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CHALLENGES RANDOM ACCESS MECHANISM FOR LTE/5G RAN

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ABSTRACT

The 5th generation (5G) technology's objective is to provide improve users' experience by increasing data rate, improving coverage and supporting Quality of Service (QoS) to various service classes. And variety of usage scenarios such as enhanced mobile broadband, massive machine-type communications and ultra-reliable low-latency communications. Due to the mounting increase in the user equipment (UE) devices of wireless communication technologies, 5G and beyond networks expect to support far higher user density and far lower latency than currently deployed cellular technologies. Random access channel (RACH) is a mandatory procedure for the UEs to connect with the Node (gNB). The performance of the RACH directly affects the performance of the whole network. Currently, RACH uses a uniform distribution-based (UD) random access to prevent a possible network collision among multiple UEs attempting to access channel resources. However, in a UD-based channel access, every UE has an equal chance to choose a similar contention preamble close to the expected value, which causes an increase in the collision between the UEs.

Therefore, we propose a Poisson process-based RACH (2PRACH). A Poisson based distribution, such as exponential distribution, disperses the random preambles between two bounds in a Poisson point method, where random variables occur continuously and independently with a constant parametric rate. In this way, our proposed 2PRACH approach distributes the UEs in a probability distribution of a parametric collection. Simulation results show that the shift of RACH from UD-based channel access to a Poisson process-based distribution enhances the reliability and lowers the network's latency.

KEYWORDS: ***5G, random access, channel access, beyond 5G, resource allocation, Machine-to-Machine communications.***

I. INTRODUCTION

A large increase in the demand for capacity in mobile communication devices has shown wireless communication industries to prepare to support up to a thousand-times increase in total internet traffic [1–3]. The 3rd Generation Partnership Project (3GPP) recommend that connecting the user equipment (UE) to an existing cellular network, such as Long-Term Evolution-Advanced (LTE-A), 5th generation (5G) networks [4], requires the higher layer connections between the UEs. Generally, a significant amount of data needs to be distributed from many UEs on a 5G network. In this way, the UEs perform a random access (RA) mechanism for transmitting resource requests to the base station, known as evolved Node B (eNB) [5]. The UEs execute RA using the physical random-access channel (RACH) through a four-step handshake process.

Many UEs attempt to communicate over the same channel resources in a dense UE deployment. The UEs contend to control the common radio resources, which makes a massive collision problem. Due to simultaneous UE channel access, preamble collisions can block the RA process. The problem of successful RA is crucial due to the increasingly growing number of connected UEs in the network [6]. A standard 5G network consists of two parts: the enhanced packet core (EPC) network and the radio access network (RAN) [7]. A high-level architecture of a typical 5G network with linked UEs' connectivity is shown in Figure 1, where the UEs are linked to the eNBs. The EPC is responsible for the optimum regulation of mobile devices and creating an Internet Protocol (IP) packet transmission path. The RAN is responsible for wireless networking and radio resource usage. The RAN, which provides the requisite protocols for the user and control plane to communicate with mobile devices (UEs) in 5G network, is composed of eNBs. The eNBs are interconnected through the X2 interface. And eNB is connected to the EPC using an S1 interface [8]. In a standard 5G network, the minimal resource scheduling unit for downlink (DL) and uplink (UL) transmission is referred to as a resource block (RB). An RB consists of 12

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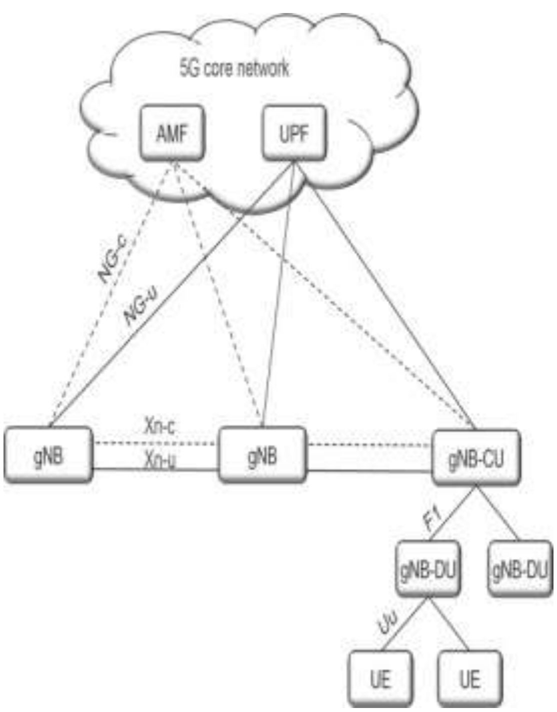
subcarriers in the frequency domain (FD), each size of 180kHz and one sub frame in the time domain (TD), length of 1 ms. This time-frequency resource is called RACH, and it is the RB on which RA is performed. RA helps UEs initialize an association, known as a contention-based RA (CB-RA) method [9]. In a CB-RA, UEs utilize preambles to launch the RA transmission attempt. There is a total of 64 preambles divided into two categories; preambles of contention-free RA (CF-RA) and preambles of CB-RA. For CF-RA, the eNB incorporates a few preambles and designates specific preambles for various UEs. Remaining preambles are used for CB-RA, where every UE randomly chooses one preamble from a set of predefined uniform random variables (RV) [7].

Figure.1



II. PRINCIPLE OF RACH

In order to connect a UE to 5G network, it has to synchronize in downlink as well as in uplink. Downlink synchronization is obtained after successfully decoding SSB, For establishing uplink synchronization and RRC connection, UE has to perform RACH random access procedure.

Types of RACH Procedure

- Contention Based Random Access (CBRA)
- Non Contention or Contention Free Random Access (CFRA)

- **Contention-based Random Access (CBRA):**

In contention based Random access, UE selects a Preamble randomly from a pool of preambles shared with other UE. This means that the UE has a potential risks of selecting the same preamble as another UE and subsequently may experience conflict or contention. The NodeB uses a contention resolution mechanism to handle this type access requests. In this procedure, the result is random and not all Random Access succeeds. CBRA is also known as four step RACH Procedure.

- **Contention Free Random Access (CFRA):**

In non-contentions based Random Access, The Preamble is allocated by the NodeB and such preambles are known as dedicated random access preamble. The dedicated preamble is provided to UE either via RRC signaling (allocating preamble can be specified within an RRC message) or PHY Layer signaling (DCI on the PDCCH). There is no preamble conflict. When dedicated resources are insufficient, the NodeB instructs UEs to initiate contention-based RA. CFRA is also known as three step RACH procedure.

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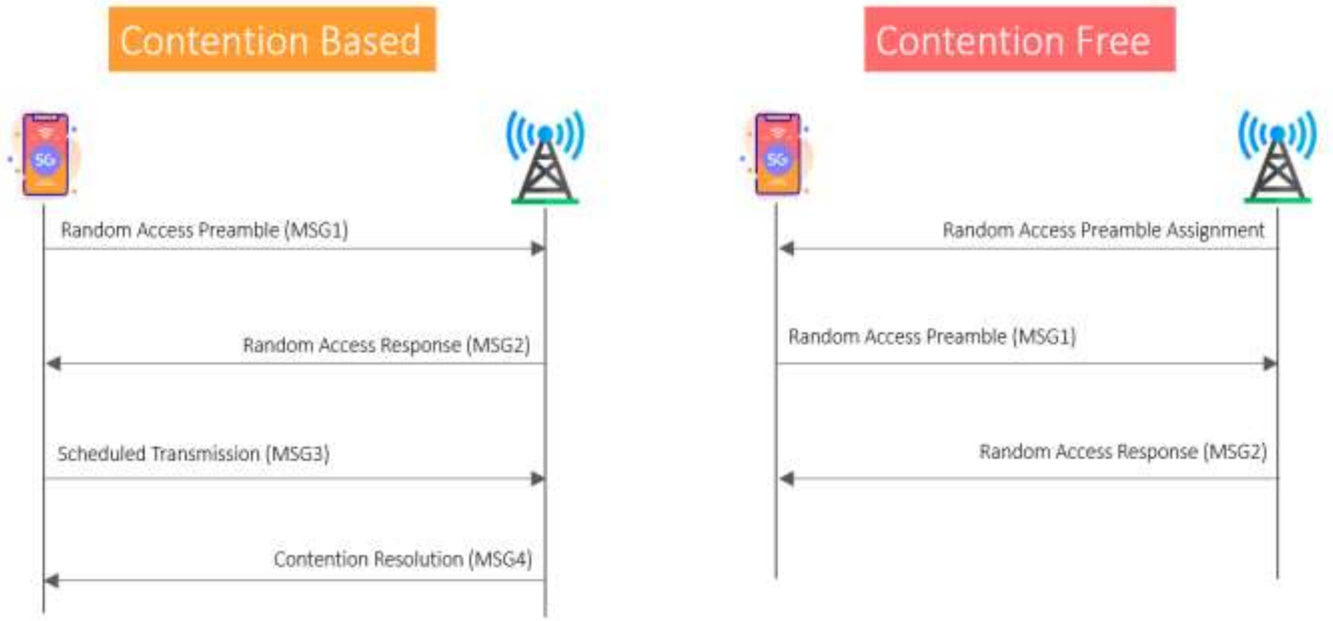

Figure. 2

III. CONTRIBUTION OF PAPER

The parametric distribution approach allows the system to disperse RVs exponentially. That's why, in this paper, we suggest using RVs with Poisson distribution, such as a continuous exponential distribution (ED). The proposed mechanism is named as Poisson process-based RACH (2PRACH). The contributions of this paper are twofold:

•This paper assesses the strengths of Poisson distribution RVs as compared to the uniform distribution RVs.

• We propose a 2PRACH mechanism, which suggests replacing UD with ED in random access mechanism for LTE/5G networks.

In the rest of the paper, we present related work on enhancing the existing RACH procedure in 5G cellular networks.

IV. METHODOLOGY

In related research contributions, many researchers have proposed mechanisms to decrease the delay at the RACH procedure. One of the proposals from 3GPP is an early data transmission (EDT) as a feature of the Release 15 specification [8]. According to EDT, data transmission services from the UL channel are sent sooner, enabling data packet transmission to be piggybacked with the RACH system. In Reference [9], authors gave some underlying findings on the execution of EDT, showing that it shows improvements at the edge of the network in-data packet latency by 85 ms. [10] conducted performance studies to show that a two-way handshake RACH mechanism is based on an exceptionally structured RA preamble that guarantees a 10–50% delay reduction for 5G macro-cell networks and 50–70% femto cell 5G networks compared to the standard RACH method. A specific RACH resource method for ultra-reliable low-latency communications (URLLC)-related traffic is proposed in Reference [11], designated as resource allocation priorities. Authors propose that by reserving RA preambles twice the amount of URLLC-based UE requests, a channel access latency of less than 10 ms can be [18] Proposed a contention-resolution-based RACH (CRB-RACH) system that dynamically adapts backoff times to allow further improvements compared to a fixed-back-off scheme. [19] propose a random-access scheme for multi-radio access technologies (RAT), named Multi-RAT RA, which uses traffic offloading configuration parameters utilizing the licensed and unlicensed bands. Although the authors achieve a higher average success probability with their proposed Multi-RAT RA scheme, the use of dual or multiple RATs is required to complete this efficiency. [20] enhanced the RACH procedure by obtaining the approximate characterization of UEs' interference in a wireless system. Their derived analytical expression of success probability helps to consider the channel collision and the preamble transmission. The authors further extend their proposed RACH success probability analysis for multiple time slots by modeling the queue evolution. In Reference [21], the authors address excessive congestion and channel collision in the RACH due to massive users' access. They propose a dynamic adjustment of the backoff parameters based on the number of contending devices. The vibrant use of backoff parameters in a RACH scheme achieves the enhanced channel access success probability for statics access and random access with a slight increase in the access delay. Another work in Reference [22] proposes a Timing Advance-based Preamble Resource Expansion (TAPRE) scheme for RACH procedure, which adjusts time slot for preamble transmission to reduce the collision probability effectively. The authors achieved this with a Resource Allocation Wait (RAW) protocol, which efficiently reduces RA failures. However, these works considered enhancing the existing uniform distribution-based RACH mechanism.

V. EXISTING CONTENTION BASED RANDOM ACCESS MECHANISM

When a UE is switched on or awakens, it initially synchronizes with the DL channels by reading the primary synchronization signal (PSS) and secondary synchronization signal (SSS) from the eNB. The UE separates the Master Information Block (MIB) at that point, which contains data on the DL and UL carriers' configuration so that the eNB receives data from the Sender Information Block (SIB). All RA parameters are included in this SIB, such as the number of available RA slots, RA preamble classes, and preamble setup. Subsequently, UEs generate CB-RA transmission attempts in order to decode the SIB. For association initialization in a 5G network, the CB-RA conducts four main phases. Figure 2 & 3 shows a CB-RA procedure in a 5G network.

VI. PERFORMANCE EVOLUTION

The proposed 2PRACH approach decreases the collision incidence and improves the performance rate of the existing RA of the UE association without altering the 3GPP recommended RA procedure. We conducted simulations in a discrete-event network simulator release 3.30.1 (ns-3.30.1) [23] to evaluate the performance of the 2PRACH approach. The network topology used in simulations includes a radio access network part of a typical UE communication, as shown in Figure 1. The proposed approach's efficiency is measured in terms of network stability (reliability) and end-to-end latency. These two evaluation parameters are tested for three different scenarios. First, we conducted simulations with increasing number of UEs in the network, that is $N = \{2, 4, 8, 16, 32, 64\}$. Later, we assess the efficiency with varying data packet sizes and inter arrival packet speeds. The objective of conducting simulations of various packet sizes and rates of inter arrival is to evaluate the impact on the proposed mechanism's real data transmissions. We observe that the users' distribution tends towards the similar density function as of a uniform distribution. Therefore, one can choose the average rate parameter (l) according to the conditions and requirements. In this paper, we use $l = 8$ as our rate parameter, which distributes the users near the initial channel access slots. Detailed simulation parameters and their used values are described in Table 1.

Table 1. Simulation parameters and their values.

Parameter	Value(s)
Simulation time	100 s
Simulation model	LTE-EPC model
Number of eNBs	2
Number of UEs	2, 4, 8, 16, 32, 64
Distance between UE and eNB	60 m
Data payload (packet) sizes	32, 64, 128, 256, 512, 1024 Bytes
Packet Inter arrival rates	5, 10, 20, 40, 80, 160, 1000 ms
Total number of RA preambles	8
CB-RA preambles	52
Rate parameter (l)	8

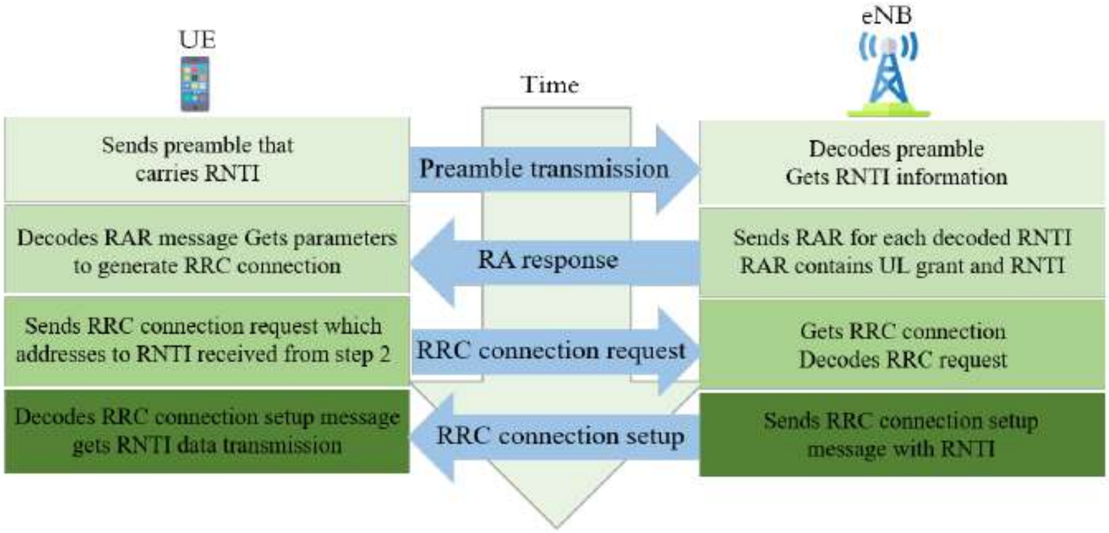

Figure 3. Contention-based random access (RA) procedure in a 5G network.

Figure 4 compares the efficiency of our proposed 2PRACH mechanism with the existing uniform distribution-based RACH procedure, and the CRB-RACH mechanism [18], where the number of contending UEs varies. In Figure 4a, we show that the 2PRACH mechanism achieves higher reliability than existing RACH and CRB-RACH procedures, also in dense UEs deployments, which is 64 UEs. Similarly, the network's end-to-end latency is also reduced for the proposed 2PRACH mechanism, as shown in Figure 4b. In the 2PRACH scheme, improved reliability and reduced latency are evident that for a denser UE environment, choosing earlier RA preambles with a constant parametric rate decreases collision among the UEs. The improved efficiency is because a Poisson process-based distribution manages the number of events in a fixed time frame and the time between occurrences of those successive events. It fits our RACH scheme's settings because it is one of the distributions with the "lack-of-memory" property. It means that, after waiting to access the channel without successful transmission, the probability of a UE to access the channel in the next contention is the same as was the probability (in previous transmission attempt) of accessing the channel in the following two transmission attempts. Thus, as a UE in the system continues to wait, the chance of successful transmission neither increases nor decreases based on the parameter selected. Although the CRB-RACH procedure improves the efficiency compared to the existing RACH with the use of dynamic backoff adjustment, due to the use of uniformly distributed backoff parameters, it achieves lesser reliability and higher latency as compared to 2PRACH. The efficiency of the proposed 2PRACH mechanism is also measured with various data packet sizes. The motivation to evaluate an RA process with different data frame sizes is that the UEs' channel capital occupancy time very much depends upon the data frame size to transmit. Figure 5a,b show the effect on the network's stability and latency of various data frame sizes. The figures reveal that the 2PRACH procedure works well for both; reliability and end-to-end latency relative to existing UD-based RACH when considering the different types of data frame sizes. However, the influence of data frame inter arrival rate has fewer effects on the network's stability and latency efficiency, as seen in Figure 6a,b, respectively. Collisions. The importance of using a Poisson process-based distribution is evident from the figures (that is, Figures 4–6).

The main purpose of the proposed 2PRACH for the RA procedure is to enable the UEs in the network to carry out their initialization of the association more effectively, where reliability is accomplished by reducing network.

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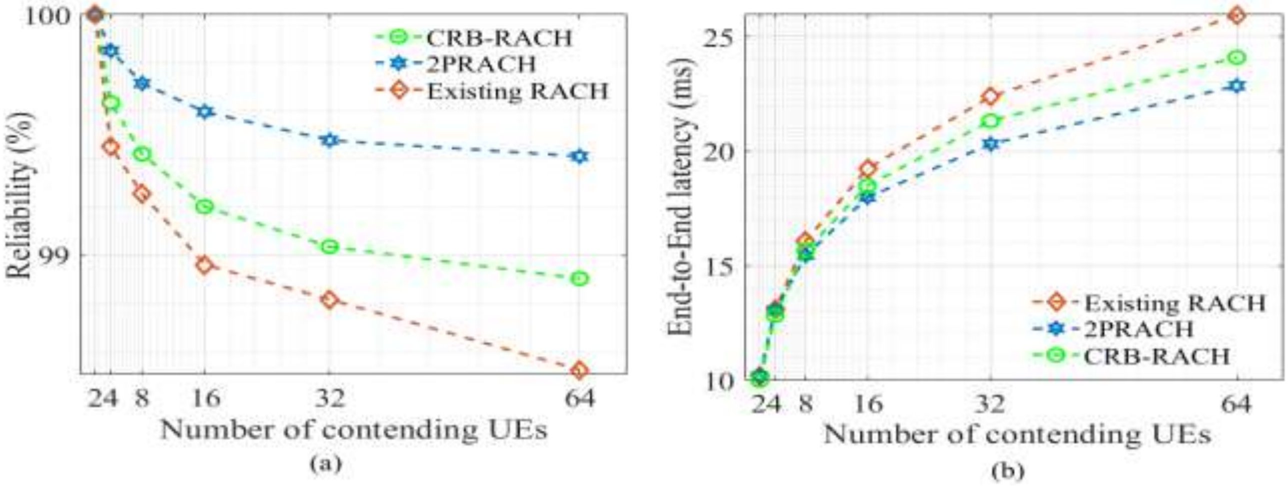

Figure 4. Performance comparison of process-based random-access channel (2PRACH) with existing random-access channel (RACH) and contention-resolution-based RACH (CRB-RACH) procedures with the varying number of contending UEs, where (a) network reliability (%), and (b) end-to-end latency (ms).

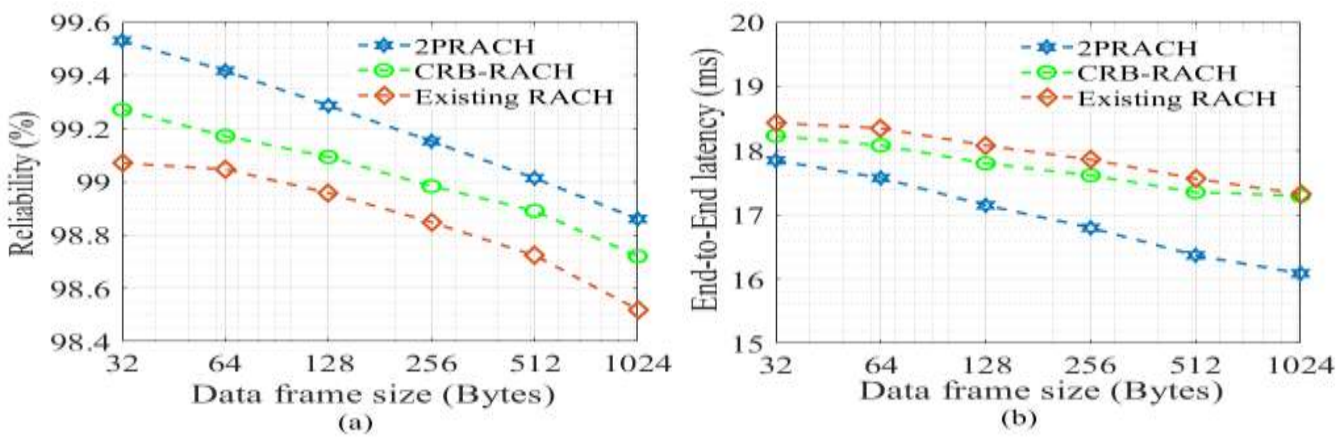

Figure 5. Performance comparison of 2PRACH with existing RACH and CRB-RACH procedures with varying data frame sizes, where (a) network reliability (%), and (b) end-to-end latency (ms).

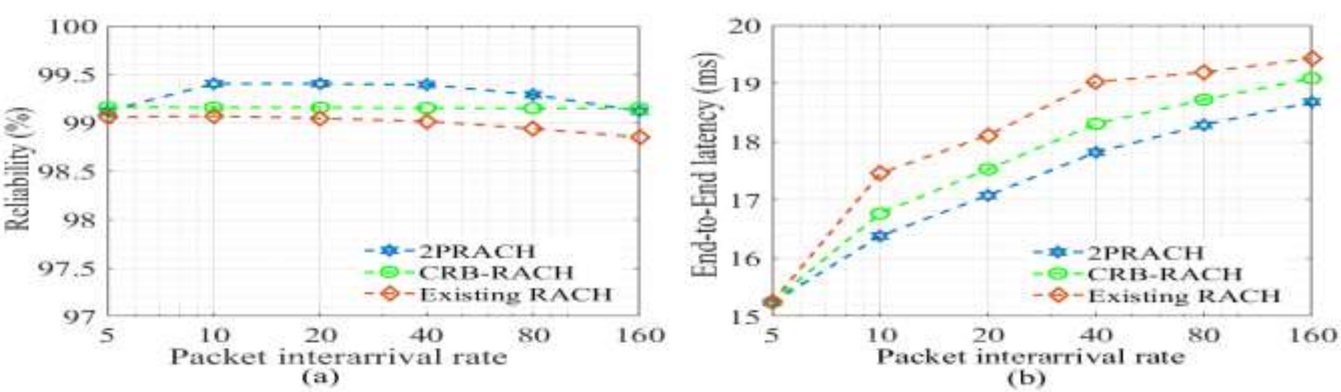

Figure 6. Performance comparison of 2PRACH with existing RACH and CRB-RACH procedures with varying packet inter arrival rate, where (a) network reliability (%), and (b) end-to-end latency (ms).

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VII.CONCLUSION & FUTURE SCOPE

One of the challenges for 5G cellular communication networks is to provide effective channel connectivity, especially for denser UE scenarios. In a 5G network, the random access channel (RACH) procedure is the core channel access mechanism to set up the wireless communication association between a UE and eNB. However, the efficiency of the currently deployed RACH system is greatly affected by the rise in the number of contending UEs in a network. It is due to the limited available channel contention preamble set. The selection of contention preambles based on the uniformly distributed random access mechanism of the RACH system is one reason for this efficiency loss. In a uniform distribution, each UE has an equal opportunity to select identical contention preambles close to the mean value of the distribution, creating a rise in collisions among the UEs. Since there is only a single contention stage for the UEs to access the channel, we may consider alternate solutions to allow the UEs to access the channel as early as possible. For this purpose, we propose a Poisson process-based RACH, named 2PRACH, which is based on continuous exponential distribution. The proposed 2PRACH distributes contention preambles between two bounds in a Poisson point method, in which random variables exist continuously and independently with a constant average rate allowing UEs to access the channel resources at their earliest slots. In this way, the 2PRACH mechanism distributes the UEs in a parametric collection of the probability distribution. The performance evaluation results of simulation experiments show that 2PRACH significantly improves the reliability of the network. The increased reliability is achieved due to the enhanced capacity of the UEs to transmit their data packets. At the same time, the long waiting period of the uniformly distributed preamble is eliminated to achieve reduced latency, as well. In the future, we plan to apply a reinforcement learning-enabled framework to improve the efficiency of 2PRACH. The behaviourist appraisal feature of reinforcement learning models is the incentive to incorporate reinforcement learning to refine the RA procedure in 5G networks. Besides, we are also working to develop a novel analytical model for Poisson process-based channel access mechanisms.

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