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Radio frequency resource management (RRM) in a multi-connection environment

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Abstract

To elaborate on IRM (Interference Resource Management) issues in a multi-connection environment with emphasis on 5G component carrier management, this paper evaluates system-level simulation approaches. Additionally, it assesses the requirements for ultra-high connection density of IoT devices in mMTC (massive Machine-Type Communications) environments. The research into the proposed solutions has resulted in various publications, conference papers, journals, books, and standards such as ITU for a study regarding the evaluation of 5G. Specifically, this paper presents an in-depth analysis of solutions for better management of networks and services based on intelligent algorithms and techniques in heterogeneous broadband environments of 5th and subsequent generations. This takes into account the current situation and new challenges of networks, focusing on optimizing connectivity and managing the complexity introduced by high-density scenarios typical of 5G deployments. The study integrates advanced modeling and simulation techniques to foresee network behavior under different configurations and usage patterns, aiming to enhance overall efficiency and user experience in 5G networks.

Keywords: Radio Frequency Resource Management (Rrm), Multi-Connection, Environment, networks

Introduction

Leveraging multiple simultaneous connections is a solution to enhance throughput performance per user. It can also be a promising technique for utilizing small cells and millimeter wave (mmWave) cellular systems that suffer from frequent link interruptions due to blockage in ultra-dense urban deployments. There are performance benefits of multi-connectivity strategies, but these remain an open research question. Carrier aggregation is one technique used in LTE Advanced to increase the bandwidth and thereby increase the data rate per user, whereby multiple frequency blocks (called component carriers) utilize multi-connectivity. Each aggregated carrier (component carrier or CC) can have a bandwidth of 1.4, 3, 5, 10, 15, or 20 MHz, and a maximum of five component carriers can be aggregated, hence the maximum aggregated bandwidth is 100 MHz. For 5G, the aggregated bandwidth should surpass LTE's and go up to 400 MHz.

To show the potential of multi-connectivity, a framework for better management has been integrated into a simulation tool and assessed in a load imbalanced scenario. System-level simulations in the 5G era consider demanding use cases with high load and very limited latency in order to cover services such as enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low latency communications (URLLC). As such, appropriate configuration, environment, and network models need to be defined in order to proceed to performance evaluation. The system-level simulation platform is a discrete event simulation environment for the simulation of heterogeneous networks which is extended with new features to support the new functionalities of 5G.

The system-level simulation platform for 5G is a Discrete Event Simulation (DES) environment for the simulation of heterogeneous networks. Also, the platform is extended with new features to support the new functionalities of 5G. The main modules supported are macro cells, small cells, and UEs. Based on the DES approach, created events are the basic Third Generation Partnership Project (3GPP) signaling events, mobility events, application layer events, and system-level events that enable the collection of measurements and the control of auxiliary artifacts (graphics, controls, etc.) as described in the sections that follow. The tool has the potential of simulating various scenarios under different assumptions and conditions. Through the flexibility of available modules, it is possible to customize various parameters. One of the functionalities that was developed for this simulation tool is to be able to deal with multi-connectivity, which aims at being one of the enablers for the wide multi-service behavior of the upcoming 5G networks. With multi-connectivity, a user may aggregate radio resources from more than two network nodes, thus allowing throughput and reliability to be noticeably increased.

Literature Review

Haddad, Majed *et al*. (2011) [1]. Distributing Radio Resource Management (RRM) in heterogeneous wireless networks is an important research and development axis that aims at reducing network complexity. In this context, RRM decision making can be delegated to mobiles by incorporating cognitive capabilities into mobile handsets, resulting in the reduction of signalling and processing burden. This may however result in inefficiencies (such as those known as the "tragedy of commons") that are inherent to equilibria in non-cooperative games. Due to the concern for efficiency, centralized network architectures and protocols keep being considered and being compared to decentralized ones. From the point of view of the network architecture, this implies the co-existence of network-centric and terminal-centric RRM schemes. Instead of taking part within the debate among the supporters of each solution, we propose in this paper hybrid schemes where the wireless users are assisted in their decisions by the network that broadcasts aggregated load information. At some system's states, the network manager may impose his decisions on the network users. In other states the mobiles may take autonomous actions in reaction to information sent by the network. In order to improve the performance of the non-cooperative scenario, we investigate the properties of an alternative solution concept named Stackelberg game, in which the network tries to control the users' behavior by broadcasting appropriate information, expected to maximize its utility, while individual users maximize their own utility. We derive analytically the utilities related to the Quality of Service (QoS) perceived by mobile users and develop a Bayesian framework to obtain the equilibria. Numerical results illustrate the advantages of using our hybrid game framework in an association problem in a network composed of HSDPA and 3G LTE system that serve streaming and elastic flows.

Tarapiah, Saed *et al*. (2015) [2, 3]. Cutting-Edge Radio Resource Management Systems for Wireless and Mobile Technologies for Multiple Access. Volume 4, Issue 3, Pages 165–169, International Journal of Enhanced Research in Science, Technology & Engineering (IJERSTE). Nowadays, there isn't just one Radio connectivity Technology (RAT) supporting wireless connectivity; in fact, 3G cells and WLAN hotspots are beginning to overlap with the vast coverage offered by 2G and 2.5G networks. It follows that studying how to make the most of the plurality of RAT is a no-brainer if we want to make excellent use of the radio resources while still providing consumers with a high quality of service. Common Radio Resource Management (CRRM) is a common abbreviation for this field of study. There has been a lot of research on this issue in recent years, particularly from a theoretical perspective. Still, further research is required into some CRRM areas pertaining to actual implementations and practicality, particularly when it comes to addressing techno-economic difficulties and the processes and functions provided by standardization. Not to mention that the most recent version of the standards has additional capabilities that, when applied to older research, might lead to some exciting new discoveries.

A potential solution to the increasing demand for infrastructure and spectrum in the age of fifth-generation (5G) cellular networks and beyond is network sharing. Open Radio Access Network (O-RAN) features enable Intelligent Neutral Host (INH), a sophisticated technique of network sharing. The difficulty of Radio Resource Management (RRM) in a situation with several operators and slices is discussed in this study. To meet the needs of a wide range of operators, we provide a method that combines Q-learning and deep Q-learning, with a focus on various kinds of Physical Resource Blocks (PRBs). Built as an x App for the Colosseum platform, our algorithm optimises throughput, buffer occupancy, and PRB utilisation, among other real-time KPMs, while adhering to Service Level Agreement (SLA) limitations. To prove that our algorithm efficiently divides up resources across operators' slices in order to meet their SLAs and make the most of those resources, we test it in a complicated traffic scenario. Allotting resources to specific slices effectively while meeting the SLA is shown by the experimental results of our suggested approach. Our method drastically reduces SLA breaches compared to conventional techniques, with eMBB slices seeing a reduction to 2.5% and URLLC slices seeing an elimination of all infractions.

Tarapiah, Saed *et al*. (2015) [2, 3]. In this paper, we will go over all the features and architecture that were explored for the AROMA project in great depth. A variety of Radio Access Technologies (RATs), such as Wireless Local Area Network (WLAN), UMTS Terrestrial Radio Access Network (UTRAN), and GSM/EDGE Radio Access Network (GERAN), are the subject of this project's investigation. The goal is to study and analyse algorithms that best fit the network in order to enable quality of service (QoS) based on the service demand in the network. The corresponding Common Core Network (CN) is considered to provide and satisfy different kinds of services, and different identified services have different QoS. In order to ensure that services are provided with a satisfactory degree of quality of service (QoS), RATs use a set of algorithms known as Radio Resource Management (RRM). There is now a trend towards RATs implementing their own Radio Resource Management (RRM) algorithms separately. Meanwhile, an approach called The Common RRM (CRRM) has been suggested in the literature as a means to optimise the utilisation of radio resources across several RATs. This study examines CRRM solutions, focussing on their implementations in particular. It all started with a review of the current state of the art, followed by a critical evaluation of the most intriguing options, and then, in-depth research into a few of those answers.

Miyamoto, Shinichi *et al*. (2014) [4]. A MAC protocol based on distributed coordination functions (DCF) allows centralised radio resource management (RRM), which in turn improves the transmission performance of wireless local area networks (WLANs). A master controller coordinates the access of linked stations inside the protocol, which involves APs and their affiliated stations working together as a cooperative group. The central controller uses an OFDMA strategy to distribute the allocated radio resources to the stations once the cooperative group has reserved them in a standard DCF-manner. The transmission opportunities may be provided to the relevant stations because the central controller uses opportunistic two-dimensional scheduling to dynamically assign fine-grained resource blocks (RBs) to the stations according to the channel and traffic circumstances of each station. The suggested protocol improves throughput while meeting QoS criteria, according to numerical findings.

Over view of the environment models

5G is poised to support a set of ambitious use cases as mentioned in [3]. For instance, use case families in NGMN include broad band access in dense areas (eMBB), massive Internet of Things (IoT) and MTC as well as ultra-reliable low-latency communications (URLLC). For the needed representation/modeling of such aspects, environment models shall take into account area aspects, traffic, mobility and propagation models based on the classification, which is depicted in Figure1.

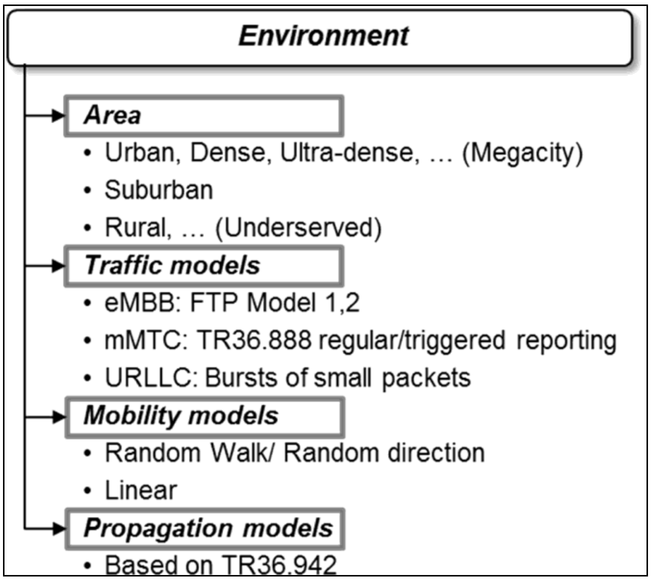

Fig 1: Environment as pects

Area

An area can be characterized by its type, for instance of being Urban, dense or ultradense (e.g. capturing megacity requirements), suburban or evenIrural (e.g. capturing underserved areas). Differentuser and traffic densities areconsidered dependingon the are a type.

Traffic models

1. **mMTC:** 3GPP has defined specific traffic models which consider bursty traffic with regular or triggered reporting The system-level simulator considers three models of m MTC based on TR36.888 [4] and TR 37.868 [5].
2. **eMBB:** 3GPP has alsodefined file transfer protocol (FTP) models with inter-arrival rates followinga Poisson process. The simulator considers FTPI Model 1, 2, 3 for simulatinge MBB-related traffic based on 3 GPPTR 36.814 [8].
3. **URLLC:** Bursts of small packets following beta distribution are considered according to [5, 6].

Mobility models

The following mobility modelswheresupported:

- **Random Walk:** according to this model each UE changes its speed and direction at each time interval. The default value of time interval is 1s, while these values can be configured from the simulator's graphical interface. For every time interval, the direction is chosen from $(0, 2\pi]$, while speed follow sauniformor Gaussian distribution from [0, vmax].
- **Linear Motion:** each UE chooses randomly a direction and moves a ong it, with a constant speed. The UEI continues moving in this direction even if it reaches the cell boundaries due to wrap-around.
- **Random Direction:** each UE chooses randomly a direction and moves along it, with a constantspeed, until it reaches the boundary of the cell. Then, the UE chooses another direction to trave and moves with the same speed untilitre aches the boundary of the cell again.

Pro pagation models

Different propagation models are taken into account depending on whether communication is taking place indoor or outdoor and depending also on the frequency of operation. Propagation modelshave been implemented based on [7].

Network/SimulatedSystemModels

A network/simulated system model consists of access points, backhaul and core entity model. In thiswork, we particularly focus on the access part and the precise modeling of base stations, as depicted in Figure 2.

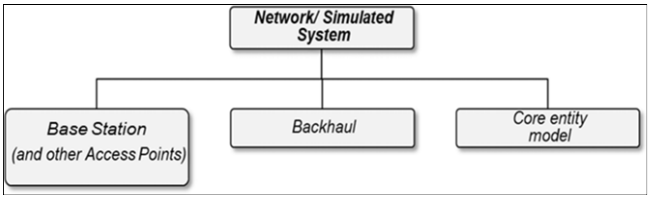

Fig 2: Network Simulated system models

A base station can be characterized by various attributes as depicted in Figure 3. Inparticular, sectorshave transceivers (TRXs) which can bechar acterized by spectrum aspects; PHY/MA Cabstraction and RRM mechanisms. For instance, typical RR Malgorithms such as round-robin, but also research algorithms as mentioned in [8] have beenimple mented in the system-level simulator.

Spectrum as pects

Spectrum aspects include information and imple mentations related to bands and carriers, policies (such as allowed carriers) and licensing schemes (e.g. licensed, light-licensed, License Assisted Access (LAA)-like usage of spectrum etc.).

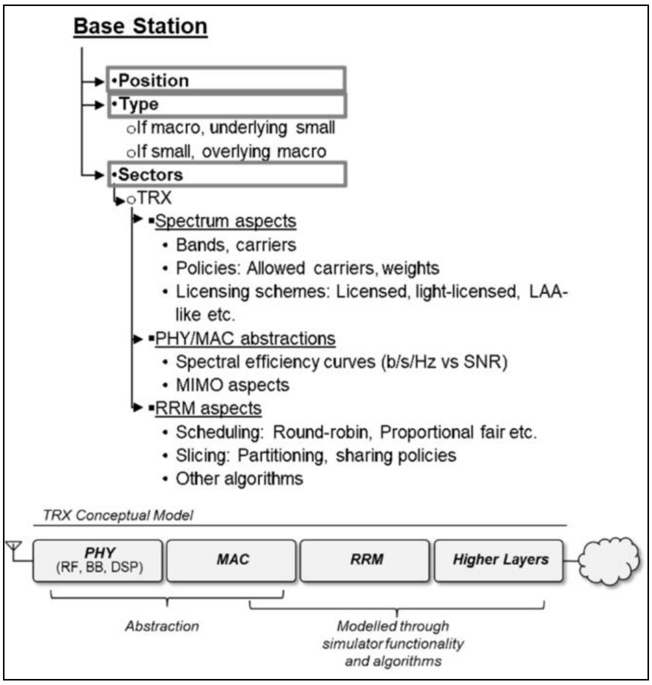

Fig 3: Base station main attributes and TRX conceptual model.

Results

The system-level simulation platform has been calibrated against the reference results of the 3GPPLT Ecalibration campaign [8]. Inthissub chapter, we present the Cumulative Distribution Function (CDF) of coupling loss for 3GPP case 1–2 D and 3 D scenarios.

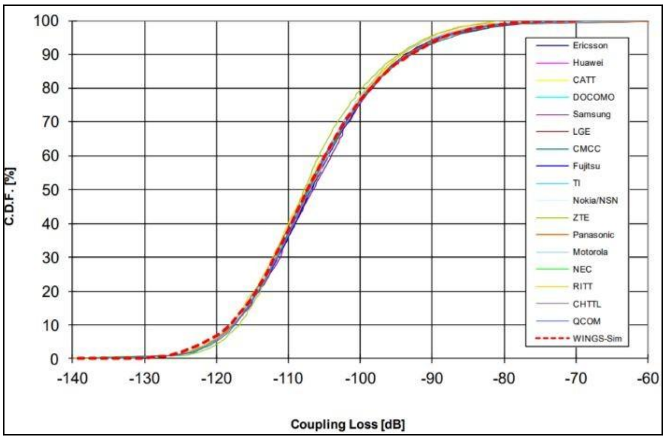

Fig 4: Coupling Loss–3 GPP case 1–2 D scenario

Illustrates the capability of the simulator to assess different IRRM algorithms and test cases (in this case we assumeal gorithm with Qo Spriority, as tate-of-the-art RRM algorith manda random RRM algorithm) as mentioned in [9]. Values of normalized throughput were calculated forvarious test cases.

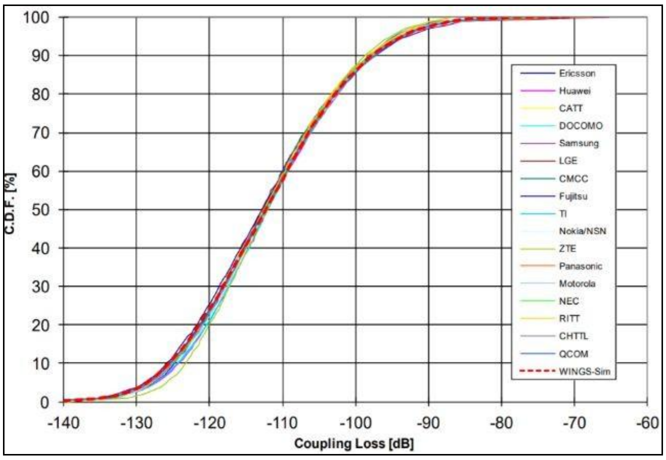

Fig 5: Coupling Loss–3 GPP case 1–3 Dscenario

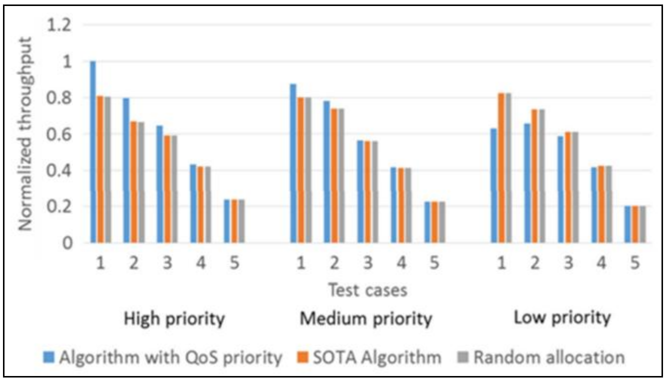

Fig 6: Normalized through put measured for variousal gorithms and test cases.

Illustrates the protocol overhead in terms of average number of retrans missions which have been calculated through the simulator. The figure shows that the one-stage pooled protocol has the lower number of retrans missions for medium arrival rates, while the one-stage protocol (20db) has the greate stper for mance for high arrival rates. In contrast to ARP with many retrans mission sand high overhead, all the proposed protocols show low overheads. In most cases, the MTC devices are low power (use of batteries) and there fore their lifetime is highly affected by the transmission phase. There fore, another important metric is the total number of transmissions per data packets. In the case of one-stage protocos the transmission of preamble and data are realized in one burst, there fore the number of transmissions is minimized. From this figure, it become sclearthat one-stage protocolsare more appropriate for low-power devices since the ymanage to minimize the total transmissions (low number of retrans missions and simultaneously transmission of control and data information) and there fore the total energy consumption. On the other hand, two-stage protocols generate more transmissions, and in order to become comparable to one-stage protocols should retain there transmission numbers in very low values.

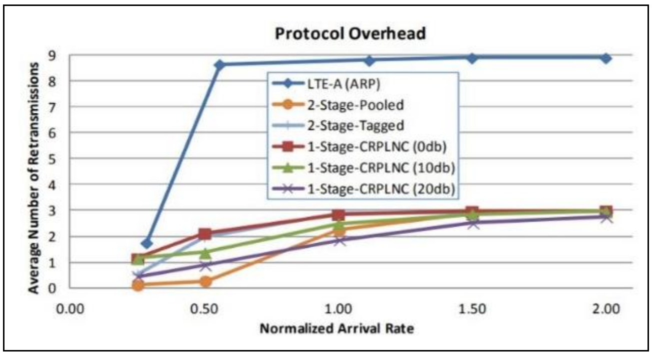

Fig 7: Evaluation of massive access protocol over head

The UE downlink throughput achieved in case a) and case b), respectively, for an increasing number of CCs eventually assigned to UEs following the baseline case (blueline) and using the CCMI(orange line). Both figures show that, given a load imbalance, the proposed approach allows to improve the users' throughput regard less the number of assigned CCs given the joint consideration of each CCRSRQ and loa. In particular, a maximum throughput gain of 40% with respect to the baseline is achieved in case a) when 2 CCs are assigned and a 60% gain is achieved when 3 CCs are considered in the 8-MBI case, which shows the potential of the proposed framework for multi-connectivity management.

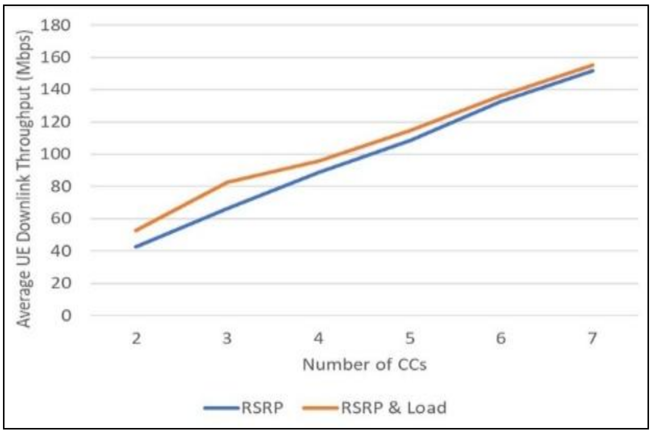

Fig 8: Impact of CCs number to throughput for 20MHz bandwidth and 1 MB file size (case a).

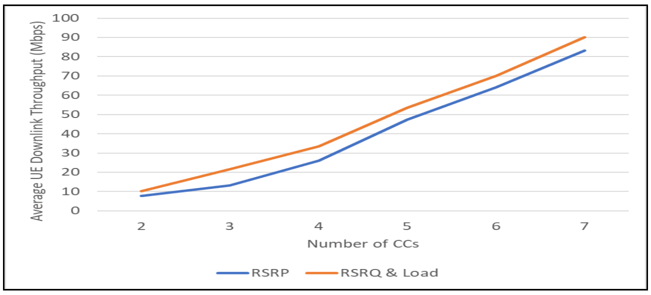

Fig 9: Impact of CCs number to throughput for 20MHz bandwidth and 8MB file size (case b).

Illustrates the result of through put by considering different number of component carriers when using higher bandwidths of up to 100MHz (for taking into account 5 G assumptions of higher bandwidths) for each CC. Similar to previous results, for all values of CC, the RSRQ & load approach achieves lightly higher through put compared to the RSRP.

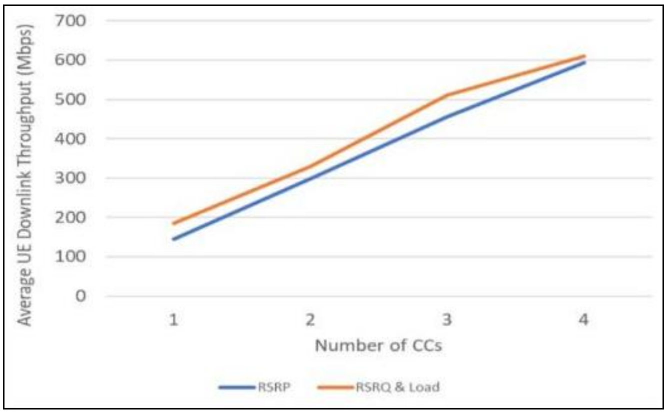

Fig 10: Impact of number of CCs to through put for a bandwidth of 100MHz and file size of 8MB

Simulation

System-level simulations have been conducted for the evaluation of connection density in mMTC environments. Narrowband parameters are taken into account in the simulation. As such, considered band width is from 180KHz up to 1.08MHz. The success rate (i.e. successful transmission of messages) is calculated in order to check the acceptable level of connection density for meeting the threes hold of 99% of success (1% of loss). During the evaluation process, the lower number of the considered message generation frequency (e.g. 1 message/day/device) full fills the requirements of the connection density. The results showed that the 99th percentile of the delay per user was less than 10s for both the 180KHz and 1.08MHz tests. Two configurations for SD of 500m and 1732m were examined during the evaluation. Asa result, the focus was given on the investigation and analysis of the higher message frequency of 1 message/2 hours/device which had a different behavior than the previous.

The success rate for different number of devices when bandwidth of 180KHz Is used. According to the results, it is evident that with such bandwidth, up to 2 million devices per km 2 assuming messages of 32 bytes and 1 message/2 hours/device can be served. When 3 million devices per km 2 were simulated, the success rate dropped below 99%.

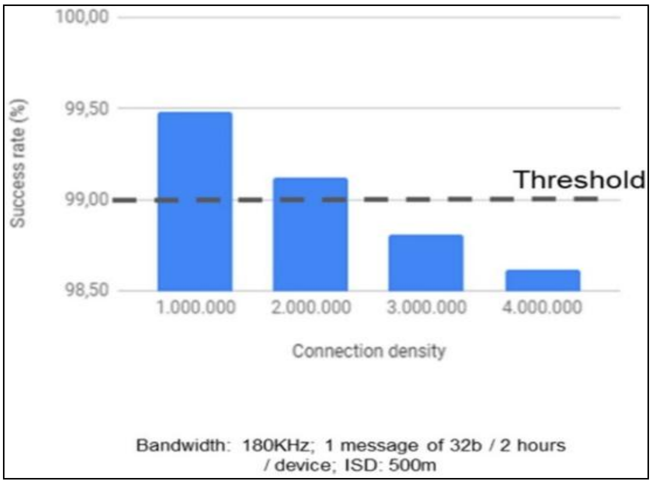

Fig 11: Connection density (nr. of devices per km 2)

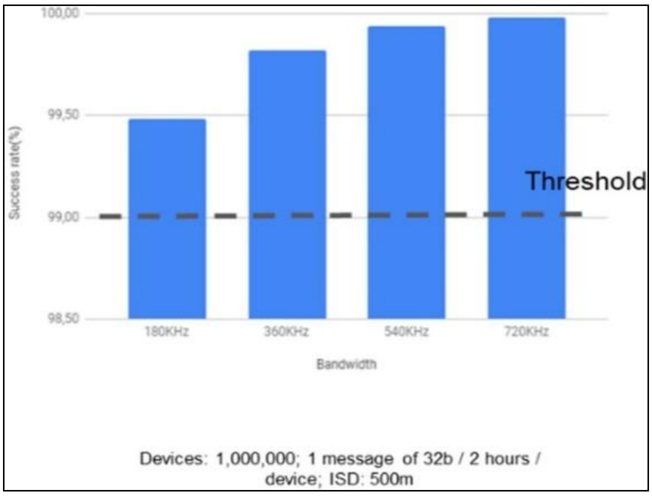

Fig 12: Success rate de pending on bandwidth (ISD500m)

How much bandwidth is needed for serving 1 million devices with 1 message of 32 bytes/2 hours/device as but this time by examining at which level the success rate will reach the highest level. The results show that even from 180KHz, the success rate of 99% is fulfilled and as the bandwidth increases, the success rate is even higher, reaching almost the 100% at 540KHz.

As a next step we changed the simulation parameters to higher ISD value of 1732m and run the same evaluation process as before. Figure 13 shows the success rate for different number of devices when bandwidth of 1.08MHz is used. According to the results, it is evident that with such bandwidth, up to 40 million devices per km2 can be enabled in the area without serious problems assuming messages of 32 bytes and 1 message/2 hours/device.

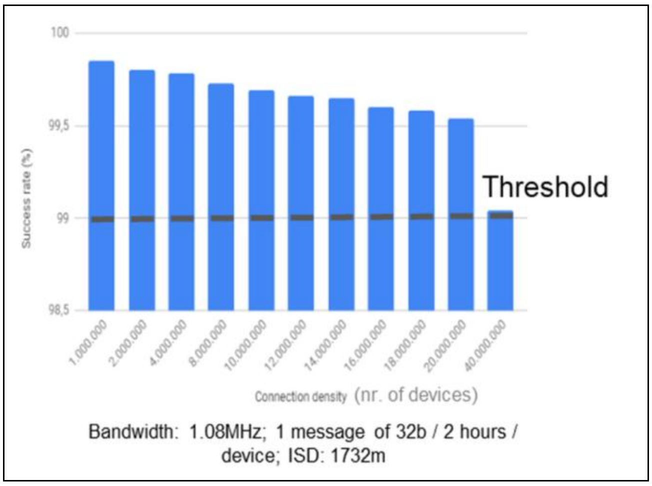

Fig 13: Connection density (nr. Of devices per km2)

How much bandwidth is needed for serving 1 million devices with 1 message of 32 bytes/2 hours/device. The results show that from I500KHz and above, the success rate of 99% is met. However, smaller bandwidths (e.g. 180 or 360KHz) are possible but the success rate is a bit lower than 99%.

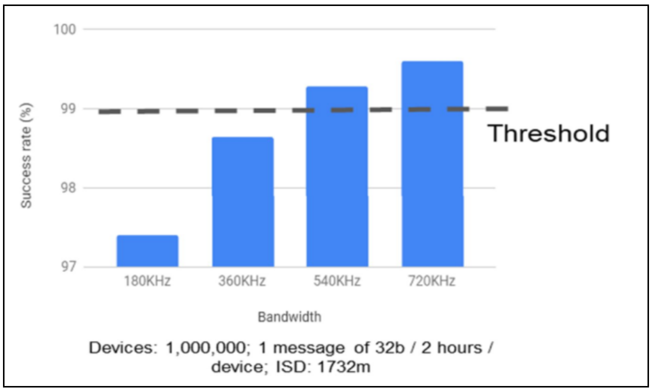

Fig 14: Success rated pending on bandwidth (ISD 1732 m)

Conclusion

This work elaborated on the presentation of the frame work for multi-connectivity, being one of the functionalities to be used to deal with the dissimilarity of service requirements of 5G networks. Simulation results show how a proper assignment of component carriers (CCs) in this situation all ow increasing the users' throughput by up to a 60% when compared to a simple received power scheme for link management. Connection density also plays an important role on 5G and beyond environments. The usage of narrowband technologies is encouraged, especially for small and frequent transmissions. As a result, the provided evaluations consider these assumptions to show the number of devices that can be supported with as pacific QoS. In cases of 180KHz of bandwidth the scenarios of ISD at 500m showed that there were not any major problems for the device density that was considered. In addition, the results for ISD of 1732m reveal that there is a need of higher bandwidths to meet the requirements and achieve the proposed success rates, which in many case smore than three times the initial bandwidth had to be used.

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