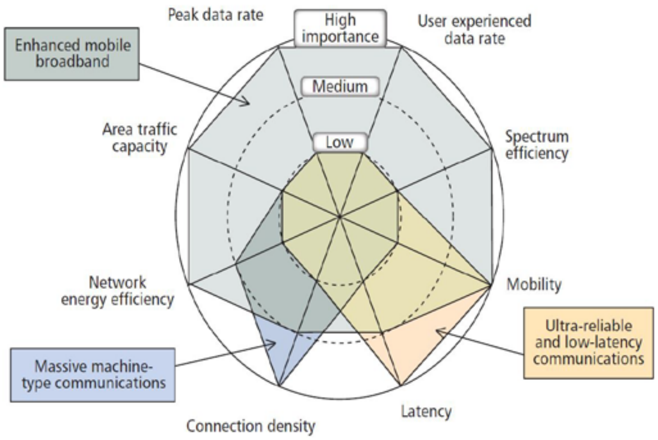

Fig. 1: 5G Case Scenarios with appropriate performance metrics

II. 5G RAN Architecture: Overview

The new RAN consists of gNBs offering the NR C-plane and the U-plane protocol terminations towards the user equipment (UE) [7]. The RAN also consists of LTE eNBs that offer E-UTRA C-plane and U-plane protocol terminations towards the UE, and whether to establish a new RAN logical node that can provide both the E-UTRA and NR C-plane and U-plane protocol terminations towards the UE will be decides in the normative phase. Xn interface interconnects the logical nodes in the new RAN, which are then connected to the NGC through the NG interface as shown in Fig 2. Many-to-many relation is supported by the NG interface between the logical nodes in the New RAN and the NG-CP/UPGWs [7].

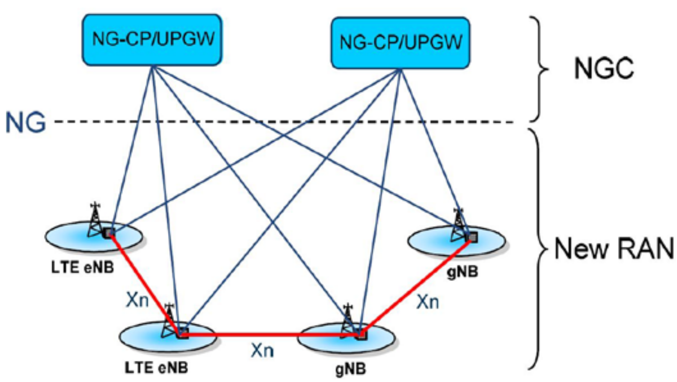

Fig. 2 5G RAN Architecture [6]

The RAN and NextGen Core (NGC) ensures quality of services by mapping packets to appropriate Data Radio Bearers (DRBs) and QoS flows, as shown in Fig. 3. Therefore, there is a 2-step mapping of IP flows to QoS flows (NAS) and then to DRBs from the QoS flows (access stratum).

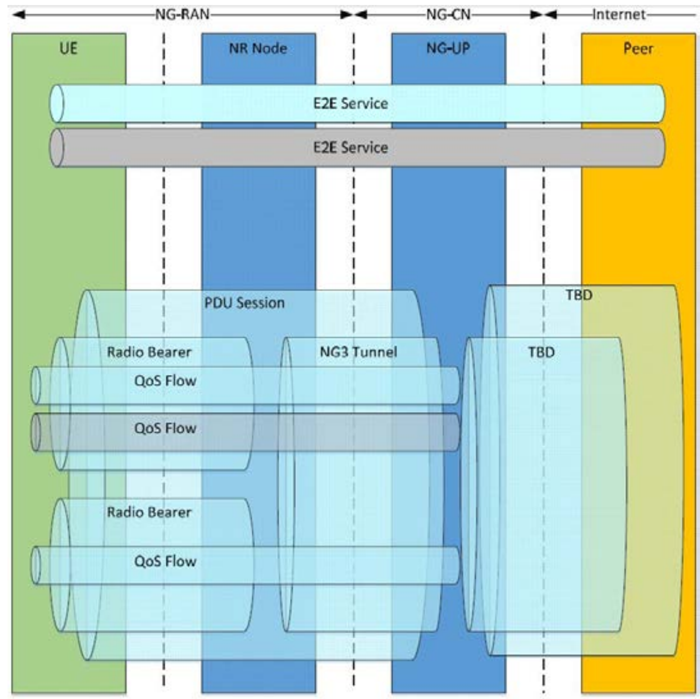

Fig. 3 QoS flow Architecture in 5G NG Network

III. 5G Enabling Technologies

The deployment and implementation of 5G wireless systems require re-engineering in the design of various existing network technologies and communication systems. Based on the service types previously stated together with the related requirements, key 5G RAN design requirements were outlined by 3GPP. Some of the primary approaches and technologies that have been developed to address the said are as follows:

A. Device to Device (D2D) Communication system

Standardised in 3GPP LTE Release 12 as LTE Device-to-Device proximity Services, Device-to-Device communication will enable mobile devices to discover the presence of the nearby devices within a defined range of up to 500 m and further directly communicate with them with minimal support from the network. Exploiting this device driven communication between devices improves overall throughput, spectrum utilisation as well as energy consumption, while still offering proximity based- and peer-to-peer applications and services [7] [8].

B. Massive MIMO

This is an evolving technology that is upgraded from current MIMO technology in which array of antenna are used containing few hundred antennas that are at the same time in one time and frequency slot serving many tens of user terminals [9]. This is particularly important in separating the indoor and outdoor scenarios during the 5G architecture design to ensure propagation loss can somehow be avoided [10].

Basically, it is a form of multiuser MIMO in which the number of antennas ate the base station is much larger than the devices per signalling resource. Massive MIMO will offer robust, energy efficient, and secure and spectrum efficient Next generation networks [11] [12].

C. Ultra Dense Network

Heterogeneous networks will play a crucial role in achieving an ultra-dense networks. With the introduction of adhoc social networks and moving networks, the heterogeneous networks are becoming more dynamic. The network will consist of a large number of macrocells along with other low power nodes such as remote radio heads, relays and small cells. Though dynamic and dense heterogeneous networks will offer some new challenges in terms of backhauling, mobility and interference, new layer functionalities design would ensure performance maximization. Therefore, future smart devices will be designed in such a way they will learn and decide how to manage connectivity through the help of context information [13].

D. Machine Type Communication

Connecting machines, apart from people, is another important aspect of 5G. It's an emerging application in which either one or both of the bearers in a communication session involve machines. However, there is still a challenges in this type of communication as the number of devices that need to be connected are tremendously large, and there is a high demand for real time and remote control of mobile devices through the mobile network [6]. This will dictate a very low latency level essentially less than a millisecond, demanding a 20 times improvement in latency from the 4G network as we move to 5G network. This will form the basis of the Internet of Things with a broad range of applications including emergency services, automotive industry, medical field and public safety.

E. Millimetre Wave Solution

As a quest for more spectrum, this forms one of the key technology enablers for 5G. The conventional sub-3 GHz spectrum is getting increasingly congested, and the present radio access technologies are approaching the capacity limit of Shannon. 5G is exploring the mm- and cmWave bands to help solve the challenge [14]. However, the mmWave development is faced with three main impediments.

First, the penetration loss through the buildings is significantly higher at these spectrum bands, blocking the indoors users from the outdoor radio access technologies [15]. Second, the electromagnetic waves have the tendency to propagate in the direction of line of sight, causing vulnerability of radio links to being blocked by people and object movement. Lastly, compared to the conventional sub-3GHz bands, the path loss is relatively higher at these bands [16].

However, the enormous spectrum available in the mmWave band is a motivation as seamlessly ultra-broadband wireless pipes can be provided and completely revolutionize mobile communications. Further with the mmWave, very high beam forcing gains can be achieved as small sized antennas and their small separations can be utilised, enabling tens of antenna elements to be packed in just one square centromere [17].

F. Interface Management

In ensuring efficient utilisation of limited radio resource, reuse is a concept that is being utilised by various specifications for wireless and mobile communication systems [18]. For improved user throughput and traffic capacity, densification and reuse concepts will ensure enhancement in terms of efficient load sharing between local access networks and the macro cells [19]. Further, advanced sharing and joint scheduling could offer solutions in interference management.

G. Cloud-Based Radio Access Network

Evolving from distributed base station architecture in which the base station server is responsible for baseband processing, the cloud based radio access network will improve network capacity, enhance scalability and extend future 5G system coverage [20].

IV. 5G Radio Resource Allocation

In the previous networks, a radio resource is considered typically as part of the convention aspect of resource. It is usually characterised by frequency (bandwidth and carrier frequency), time (duration of the transmission), transmit power, and other parameters of the network such as modulation/coding schemes and the antenna configuration. In NR scheduling, both control and data are supported with the same numerology. Cross-slot and same slot scheduling is supported for both uplink and downlink transmission [6].

In a recent study on radio resource management for mmWave RAN that is being considered as a key enabler for 5G network, various challenges were raised [21]. Performance can be severely deteriorated by the high penetration loss of mmWave frequencies. Therefore, it was identified that maintaining a reliable connectivity would be difficulty particularly for services that are delay critical. The author noted that advanced interference management will be required in 5G system as the highly directional transmissions will make cross link interference characteristics become much different from systems of sub-6 GHz, introducing challenges such as flashlight effects [21]. During the movement of the users, link quality and wireless channels conditions can change significantly thus demanding multi connectivity support and fast RRM decisions. The study suggests the need to reengineer the conventional RRM functionalities for load balancing and connection management to overcome the challenges [21].

Auction algorithm method, message passing and stable matching mathematical models have been proposed in the development of radio resource allocation algorithms in the heterogeneous multi-tier 5G network [22]. The solution tool presented in the study are suggested for other enabling 5G system technologies in addressing the resource allocation problems [23] [24]. Challenges of resource allocation under the constraints of MU-MIMO and carrier aggregated 5G network were addressed in a recent study carried in Huawei

Labs [25]. A MU-MIMO aware CA scheduler is proposed in the study that assigns the resources available in frequency, time and MIMO dimensions under wireless system architecture and realistic traffic constraints. The comparative performance analysis indicated a user throughput of up to 190% compared to the baselines schemes, and a fairness of almost 1 using the Jains index value [25].

Efficient scheduling radio access technology in improving the quality of service has been investigated in [26], addressing the three scenario introduced in 5G network; dual connectivity (UE is served by NR and LTE at the same time), single connection (the UE is served only by one radio access technology), and fast radio access technology (in which the UE switches from one radio access technology to another) [16]. The Fig. 4 indicates instantaneous UE throughput comparing the fast radio access technology (FS-RAT) and the dual connectivity. The study concludes that 5G networks could merge the fast scheduling and the dual connectivity scheduling solutions in developing efficient scheduling algorithms for the 5G. The time between the consecutive evaluations of the RAT scheduling is also suggested to vary according to specific parameters as opposed to a fixed value [26].

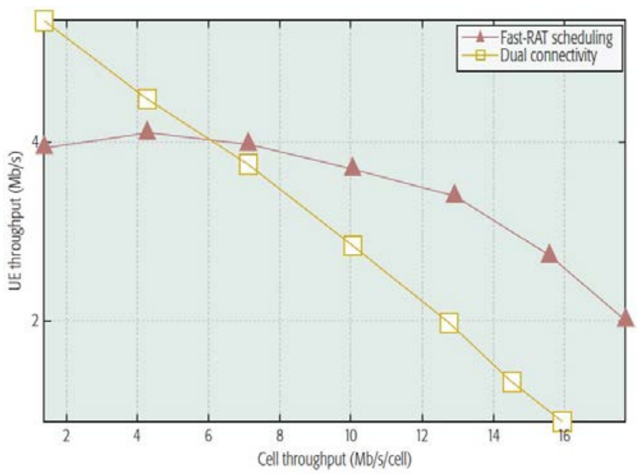

Fig. 4 UE Throughput Analysis for Dual connection and Fast RAT Scheduling [26]

The study in [27] tackles the problem of resource allocation for combined licensed and unlicensed CA MIMO systems through a Lagrange dual decomposition method for low complexity reasons. The allocation scheme proposed handles the coexistence matters within the unlicensed bands involving solution to a mixed integer nonlinear programming.

V. Allocation Optimisation in D2D Communication

In D2D enabled mobile network, radio resource management introduces certain challenges such as interference with D2D and cellular users, while reusing and underlaying the same radio resources with the users. To attain considerably high data rates in 5G future networks while ensuring the power and quality of service constraints, it is very important to intelligently select the specific operation mode for optimal scarce resource sharing.

Problems relating to D2D communications have been addressed in various studies, and different researchers have taken different perspectives of handling the issues, in effort of either maximising or minimising certain system parameters. Some of the problem aspects associated to the D2D resource management are power control, fairness, quality of service (QoS) and cooperative communication. In the various resource allocation schemes, the primary objectives are ensuring maximised system throughput, energy efficiency, and battery life, while minimising the overall system cost.

In [28], a D2D communication study is done focused on maximising the system throughput in the network. A distance dependent algorithm for mode selection was studied, ensuring QoS and power optimisation of the users were maintained. Dynamic power allocation, as opposed to fixed power control, was used to offer efficient resource utilization as well as better throughput gain.

Using shrinking reuse distances with frequency resources deployment, the authors [29] in presented a spectrally efficient radio resource management technique for device driven cellular network. The authors presented a D2D pair cluster formation and D2D pairs are grouped according to interference alignment similarity. This offers additional gains in throughput of the cellular system and a 33% extra rate increase compared a point to point type of communication. Frequency resources reuse over the clusters offers rate increase proportional to clusters [29].

Considering wireless channel uncertainties, authors in [30] investigated radio resource allocation challenges in a relay aided device driven network. Using stable matching, the study provided an iterative distributed solution to the problem. The study compares the proposed scheme against the underlay D2D communication scheme [30]. Stochastic geometry concept in a heterogeneous network is considered in enhancing the capacity of D2D mobile network while maintaining the constraint of outage probabilities of both cellular and D2D communication [31]. The authors present an algorithm that determines the set containing the critical points (believed to exhibit maximum capacity) and then subsequently obtain optimal solution from the points. The algorithm guarantees the QoS of service as the transmission reuse the licensed spectrum. The strategy manages resources by taking into account the co-tier and cross-tier interference [31]. Rate maximisation in D2D MIMO systems is studied in [32] while [33] discuss the sum rate maximisation in D2D enabled network. The paper applied the technique in which for better spatial reuse, short range D2D links are allowed to share the channels of other users in the same cell. On the pareto optimal boundary, there exists four points that comprise feasible SINR regions. The author argue that, out of the four points, one of the point comprises of the optimal solution to the non-convex optimisation problem. Using a greedy algorithm with low computational complexity, authors suggest that the optimal solution can be obtained.

Particle swarm optimisation solutions for resource allocation in D2D communication have been suggested in [34] [35] [36]. Resource allocation and joint mode selection is studied to maximise the system throughput, while maintaining required data rates and minimum interference [34]. The main objective of the studies is to maximise the overall system throughput while managing the resource assignment, rate and QoS constraint. Power allocations and resource scheduling for the vehicular user equipment were studied in a recent study [37]. A dynamic radio resource allocation algorithm was developed based on Lyapunov optimisation theory, considering interference reduction in vehicle to vehicle (V2V) communications as well as reliability and latency requirements such communications.

Battery life as part of resource optimisation has been studied in the recent papers for the D2D communications [38] [39] [40] [41] [42] [43]. Energy efficiency have been studied with respect to various aspect in the studies. However, the general principle towards a longer battery life of a device is a factor of their transmit power. However, even though lower transmit power is desirable, the optimisation process will involve a trade off since higher data rates require higher SINR ratio and compromise transmit power minimisation [43].

VI. CONCLUSION

Adapted as an enabling technology in 5G Network, D2D communication enables communication between devices vicinity with low energy consumption and low latency, and potentially to offload cellular network from handling local network traffic. It is also anticipated to improve energy and spectral efficiency of cellular networks, while offering proximity based services such as file sharing and social networking. However, energy efficiency and interference management have been fundamental requirement in curbing the interference brought about by the device driven users under control, while still extending the lifetime of the user equipment battery.

The architecture of 5G RAN and other enabling technologies are presented. Radio resource management in 5G network is briefly introduced, and some of the issues studied in recent papers in regard to radio resource management in 5G presented. In the sequel of the paper, D2D communication is introduced. Various resource allocation schemes and strategies for the D2D communication in 5G network have been presented in this paper, and particularly in regard to constraints of the system throughput, energy efficiency, battery life, and the overall system cost.

While several techniques have been proposed in solving the optimisation problems in the device driven networks, the techniques deployed most in this study were based on heuristic algorithms, lagrangian formulation, graph theory, particle swarm optimisation, greedy algorithm, matching game, stable matching, game theory, stochastic search methods, among others.

The paper attempts to exploit an emerging field, and most areas are still unexploited. Improvements of battery life, energy efficiency improvements, optimal power allocations and energy harvesting are some of the interesting unexploited research domain. Segregation of indoor and outdoor antennas, as well as cell densification could also form future research areas.

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