5G NR-LTE Coexistence: Opportunities, Challenges, and Solutions

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ABSTRACT

5G New Radio (NR) promises to support diverse services such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC). This requires spectrum, most of which is occupied by 4G Long Term Evolution (LTE). Hence, network operators are expected to deploy 5G using the existing LTE infrastructure while migrating to NR. In addition, operators must support legacy LTE devices during the migration, so LTE and NR systems will coexist for the foreseeable future. In this article, we address LTE-NR coexistence starting with a review of both radio access technologies. We then describe the contributions by the 3rd Generation Partnership Project (3GPP) to solving the coexistence issue and catalog the major coexistence scenarios. Lastly, we introduce a novel spectrum sharing scheme that can be applied to the coexistence scenarios under study.

I. INTRODUCTION

The proliferation of multimedia applications and the rapid digitalization of industries has led to an exponential growth in mobile data traffic in the recent years [1]. To cater to this increasing demand for data traffic, 3rd Generation Partnership Project (3GPP), the global standards development organization, is currently specifying a fifth generation (5G) of radio interface referred to as New Radio (NR) [2]. 5G NR will support increasing traffic demand and wireless connectivity for a wide range of new applications and use cases, such as automotive, healthcare, public safety, and smart cities.

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Fig. 1: 5G NR services, associated applications and their respective requirements.

Specifically, as illustrated in Figure 1, NR will support three main use cases: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC), each with different requirements and applications. eMBB and URLLC services require high data rates and high reliability with low latency, respectively, which in turn require large bandwidths such as what is available above 3 GHz. In addition, mMTC services require good coverage to ensure network access for most users, which can be best achieved by operating below 2 GHz. To provide high data rate, low latency, and good coverage, 5G NR will operate in two spectral bands: Frequency Range 1 (FR1) from 410 MHz to 7.125 GHz, previously known as sub-6 GHz band, and Frequency Range 2 (FR2) from 24.25 GHz to 52.6 GHz, also known as mmWave band.

Because almost all accessible low frequency bands are occupied by existing 4G Long Term Evolution (LTE) operators have two choices: acquire
new spectrum or refarm the existing spectrum from LTE to NR. Both options are expensive and, since majority of the traffic in the near future will be carried by LTE networks, refarming low frequency bands from LTE without a corresponding increase in NR devices will lead to congestion in the LTE bands and degrade network performance. Therefore, operators must leverage the existing 4G infrastructure as they migrate to NR while providing services to legacy devices. As a result, LTE and NR networks will coexist for the foreseeable future.

In this article, we discuss the LTE-NR coexistence issue with a focus on eMBB, mMTC, and URLLC, in the context of Public Safety Communications (PSC) networks, Machine-Type Communications (MTC) networks, and Vehicle-to-Everything (V2X) networks. We discuss the coexistence techniques being developed by 3GPP and examine the major coexistence scenarios that can occur between LTE and NR devices. Lastly, we propose a spectrum sharing scheme and discuss how a network operator could use the approach to support static and dynamic resource allocation for coexisting networks.

In Section II, we review the evolution of radio access technologies from LTE to NR. In Section III, we address the LTE-NR coexistence issue in different applications under study, describe the scenarios for each of them, and discuss 3GPP’s proposed solutions. Lastly, in Section IV, we introduce a novel and generic spectrum sharing scheme that is applicable to the coexistence scenarios under study.

II. LTE TO NR: AN OVERVIEW

3GPP introduced LTE in Rel 8 with high spectral efficiency, variable bandwidths up to 20 MHz, and peak downlink (DL) and uplink (UL) data rates of 300 Mbit/s and 75 Mbit/s, respectively. Rel 9 introduced Multiple-Input Multiple-Output (MIMO) beam forming, multicast/broadcast services, and location-based services.

In Rel 10, Rel 11, and Rel 12, also known as LTE Advanced, 3GPP introduced several new features. In Rel 10, features such as carrier aggregation, UL multiple antenna transmission, relaying, and enhancements to multicast/broadcast services were introduced, enabling peak DL and UL data rates of 3 Gbit/s and 1.5 Gbit/s, respectively. Rel 11 introduced Coordinated Multi-Point (CoMP) transmission/reception to improve coverage, cell-edge throughput, and spectral efficiency. Rel 12 included support for MTC and public safety services such as Device-to-Device (D2D) communication, which is an enabling feature for V2X communication.

Rel 13 and its successors are known as LTE Advanced (LTE-A) Pro. Rel 13 introduced extended support for MTC through Narrowband-Internet-of-Things (NB-IoT) and enhanced MTC (eMTC), enhancements to D2D to support advanced proximity services for public safety services, and spectral efficiency enhancements via Full-Dimensional multiple-input multiple-output (FD-MIMO). LTE-A Pro brought enhancements in multiple dimensions. It supported higher level of carrier aggregation and Licensed-Assisted Access (LAA), which led to the introduction of Gigabit LTE offering data rates up to 2 Gbit/s. It introduced enhancements to NB-IoT and MTC. It also expanded the reach of cellular technology to vehicular communication and introduced Cellular V2X (C-V2X), which is a crucial element of autonomous driving. The enhancements in Rel 15 made LTE-A Pro meet the International Telecom Union’s (ITU) IMT-2020 requirements, which entitled it to be referred to as 5G.

3GPP in Rel 15 designed 5G NR to address a variety of usage scenarios requiring enhanced data rates, latency, coverage, and reliability. The key features of NR include ultra-lean design, spectrum flexibility including operation in high frequency bands, interworking between high and low-frequency bands, and advanced antenna technologies. Rel 16 focused on URLLC and Industrial Internet of Things (IIoT)-related enhancements, NR on unlicensed bands (NR-U), and NR V2X. Recently, 3GPP completed Rel 17 which includes enhanced support for IIoT proximity services, and network automation, as well as sidelink (SL) enhancements for V2X and public safety. It extends NR operations to frequencies beyond 52 GHz, which is anticipated to lead to specifications in Rel 18. Figure 2 summarizes the evolution of radio access technologies from LTE to NR and beyond.

III. LTE-NR COEXISTENCE

5G NR will operate in FR1 and FR2 bands, and coexist with legacy users, including LTE and radar systems. In this article, we consider only LTE-NR coexistence, with a focus on different applications of eMBB, mMTC, and URLLC.
**LTE-NR Coexistence in PSC Networks:** PSC networks exist to protect people, maintain order, and facilitate recovery operations during emergencies, both natural and man-made. In addition to MTC and URLLC services, the network relies on eMBB services supported by NR, which must coexist with LTE. To support coexistence, 3GPP introduced an LTE-compatible NR numerology based on 15 kHz subcarrier spacing, which enables identical time/frequency resource grids for NR and LTE. Flexible NR scheduling, with a granularity at the subframe, slot, or symbol level, can also be employed to avoid collisions between NR transmissions and LTE signals such as Cell Specific Reference Signal (CRS), signals/channels used for LTE initial access, and Channel State Information Reference Signal (CSI-RS). 3GPP also proposed resource reservation by competing systems to prevent collisions.

The research community has studied LTE-NR coexistence in eMBB services in [3]–[10]. In [3], the authors investigated the NR numerology coexistence issue and evaluated the guard band size required to meet a target signal quality. In [4], the authors investigated co-channel interference between non-colocated LTE and NR systems and proposed a novel low-complexity CRS interference mitigation algorithm for NR User Equipment (UE). In [5], authors reported the experimental results corresponding to LTE-NR coexistence in 700 MHz band and demonstrated peaceful DL coexistence between the two technologies. In [6], the authors introduced a spectrum exploitation mechanism that balances the requirements of high transmission efficiency, large coverage area, and low latency. In [7], authors discussed LTE-NR UL coexistence and showed that from LTE system perspective a single resource block is sufficient as guard band to operate efficiently in the presence of NR signal, whereas, NR needs no guard band and is not affected by LTE.

In [8], authors explored the coexistence of LTE Frequency Domain Duplex (FDD) and NR FDD in 2.1 GHz band and showed that LTE FDD DL causes harmful interference to NR FDD DL. In contrast to [8], authors in [9] analyzed the coexistence of NR FDD and LTE Time Domain Duplex (TDD) in 1.8 GHz band and showed that these two technologies can coexist in adjacent bands. Lastly, in [10], authors studied the coexistence of NR UL/DL with LTE UL/DL and showed that UL sharing helps achieve a balance between spectrum efficiency and low latency and coverage and channel bandwidth.

**LTE-NR Coexistence in MTC Network:** 3GPP specified two low-power wide-area technologies, enhanced MTC (eMTC) and NB-IoT to handle machine-centric use cases in 4G LTE. While eMTC is for mid-range machine-type applications and can support voice and video services, NB-IoT supports low-cost devices and provides good coverage. Assessment of these technologies showed that each can satisfy NR MTC requirements; thus, 3GPP
decided to reuse them to support NR MTC services within the NR carrier. This is beneficial because eMTC and NB-IoT devices are expected to remain in service even after LTE spectrum transitions to NR and reusing the technologies will support legacy LTE devices. However, it will also lead to LTE-NR coexistence issues in MTC networks.

To tackle this issue, 3GPP in TR (Technical Report) 37.823 investigated eMTC deployment within NR carrier and proposed two solutions: resource reservation and DL subcarrier puncturing. The first allows reserving unused eMTC DL and UL resources for NR signals at the subframe, slot or symbol level in the time domain and at the resource-block (RB) group level in the frequency domain. The second allows up to 2 subcarriers of eMTC UE to be punctured to achieve RB alignment between eMTC and NR.

In TR 37.824, 3GPP investigated the coexistence issue when NB-IoT operates: (a) in NR in-band, (b) in NR guard-band, and (c) independently of NR. While no coexistence issue exists when NB-IoT operates independently of NR, 3GPP proposed resource allocation on non-anchor carriers to support coexistence when NB-IoT operates in NR in-band and guard-band. Resource reservation allows unused NB-IoT DL and UL resources to accommodate NR signals. The reservation is in time domain and can be at the subframe, slot, or symbol level.

The issue of coexistence between eMTC/NB-IoT and NR has also been studied in [11]–[13]. In [11], authors analyzed subcarrier grid and RB alignment problem and developed a framework for efficient placement of eMTC/NB-IoT DL carriers in NR to avoid inter-carrier interference. In [12] and [13], authors discussed the deployment of eMTC/NB-IoT within the NR carrier, the resulting coexistence issues, and mechanisms to alleviate them.

**LTE-NR Coexistence in V2X Network:** 3GPP developed NR V2X to supplement LTE V2X rather than supplant it, by providing support for advanced applications that the LTE system cannot carry. Since LTE V2X has been standardized and is being deployed, it is likely that LTE V2X and NR V2X will coexist. The coexistence can be within a single device, also known as in-device coexistence, or it can be between vehicles with LTE and NR capabilities.
V2X networks, 3GPP in TR 37.985 proposed Frequency Domain Multiplexing (FDM) and Time Domain Multiplexing (TDM) solutions. With FDM, a vehicle can simultaneously transmit over both LTE and NR. However, the maximum transmit power must be shared between both technologies. To do so, 3GPP proposed dynamic and static power sharing. FDM solutions can be intra-band or inter-band. For intra-band operation, 3GPP proposed a static power allocation that is feasible for resolving conflicts due to simultaneous transmissions (Tx/Tx) from both technologies or when the transmission of one technology overlaps the reception of another (Tx/Rx), if the band separation is large enough. For inter-band operation, 3GPP proposed dynamic power sharing, which is feasible only if NR and LTE transmissions fully overlap in time domain such that the total power across the transmissions is constant.

In contrast to FDM if TDM solutions are implemented, vehicles cannot simultaneously transmit over both technologies. 3GPP defined long term and short-term TDM solutions. In long term solution, non-overlapping resource pools are pre-configured for NR and LTE signals. In short term solution, provided the load for the vehicle from LTE and NR side is at or below an acceptable level and assuming LTE employs semi-persistent scheduling, for each occurrence of Tx/Tx and Tx/Rx overlap, access technology prioritization is employed.

The issue of LTE-NR coexistence in V2X networks has also been addressed in [14] and [15]. While in [14] authors focussed only on cellular technologies, i.e., LTE and NR, V2X in [15], authors discussed both cellular and Wi-Fi technologies along with their predecessors, i.e., IEEE 802.11bd with Dedicated short-range communications (DSRC) and NR with LTE-V2X. Authors provided an in-depth description of the technologies, described their key features, and discussed the issue of coexistence between them.

IV. SPECTRUM SHARING SCHEME

Spectrum is the key enabler for NR features such as enhanced data rates, ultra-low latency, and good coverage. However, to attain these features NR has to efficiently share spectrum with LTE. In this section, we propose a spectrum sharing scheme for coexisting LTE and NR networks. The proposed scheme uses a high-level model that makes few assumptions about the underlying technology and is therefore applicable to a general class of spectrum sharing scenarios beyond LTE-NR coexistence.

In general, let \( N_G \) denote the set of coexisting networks. For LTE-NR coexistence, \( N_G = \{ \text{RAN}_A, \text{RAN}_B \} \), where, \( \text{RAN}_A \) and \( \text{RAN}_B \) corresponds to an LTE and an NR network, respectively. We assume that both networks use a shared pool of time-frequency resources and at regular intervals, the network operator measures the networks’ respective demand for resources, so that each network’s demand history forms a discrete-time random process. The intervals between measured demand levels can represent time slots in an LTE system, or 1 ms subframes, or periods of several seconds, depending on the scenario being modeled.

Let \( N_R \) denote the resource pool size that the network operator uses to allocate \( N_A \) and \( N_B \) resources to \( \text{RAN}_A \) and \( \text{RAN}_B \), respectively. The proposed scheme determines the optimal allocation that satisfies the networks’ randomly varying demands by defining a metric to assess the performance of a particular allocation. The scheme can support static or dynamic (i.e., time-varying) allocations.

When partitioning the pool, we constrain each network’s allocation and the total allocation to lie in the interval \([0, N_r]\). We define a function \( J \) that maps the ordered pair \((N_A, N_B)\) defined by the pool partition, to a scalar value that measures the performance of the network operator’s partitioning of the pool. The objective is to find the partition that minimizes \( J \), given the set of constraints. We choose \( J \) based on the normalized Euclidean distance between \((x_A, x_B)\), an ordered pair containing statistics associated with the distributions of \( \text{RAN}_A \)’s and \( \text{RAN}_B \)’s respective demands, and \((N_A, N_B)\). We define the function as

\[
J = \gamma \left( \frac{N_A - x_A}{x_A} \right)^2 + (1 - \gamma) \left( \frac{N_B - x_B}{x_B} \right)^2,
\]

where, \( \gamma \) is a weighting factor that allows the network operator to prioritize one network over the other, if desired, and \((N_A - x_A)/x_A\) and \((N_B - x_B)/x_B\) are the fractional resource surpluses or deficits experienced by \( \text{RAN}_A \) and \( \text{RAN}_B \), respectively. While a surplus refers to over-provisioning or excess of resources, which could be used if the demand exceeds the estimated value, a deficit refers to under-provisioning or lack of resources and results in lost or buffered packets. Our goal is to
The measured 95% confidence intervals for the RAN_A and RAN_B demand processes are as follows. For the process means, $\mu_A = [29.96, 30.03]$ and $\mu_B = [49.60, 50.36]$, for the process variances, $\sigma^2_A = [20.30, 20.62]$ and $\sigma^2_B = [28.42, 31.06]$, and for the maxima, $P_A = [43, 43]$ and $P_B = [62, 63]$. Thus, the expected total demand is approximately 80 resources while the maximum total demand is approximately 105 resources. In the interest of space, we only shows the results for $N_r = 20$ in Figure 4. Also, since the 95% confidence interval values for the statistics are very close, we show results corresponding only to the lower interval values.

When $N_r = 20$, the pool size is much smaller than the estimated demand, and starvation is an issue for both networks. Total starvation (i.e., the network receives no resources) corresponds to a fractional deficit of $-1$. From Figure 4b, the range of values for $\gamma$ over which both networks experience total starvation is smaller when we use the statistics. Also, Figure 4c shows that using the statistics produces a fairer allocation over a wider range of $\gamma$.

When $N_r = 60$, while the pool size is more than the mean demand of both the networks, it is close to the peak demand of RAN_B and more than that of RAN_A. Using the statistics-based optimization allows us to achieve a perfectly fair allocation when $\gamma \approx 0.55$, although the maxima-based optimization is fairer when one network has much higher priority than the other, i.e., when $\gamma$ is very close to 0 or 1, and results in an optimal allocation that leads to surpluses or over-provisioning of resources. In this scenario, the scheduler can use the maxima to partition the pool when one network has higher priority than the other.

Lastly, when $N_r = 100$, the pool is sufficient to meet the mean demands, and is large enough to support the maximum total demand. In this case, using the maxima-based optimization performs better for both networks, and results in an allocation that leads to surplus, i.e., over-provisioning, of resources. Thus, as the resource pool size gets closer to the maximum total demand, using the process mean and variance results in an allocation equal to the mean demand and results in a deficit, while using the maxima results in over-provisioning.

In future, we will consider other stationary and non-stationary demand models and develop a learning-based resource allocation scheme that employs the proposed optimization strategy.
V. CONCLUSIONS

In this article, we discussed LTE-NR coexistence for eMBB, mMTC, and URLLC use cases in PSC, MTC, and V2X networks. We examined how 3GPP is developing solutions for performance improvement when NR and LTE devices coexist and listed some approaches. Lastly, we introduced a novel and generic spectrum sharing scheme that is applicable to a variety of use cases and which allows for static resource allocation.

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BIOGRAPHY

Sneihil Gopal received her Ph.D. degree in Electronics and Communications Engineering in 2021 from IIIT-Delhi, India. She is currently working as a Postdoctoral Researcher at the Department of Physics, Georgetown University, and as an International Associate Researcher in the Wireless Networks Division, NIST. Her research interests include dynamic spectrum sharing, wireless network optimization, applications of game theory in wireless networks, and machine learning.

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Richard Rouil received his Ph.D. degree in computer science in 2009 from Telecom Bretagne, France, that focused on mobility in heterogeneous networks. He is currently the Division Chief of the Wireless Networks Division at NIST. His research focuses on the performance evaluation of wireless technologies, such as LTE and NR, to support the development, analysis, and deployment of networks used by public safety. His main interests include protocol modeling and simulation of communication networks.

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