Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Cloud RAN (C-RAN) Accessed Multi-connectivity for 5G Targeted Ultra Reliable Communication (URC)

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Abstract

Internet of things is in progress to build a smart society, and wireless networks are critical enablers for many of its use cases. This growing demand for data rate and volume in different areas and different scenarios manifest that the new generation of mobile networks is in headway, developed and is being standardized in upcoming networks called, 5th Generation (5G) network. 3GPP visualize this concept of 5G NR (new radio) considering three different categories: Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable low Latency Communication (uRLLC). Low latency targeted URC i.e. URLLC is concerned with application such as automation and vehicle to vehicle communication that demand reliability of five 9's 99.999%. In this study, the concept of Multi-connectivity (MC) is presented to achieve ultra-reliability and low latency for machine type wireless communication networks. It has been evaluated an interference-limited network is composed of multiple remote radio heads connected to the user equipment. Some of those links are allowed to cooperate, thus reducing interference, also Ultra-Reliable Low Latency Communication (URLLC) can be enabled, using MC. Different MC transmission schemes in interference scenario is evaluated, while managing BSs coordination Intra-frequency multi-connectivity, which leads to the fact that interfering BSs become desired BSs, i.e., an improved signal-to-interference-plus-noise ratio (SINR) budget. Therefore, we derive their respective closed-form analytical solutions for respective outage probabilities. Some findings regarding the paper are: (1) finding the exact coding gain of the outage probability considering SINR at the given threshold of SC over MC; (2) quantifying the performance improvement of MC over SC in terms of sum-rate for different UE positions. The performance is evaluated using computer simulations and discuss the gains of cooperation and MC enabled centralized radio access network.

Keywords
MTC, URLLC, reliability, diversity, multi-connectivity

1. Introduction

Currently we are in inception of transformation into fully connected Information Connected Society (ICS) that will provide access to information and sharing of data anywhere, anytime, anyone, and for anything [1]. Thus, in the future connectivity will not only be the wireless access will for people but for anything that benefits from being connected [2]. As broached earlier, today a large number of devices are connected to the network, mobile phones, computers, sensors, actuators are connected to the network. Since there is demand for a large volume of data with higher the speed it can be achieved as we are moving towards smart society, which present and previous network could not sufficiently fulfill. According to Cisco [3], mobile data traffic has increased 18-fold between 2011 and 2016. At the end of 2016, traffic volume per month had reached 7.2 Exabyte's showing 63% growth in one year. Connection speed has also grown 3-fold. As we compare generated mobile traffic between 3G and 4G, we find that, with only a 26% share of mobile subscription, 4th Generation (4G) connection have generated 69% of the mobile traffic-which is four times greater than the traffic generated by 3rd Generation (3G) connections. Cisco [3] also predicts that mobile "traffic will increase seven-fold between 2016 and 2021, while the speed increase will be three-fold". By 2021, the mobile traffic will reach 49 exabytes per month, accounting for 20% of the total Internet Protocol (IP) traffic. Based on this analysis, forecasts, predictions, statistics, and changing scenarios, how society is changing, will lead to changes in the way mobile and wireless communication systems are used. Crucial services such as e-banking, e-commerce, e-governance, e-learning, e-business, and e-health will continue to multiply and become more mobile. On-demand information and entertainment world (e.g., in the form of augmented reality, virtual reality) will gradually be delivered over mobile and wireless communication systems. These developments will lead to a torrent of mobile and wireless network traffic volume to increase a 1000 fold over the next decade [3] [4]. In the future, there will be stiff growth in machines and gadgets in the communication field, so communication will not only be Human Centric type, but will be accompanied by Machine Centric. This is what we say as Internet-of-things (IoT), which makes our life comfortable, efficient, easier, and safe. There are speculations of a total of 50 billion connected devices by 2020 [1] [4]. This growing demand for data rate and volume in different areas and different scenarios manifest that the new generation of mobile networks is in headway, developed and is being standardized in upcoming networks called, 5th Generation (5G) network.

3rd Generation Partnership Project (3GPP) and the International Telecommunication Union (ITU) has progressed its work towards standardization. There is no such specified requirements presented by ITU for 5G mobile network, but have released a report called as "Framework and overall objectives of the future development of IMT for 2020 and beyond" [5]. The main vision of ITU, behind this report, is to develop a framework to meet 5G requirements. Eyesight of 5G is connectivity with a wide range of real-time applications. 3GPP visualize this concept of 5G NR (new radio) considering three different categories, Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable low Latency Communication (uRLLC). eMBB supports more throughput, referring to applications such as video streaming, on-line gaming, and virtual reality which need high BW data access. mMTC deal with more connected devices, expected connection of billions of devices to the internet, low data rate with high reliability, and with massive connectivity. URLLC is concerned with high reliability at stringent latency constraints concerned with application such as automation and vehicle to vehicle communication that demand reliability of five 9's 99.999%. So in this study our main approach is towards URLLC services with MC schemes.

In context to our work, we address issues related to URLLC, where reliability and low latency are more relevant than throughput. The recently launched fifth-generation (5G) New Radio (NR) system is the first cellular wireless standard designed to meet the growing demand for multi-service communication [7]. In particular, a key feature of 5G NR is the introduction of the Ultra-Reliable Low-Latency Communication (URLLC) service class. URLLC targets applications in critical use cases like Factories of the Future, Automotive sector, eHealth, etc. The reliability and latency levels demanded by URLLC is unprecedented in existing wireless systems, and therefore novel solutions are required. High reliability is the process of receiving data and decoding a packet of data correctly with very high probability whereas latency is the time duration transmitter decides to send data to the receiver receives the data and it is successfully decoded.

The way to generalize the latency and reliability is to plot the Cumulative distribution function (CDF) of the latency as shown in the Figure 1 where CDF shows that concerned latency will be less than or equal to a certain threshold. Due to transmission infrastructure failures all packets will not be received so there will be a probability of dropped packets. And as shown in figure with certain threshold reliability of successful transmission is measured and the given reliability corresponds to 1-P_e, where P_e is the transmission infrastructure failure or drop packets.

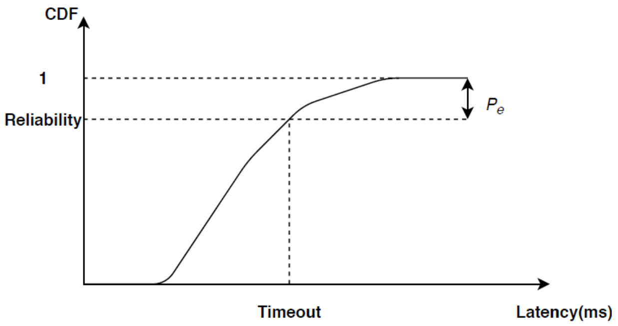

Figure 1: Conceptual illustration of latency-reliability function

We deal with multi-connectivity in a way, that different Base Station (BS) equipped with a single antenna are connected to the User Equipment (UE) and form a special case of multi-connectivity or spatial diversity. The multiple diversity branches that correspond to an orthogonal Multiple Access Channel (MAC) are realized by different carrier frequencies.

Thus, the information can, in the best case, be delivered in a single time slot, which helps to satisfy the URLLC requirements [8]. Multi-Connectivity can also be utilized to enhance the reliability i.e. the same information is transmitted over all branches simultaneously [9]. Diversity can be considered as a key catalyst of URLLC in the MTC (Machine Type Communication) network which in term is the facilitator of different critical IoT services. In the case of multi-cell deployment to activate the critical MTC network applications, such as factory automation two possible options could be considered as mentioned in [10].

- Frequency planning and coordination where the cells may use at least partially separate frequencies,
- Frequency reuse where neighboring cells fully operate on the same frequency bands or resources.

Above mentioned planning can play a vital role in limiting the interference, in a particular area to activate any MTC network, which also plays a crucial part in maintaining the reliable coverage area and minimum threshold to maintain heterogeneity order? This is possible today because we envision the use of C-RAN and virtualization in the network. MC can be implemented by the initiation of CRAN where the baseband unit at CRAN facilitates coordination and cooperation among BS and necessary resource allocation locally at the edge.

2. Related Works

With an increase in diverse market and industrial demand and increasing data traffic requirements ranging from paramount to massive machine connectivity, the expectancy of the fifth-generation (5G) is growing at an exponential rate. Now such requirements open new ways to emerging features and business models, the delivery of these requirements for such intense traffic and diverse services remains a challenge for the telecom and wireless industries. These challenges increase day by day to further fulfill expectations such as backward compatibility, user equipment resource allocation, diverse application requirements, an increasing number of devices, and so on[11].

In recent years works related to 5G, mainly focuses on latency and reliability aspects of URLLC. Pioneering work related to information-theoretic finite block length communication by Polyanskiy developed bound on block error rates for short packet transmission[12][13] . Relevant work particularly approximates for performance analysis of finite block length communication and also focuses on performance losses compared to asymptotic Shannon coding. These results provide a useful contribution in the URLLC environment where packets size is typically small. Similarly, a detailed look over on qualifying technologies in the circumstances of URLLC from the physical layer and Medium Access Control (MAC) , which figure outs on key contributors covering both licensed and unlicensed spectra below 6 GHz.

Multi-connectivity, diversity, modulation, and coding schemes are considered to be possible enablers for URLLC. The most challenging URLLC service target is 99.999% (five 9's) reliability at millisecond-level latency. To achieve above target, solutions have been proposed which include, flexible frame structure design with shorter (and variable) transmission time intervals (TTI) , preemptive scheduling for critical low latency data , and diversity as a reliability improvement feature . As we move further for finding a solution based on diversity. To guarantee high reliability, micro as well as macro along with multiple antenna is required. We can say that macro-level diversity along with multiple channel access (MCA), like multi-connectivity (MC) is an expected potential solution for URLLC applications.It is elaborated with the concept of the CRAN, enabling centralized baseband processing of signals from multiple BSs. Dual connectivity (DC) achieves higher reliability, at the cost of lower mean spectral efficiency (due to redundancy) as potential solutions concerned with high reliability.

As per 3GPP Release 15, 5G-NR, Ultra-Reliable Low-Latency Communication (URLLC) is a set of features that provide low latency and ultra-high reliability for mission-critical applications such as industrial internet, smart grids, remote surgery, and intelligent transportation systems. We remark that ensuring high reliability using multiple node redundant transmission is also included in the study of enhancements for URLLC support in the 5G Core network in 3GPP (Release 16)[34] 3GPP has specified URLLC as a key feature for Release 15 5G NR, in addition to eMBB. As per 3GPP Release 14, Latency with 4G LTE is in the 4-millisecond range but with the introduction of URLLC in Release 15, the target is 1-millisecond. URLLC also provides end-to-end security and 99.999% reliability. 3GPP has specified normative requirements for the 5G system. This includes service requirements and KPIs (key performance indicators) for private networks, industrial automation, AR, VR, and the tactile internet. These requirements will be fully specified with URLLC capabilities defined in 3GPP Radio Access Network (RAN) and Services and Systems Aspects (SA) groups. 3GPP has recently benefited from an influx of non-traditional participants who would like to use 5G to serve new markets such as industrial automation, entertainment, and transportation systems . There are two dimensions to URLLC, namely latency and reliability. Improving one of these aspects, without a strict constraint on the other is rather trivial. For example, the reliability can be perpetually improved by repeating a given message continuously. URLLC solutions should therefore consider jointly improving both, the latency and the reliability. Most works on URLLC consider the reliability for a given target latency. For example, one of the URLLC targets defined by 3GPP is to achieve a maximum outage probability of 10^{-5} at one millisecond user-plane latency. However, works considering an analytical investigation of the latency in itself is rather limited. This work will therefore attempt to propose an analytical framework that considers the latency and the reliability as a joint performance metric, which will then be used to investigate URLLC solutions.

3. Methodology

Overall system architecture has been illustrated in above fig 2.a. We deal with introduction to 5G protocol analysis, where we define about requirements and facts about 5G which had been addressed in Chapter 1. As mentioned above in previous sections, 3 generic connectivity schemes introduced by 3GPP namely; eMBB, mMTC and URLLC. In this research we have focused only about noble solutions regarding URLLC. This heads towards enablers for required solution, where, Multi-connectivity is introduced as one of our approach regarding ultra-reliable communication in given latency. Further Latency and Reliability-Latency can be analyzed in upcoming proceedings towards our paper shown by dotted line.

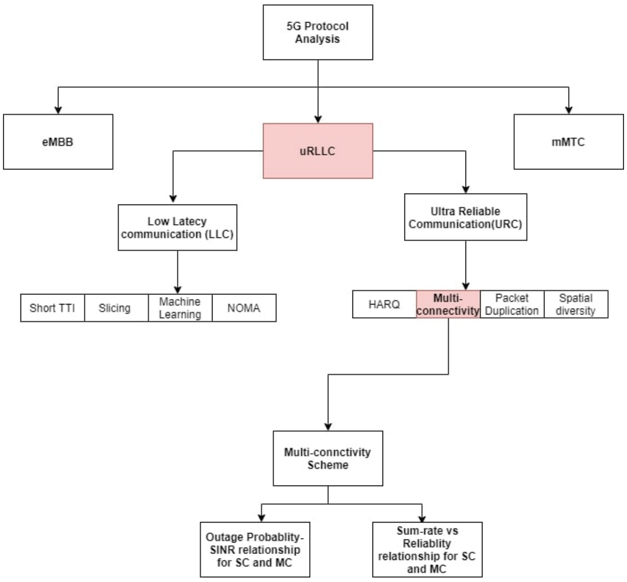

Figure 2.a: System flow

3.1 System Architecture

3.1.1 System Model and Operations

We consider a CRAN-enabled downlink cellular network scenario, as shown in Fig 2.b. In CRAN architecture, functionalities of RAN is split between baseband unit (BBUs) and distributed remote radio heads (RRHs). Here, BS act as a remote radio head (RRHs) which converts the baseband signal into RF signal. BBU present at cloud act as virtual BS responsible for resource allocation and centralized baseband processing. MC which adopts spatial diversity is mentioned with the concept of CRAN to ensure ultra-reliability through cooperative solutions. Furthermore, CRAN connects to base stations (BS) with cable (optical fiber) or wireless cloud links. CRAN has high-speed optical fiber links in the fronthaul that can support low latency and high bandwidth communication both of which lead to improve network performance. The system model consists of two cells. In each cell, there are centrally located BSs. In each cell there is one user. Both BSs and UE are equipped with a single antenna. In the set-up, both the BSs operate at the same frequency. Let, d_{ii} is the distance from BS_i to UE_i, d_{jj} distance from BS_j to UE_j, and d_{ij} or d_{ji} is the distance from BS_i to UE_j, vice-versa where $\{i, j\} \in \{1, 2\}$. Here, d_{ii} and d_{jj} are referred to as typical or desired links, and d_{ij} or d_{ji} is considered as interfering or non-desired links. We focus on the UE1 performance while other cells are using the same channel to transmit data to their corresponding UE. The analysis is carried out when UE1 is in single connectivity mode i.e. our baseline calculation and next in MC mode. The channel is modeled by distance-dependent path loss and small scale fading. We assume the channel undergoes quasi-static Rayleigh fading and path loss exponent is denoted by α. Due to latency constraints, all processing is done centrally at CRAN and full channel state information (CSI) and statistics are available at CRAN BBU.

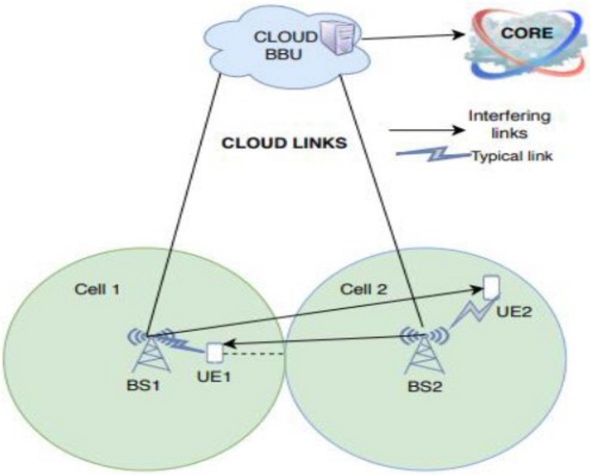

Figure 2.b: Illustration of CRAN system model with two cells, two users, two centrally collocated BS

We denote the squared-envelope coefficients of the desired and interfering links as h_{ii}, h_{jj}, h_{ij}, h_{ji} Exp (1), respectively which means the channel is exponentially distributed mean 1. We consider that each BS transmits with fixed unit power and the system has some interference from neighboring cells. Under these assumptions, settings and operation we define signal-to-interference-noise-ratio SINR as,

$$\mathrm{SINR}_i = \gamma_i/(1+\sum_{i\neq j}\gamma_{ij}) \tag{1}$$

where, $\gamma_i = (h_{ii}d_{ii}^{-\alpha})/N_0$ is desired SNR from BS_i to UE_i and $\gamma_{ij} = (h_{ij}d_{ij}^{-\alpha})/N_0$ and, is the undesired SNR from BS_j to UE_i and N_0 denotes the noise power. Similarly, we can represents the $SINR_j$. But, our reference is UE1. We can represent the channel and distance with the following matrix whose dimension is N*K where N is the number of BSs and K is the number of user.

$$D_{ij} = \begin{bmatrix} d_{i,i} & d_{i,j} \\ d_{j,i} & d_{j,j} \end{bmatrix} \tag{2}$$

$$H_{ij} = \begin{bmatrix} h_{i,i} & h_{i,j} \\ h_{j,i} & h_{j,j} \end{bmatrix} \tag{3}$$

Note that, for reference UE1 as UE moves along the dashed line shown in system model the corresponding distance matrix value also changes which we will discuss in detail in simulation results and discussions chapter

3.1.2 Performance Analysis

The main system performance target in this work is to ensure the ultra-reliable region of operation in URLLC services. We carry out MC transmission schemes in the interference scenario while managing BSs coordination. In this sequel, let us define these performance metrics.

3.1.3 Basic Connectivity Approaches

To approach our discussion further on MC, we discuss different connectivity options of BSs operating at the same sample frequency but providing uncorrelated links. Consider a system of two BSs as BS1 and BS2 and two UEs as UE1 and UE2. The following connectivity options may be applied to our scenario, as depicted below in Fig. 3

a) Connectivity Option 1: In a given setup, each UE is connected to a single BS i.e. UE1 is connected to BS1 and UE2 is connected to BS2, hence we say single-connectivity is applied. Also, complete Bandwidth is allocated to each UE, so it faces full interference from the BS it is not assigned to.

b) Connectivity Option 2: In the same setup, each UE is connected to both BSs simultaneously, and hence Intra frequency multi-connectivity is achieved. Also interference is significantly reduced for both UEs, as both UEs are connected to low BW compared to previous connectivity options. So as we move from single connectivity option to multi-connectivity option, we see significant improvement in SINR values i.e. it is maximized leading to an SINR outage probability reduction.

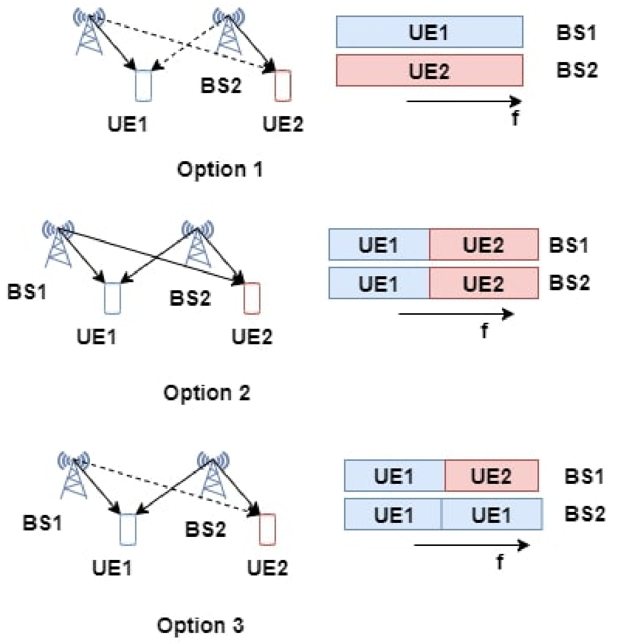

Figure 3: Sample connectivity options in two BSs and UE scenarios. Solid lines: desired links, dashed lines; non-desired links, interfering links

As explained above, we have three different sample connectivity options, but we consider only Option 1 and Option 2 in the context of our model.

3.1.4 Multi-connectivity and Reliability

Multi- connectivity (MC) first appeared in 3GPP release 12 as Dual Connectivity (DC). According to DC definition, we define MC as: ”The ability for a User Equipment (UE) to connect and consume radio resources for at least two access nodes simultaneously, both for inter-frequency and intra frequency scenario”. These are of two types: Inter- frequency and Intra-frequency multi-connectivity. In our model, we are using Intra-frequency MC, where both RRH are using the same frequency. Intra-frequency multi-connectivity, is an approach in which multiple base stations (BSs) operating at the same carrier frequency transmit simultaneously to the same user equipment (UE). This process leads to the fact that interfering BSs become desired BSs, i.e., an improved signal-to-interference-plus-noise ratio (SINR). Reliability is the successful transmission of a given amount of data from source to destination within a given latency budget. Also 3GPP defines reliability as “capability of transmitting an amount of traffic within a predetermined time duration with high success probability. The minimum requirement for reliability is $1\text{-}10_{-5}$ success probability of transmitting over a layer 2 protocol data unit of 32 bytes within 1ms.” MC approach does not always guarantee high reliability due to the scarcity of frequency resources. So different connectivity approaches for varying number of BS and UEs are sampled and the feasibility of prescribed approaches are demonstrated under different load conditions. So far we have come across various approaches in the context of reliability for URLLC services, which includes packet structure for short packet transmission, adaptive modulation and coding for short packet transmission, fast HARQ scheme, wireless caching, edge computing, control channel adaptation, and multi-connectivity.

3.1.5 Problem Formulation

Our problem is to find the feasibility of ultra-reliable operation with MC schemes as stated in our objectives. To do that we define Reliability and latency function as from (1)

$$P_r(\mathrm{SINR}_i < \theta | x) \tag{4}$$

where,θ is the SINR threshold and defined as $\theta = 2^r-1$ given r is the target transmission rate and x is the latency constraint. It means that we relate our calculation with the outage probability as CDF of function SINR_i and is defined as,

$$F_{\mathrm{SINR}_i}(\theta) = P_r(\mathrm{SINR}_i < \theta | x) \tag{5}$$

and the corresponding reliability as Reliability = 1 – $F_{\mathrm{SINR}_i}(x)$. Here, x is the latency constraint and we assume our system model has sufficient bandwidth at fronthaul such that latency deadline is fulfilled in this requirement. According to (1) we can formulate for multi-connectivity schemes as,

$$\mathrm{SINR}_i^{MC} = \gamma_{ii}/(1+\gamma_{ij}) + \gamma_{jj}/(1+\gamma_{ji}) \tag{6}$$

where, γ_{ij} is the SNR at UE_i from BS_j . In this sequel corresponding sum rate is calculated for both SC and MC in intra-frequency multi connectivity as,

$$R_{SC} = \log_2(1+\mathrm{SINR}_i) + \log_2(1+\mathrm{SINR}_j) \tag{7}$$

$$R_{MC} = \log_2(1+\mathrm{SINR}_i^{MC}) \tag{8}$$

Here, R_{SC} and R_{MC} are the corresponding sum rate for SC and MC respectively.

Table 1: System Parameter

Paramater	Value
Bandwidth	100MHZ
BS inner distance	10
Number of BS	2
Noise power	Thermal noise power
Channel	Rayleigh fading Exp(1)
Antenna configuration	1*1
Path loss exponent	3.5
BS cell geometry	Regular circular grid
Cell range	5
Far-field	1

4. Result and Discussions

In this section, we analyze the simulation results to discuss some insights with our system model. Also, we evaluate the system performance in terms of reliability, with schemes. In the analysis, we set α = 3.5 unless stated otherwise. The topology consists of N = 2 BSs centrally located at each cell. Herein, we used a Monte Carlo simulation of 105 runs1. Notice that when there is no MC schemes than the system model resort to connectivity option 1 as discussed earlier. To move forward with the calculation set the following system parameter shown in I and resort to MATLAB to simulate our design system model with the following system configuration shown in table I. Here we have considered assumed statistics based on Monte Carlo simulation as mentioned above .We have taken assumed statistics which mainly depends on required power, as required power increase for low BW requirement .If we consider mm-wave required power may decrease, so it depend on overall requirements of system. Also unit power (1 W) is sufficient for high BW to send data. For small scale fading like Rayleigh, path loss exponent α = 3.5 is considered. In fig (4,5), it is shown that at each run UE1 which is our desired user for the calculation changes its position as indicated earlier in the dashed line of system model approaches the cell edge. Our analysis is based on different UE position and calculation of outage probability, reliability and sum rate with this position.

In fig 9, we evaluate the outage probability calculation for different UE position over different SINR threshold value (for both MC and SC). Also fig 10 we evaluate system sum-rate w.r.t reliability calculation for UE different position (for both MC and SC)

4.1 Outage probability calculation for different UE position over different SINR threshold

It can be observed from fig 6 that as UE1 moves from the center of cell 1 i.e. position 1 towards the edge of the cell in straight line i.e. to position 5, outage probability decreased for multi-connectivity option compared to single connectivity option for a range of threshold value from (-20 to 20), which leads to significant improvement in SINR values i.e. improved reliability

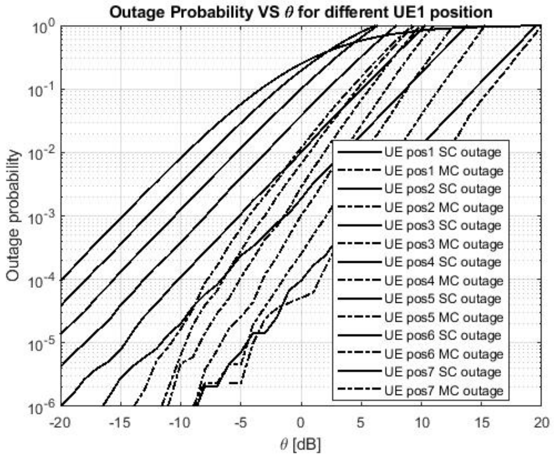

Figure 6: Outage probability calculation for different UE position over different SINR threshold

4.2 System Sum-rate vs Reliability calculation for different UE position

It can be observed from fig.7 that, as UE1 moves from position 1 to position 5, following an intermediate positions, it can be seen that reliability increases for MC compared to SC, that is what we observed throughout the paper, i.e. MC is a feasible solution for ultra-reliable communication. In contrast, the system sum-rate decreases as we move from position 1 to position 5. For UE position 3, we observe that sum-rate value for MC is almost 7.5 whereas for SC it increases to approximately 5, at same position if we observe, reliability, we analyze that value of MC is 0.9 and 0.999 for SC, which shows that reliability increase in case of MC. So we can say trade-off occurs between sum rate and reliability

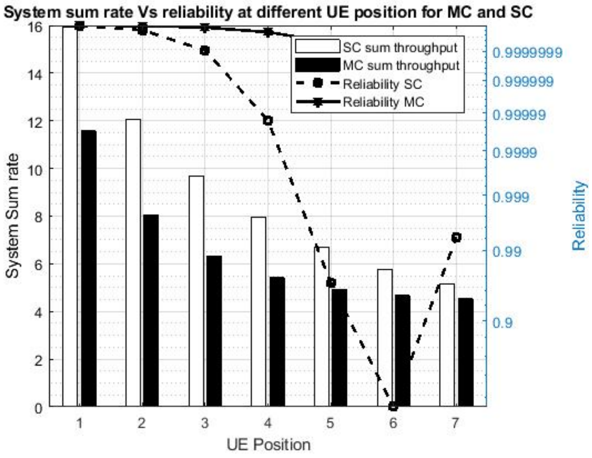

Figure 7: System Sum-rate vs Reliability calculation for different UE position

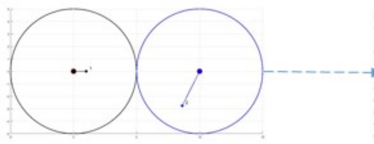

Figure 4 : UE position 1

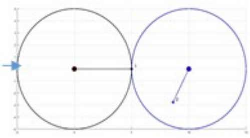

Figure 5 : UE position 7

5. Conclusions

In this paper, we evaluated the performance regarding the reliability of URLLC using multi-connectivity and antenna diversity for transmission in a downlink cellular system to ensure ultra-reliable communication via CRAN. The performance depends on the SINR, desired and interfering distance to UE, path loss exponent. We provided numerical results and discussion by showing outage probability and reliability analysis of the scheme when varying different system parameters. Our results showed that in the case of ultra-reliable operations, MC schemes outperformed the SC w.r.t outage probability and sum-rate. The analysis showed that the outage probability decreases as the UE1 position changes from the center of BS towards the edge of the cell. Finally, in our future work, further analysis will be focused to trace the tradeoff between latency and reliability considering larger diversity matrices and develop reliability and latency relationship metrics. Also we will upscale 4G standard data to further analyze our solution in more efficient manner.

Acknowledgments

The authors are grateful to Department of Electronics and Computer Engineering, Pulchowk Campus, IOE,

TU . Also we owe a great deal to express thanks to Binod Kharel (University of Oulu) and Rabin Kasula (Nepal Telecom) for technical support and guidance.

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