Effect of Users' Equipment Capability on Utilization of Heterogeneous Wireless Networks

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***Abstract*—This paper investigates the effect of users' device capability on radio resource utilization in a heterogeneous wireless network consisting of a mixed deployment of non-standalone (NSA) and standalone (SA) 5G network. Existing works in the literature have not considered the effect of users' equipment capability on radio resource utilization the 5G network with mixed deployment of NSA and SA options. Consequently, this paper focuses on the above subject and develops a Markov model to investigate the average utilization in a heterogeneous network having subscribers with different users' equipment capabilities. Simulation results show that users' equipment capability significantly affect the average utilization in a heterogenous network. The study underscores the importance of upgrading users' equipment in a heterogeneous network.**

Keywords—Heterogeneous network, 5G deployment, Radio resource utilization, network selection, users' equipment.

I. Introduction

It is projected that in 2025, 4G will account for about 57% of the global mobile connections while the 5G will account for just about 21% of total mobile connections [1]. Thus, the 4G network and the 5G network will coexist for some time in the future. The transition from 4G to 5G is a significant step for many operators as it impacts and disrupts many areas of the network, and therefore, it needs to be planned carefully [2]. As 5G networks are being rolled out around the globe, network operators are faced with different options in migrating from the 4G network to a unified 5G network. These migration options have been broadly classified as standalone (SA) and non-standalone (NSA) options. Under the SA 5G network, there are three variations defined in the 3rd Generation Partnership Project (3GPP) namely Options 1, 2, and 5. Under the NSA 5G network, there are three variations defined in 3GPP namely Options 3, 4, and 7. The details of the architectural options can be found in [3].

It is possible for a network operator to migrate from the 4G network to the 5G network in one step, using the SA 5G deployment options such as Option 2. However, for most network operators, the migration from the 4G network to a unified 5G network is a multistage process, starting with an NSA 5G new radio (5G-NR) deployment option. Therefore, for a migration path starting with an NSA to a unified 5G network, a network operator would have to support several radio access technologies (RATs) such that service and monetary benefits are enhanced in the transition period [4]. It is during the transition period that a network operator may have a mixed deployment of NSA and SA 5G networks.

For example, an operator may start with the NSA Option 3 as shown in Figure 1 (Phase 1), and later add an SA option as shown in Figure 1 (Phase 2). Thus, for many operators, there will be a mixed deployment of the NSA and SA 5G networks during the period of transitioning from the 4G network to a unified 5G network. In the same vein, network operators transitioning from the 4G network to the 5G network may plan their device transitioning incrementally where the user equipment (UEs) are upgraded sequentially from 4G UE to NSA 5G UE, and then from NSA 5G UE to SA 5G UE. This leads to a situation where the heterogenous network needs to handle UEs of different capabilities [2].

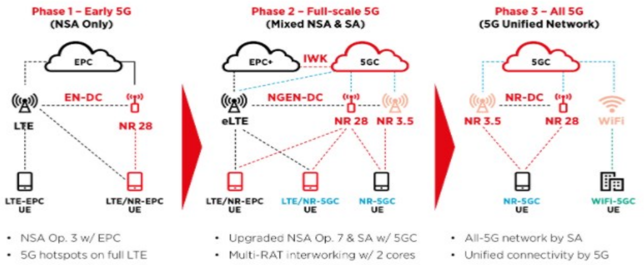

Fig. 1. An operator's migration path from the 4G to a unified 5G network [5].

An important aspect of mixed deployment of NSA and SA 5G network is joint management of radio resources across the different RATs [6]. For efficient radio resource management in the network, the network selection algorithm needs to consider available RATs (LTE, NSA 5G-NR, and SA 5G-NR) and UE capability (terminal modality) in making network selection decisions for UEs. Figure 1 illustrates a multi-stage transition path from the 4G network to a unified 5G network. The mixed deployment stage consists of different RATs, dual core networks (the evolve packet core (EPC) and the 5G core (5GC)), and UEs with different capabilities. As shown in Figure 1, diverse users in the heterogeneous network have UEs with different capabilities. For example, a network subscriber who have just an LTE-capable UE needs to acquire a 5G capable UE to connect to the 5G network whereas a network subscriber who have an NSA 5G capable UE can connect to both the LTE network and the NSA 5G network but unable to connect to the SA 5G network. For connection to the SA 5G network, a network subscriber needs to acquire an SA 5G capable UE.

Some research works have focused on resource allocation in heterogeneous wireless networks. In [7], Ha *et al* have studied the admission control and network slicing design for 5G New Radio (5G-NR) systems in which the total bandwidth is sliced to support enhanced mobile broadband service (eMBB) and ultra-reliable low latency communication (uRLLC) services. They have developed a mathematical framework to analyse the blocking probabilities of both eMBB and uRLLC services. However, mixed deployment of NSA and SA have not been considered in the scheme, and the effect of the of users' equipment heterogeneity and users subscription profiles have not been investigated in the scheme.

In [8], Zhu *et al* have investigated a network selection problem of network users requesting different services as a bipartite graph and propose a network selection algorithm based on weighted bipartite graph matching for a 5G heterogeneous networks, named BGMNS. The proposed algorithm uses the Analytic Hierarchy Process (AHP) and Grey Relation Analysis (GRA) to analyse the preferences of different services for the different networks. The proposed algorithm reduces user blocking probability and total packet loss rate, as well as enhances user average energy efficiency.

In [9], Ma *et al* have proposed an intelligent network selection algorithm for multiservice users in 5G heterogeneous network based on Nash Q-Learning. In the proposed scheme, the authors have used the discrete-time Markov chains to model the network selection and applied both the analytic hierarchy process (AHP) and gray relation analysis (GRA) to obtain user preferences for each network. Simulation results show that the proposed scheme enhances throughput, reduces call blocking probability, and improves users' satisfaction.

In [10], Asad *et al* have proposed a client-centric access device selection for heterogeneous QoS requirements in beyond 5G IoT networks. The proposed scheme allowed IoT nodes to specify their own QoS requirements. For performance evaluation, a hybrid indoor network consisting of Wireless Fidelity (WiFi) and Light Fidelity (LiFi) RATs has been considered. Results shows that the proposed scheme enhances throughput and reduces delay.

In the related works reviewed above, the effect of users' equipment capability has not been investigated in a heterogeneous network consisting of mixed deployment of SA and NSA 5G networks. Therefore, this paper focuses on the above topic. The main contribution of the paper is the investigation of the effect of user equipment capability on average system utilization in a heterogeneous network with missed deployment of SA and NSA 5G network.

The rest of this paper is organized as follows. Section II describes the system model of the heterogeneous network. In Section III, the Markov model is presented. In Section IV, simulation results are presented, and Section V concludes the paper.

II. System Model

A heterogeneous network consisting of a mixed deployment of NSA and SA 5G network is considered as shown in Figure 2. The heterogeneous network supports heterogenous UEs with different capabilities (UE1, UE2, and UE3). The LTE network supports MBB service while the NSA NR and SA NR support MBB/eMBB service. As shown in Figure 2, a user with a UE1 can only connect to the LTE while a user owning a UE2 can connect to the LTE and NSA 5G-NR. A user having a UE3 can connect to the LTE, NSA 5G-NR and the SA 5G-NR.

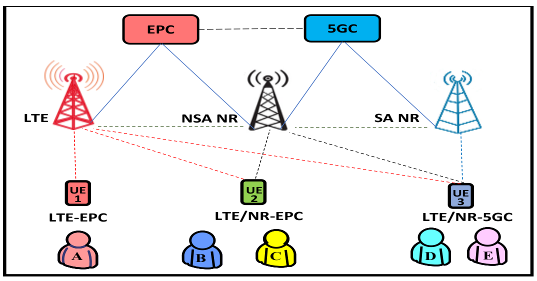

Fig. 2. An example of mixed deployment of NSA and SA 5G Network.

Table 1 shows users with UEs with different capabilities and diverse service subscriptions in the heterogenous network. It also shows possible RATs to which a UE can be connected based on the user's equipment capability and user's service subscription. As shown in Table 1, there are five group of users (A, B, C, D, and E) in the heterogenous network. When a Group A user sends a request for a mobile broadband (MBB) service, the service request can only be accepted into the LTE network or rejected.

TABLE I. Possible Users' Subscriptions in Mixed Deployment of NSA and SA 5G Network

User Group	Equipment	Service Subscription	Possible RAT(s)
A	UE-1	LTE (MBB)	LTE
B	UE-2	LTE (MBB)	NSA LTE
C	UE-2	5G (eMBB/MBB)	NSA (eMBB/MBB) LTE (MBB)
D	UE-3	LTE (MBB)	NSA LTE
E	UE-3	5G (eMBB/MBB)	SA (eMBB/MBB) NSA (eMBB/MBB) LTE (MBB)

However, when an MBB service request arrives from Group B, C, D, or E user, the request can be accepted into more than one RAT. When a service request arrives, from user group B, C, or D, a network selection algorithm attempts to admit the service in the NSA 5G NR but if no resources is available to admit the service, the algorithm accepts the call in the LTE network. Otherwise, the service request is blocked. When a service request arrives from a group E user, the algorithm attempts to admit the service in the SA. If the service cannot be accepted into the SA, the algorithm attempts to accept the service into NSA. If the service cannot be accepted into the SA, the service is blocked.

In the heterogeneous network, it is assumed that MBB and eMBB service requests arrive according to Poisson processes [7, 9] with arrival rates λ_1 and λ_2, respectively. Moreover, the corresponding departure rates of MBB and eMBB services follow Poisson distribution with the average values of μ_1 and μ_2, respectively.

The bandwidth (BW) assigned to the LTE, NSA 5G-NR, and SA 5G-NR RATs are B_L, B_N, and B_S, respectively. In the LTE network, B_L serves the MBB service while in the NSA 5G network, B_N serves the MBB/eMBB service. In the SA 5G network, B_S serves the MBB/eMBB service.

Each BW is divided into a number of sub-channels (SCs) each of which spans over a group of 12 contiguous sub-carriers in the frequency dimension. In the LTE, the bandwidth of a SC is 180 kHz. In the NSA 5G-NR and SA 5G-NR, the bandwidth of a SC corresponding to numerology N^i is 2^{N^i} times of 180 kHz, used in the LTE [7].

III. Markov Model

The network selection policy described in Section III can be modelled as a multi-dimensional Markov chain. The state space of the heterogeneous network can be represented by a (I*J)-dimensional vector given as:

$$\Omega = (m_{ij} : i = 1,2,\ldots I, j = 1,2,\ldots J). \qquad (1)$$

The non-negative integer $m_{i,j}$, denotes the number of ongoing service of type-*i* in RAT *j*. Let *S* denote the state space of all admissible states of the network as it evolves over time. The mixed deployed NSA and SA network considered in this paper is a five-dimensional Markov chain and it is given as follows:

$$\Omega = (m_{11}\ m_{12}\ m_{13}\ m_{22}\ m_{23}\ ). \quad (2)$$

where m_{11} is the number of MBB service accepted into the LTE network; m_{12} and m_{22} are the number of MBB and eMBB services accepted into the NSA 5G-NR, respectively, and m_{13} and m_{23} the number of MBB and eMBB services accepted into the SA 5G-NR, respectively.

Let ⌊ . ⌋ denote the floor operator, the numbers of SCs in the bandwidth (B_L) allocated to the LTE network, $D_1 = \lfloor B_L/180\text{KHz} \rfloor$. The number of the SCs in the bandwidth allocated to service i in the NSA 5G-NR or SA 5G-NR is $\lfloor B_i/(180\text{KHz x } 2^{N_i}) \rfloor$, where n is the numerology used for service of type i [7].

An admissible state, ***s*** is a combination of the numbers of users in each service type that can be supported simultaneously in the network while maintaining adequate QoS and meeting resource constraints. The state *S* of all admissible states in the network is given as:

$$S \in \Omega \mid m_{11}d_{11} \le D_1 \ \wedge \ (m_{12}d_{12} + m_{22}d_{22}) \le D_2 \ \wedge \ (m_{13}d_{13} + m_{23}d_{23}) \le D_3\ ). \quad (3)$$

where $d_{i,j}$ denotes the number of subchannels assigned to service i in RAT j. D_1, D_2, and D_3 are the number of subchannels in B_L, B_N, and B_S, respectively. The constraints simply state that the sum of the subchannels assigned to all admitted type-i service cannot be more than the total number of subchannels available for that type of service(s) in a RAT.

A. Network state transition

Figure 3 shows the state transition diagram for the network. The decision epochs are the arrival or departure of a service.

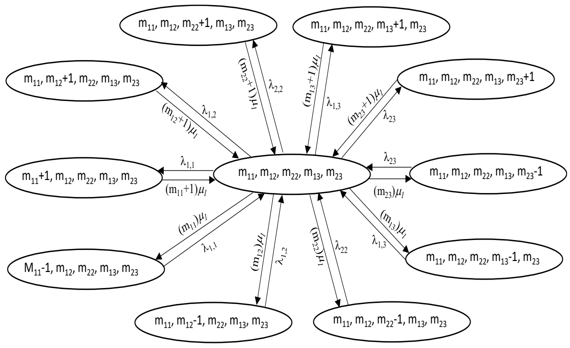

Fig. 3. State transition diagram of the five-dimensional Markov chain.

In the heterogeneous network, network selection decisions are made in the arrival epoch. Whenever there is a service request, network selection algorithm decides which network to accept the service based on the requested service type, UE capability, and user subscription profile. The metric namely average network utilization is used to investigate the performace of the heterogeneous network.

B. Average heterogeneous network utilization

Based on its Markovian property, the network selection process described above be modelled as a Markov chain, from which the average utilization of the network the network can be obtained. Let the traffic intensity type-i service in RAT *j* be donated as ρ_{ij}. Then

$$\rho_{ij} = \frac{\lambda_{ij}}{\mu_i}, \quad (4)$$

The steady state probability, P_s that the system in state, s is given by Equation (5).

$$P_s = \frac{1}{P_0}\prod_{i=1}^{I}\prod_{j=1}^{J}\frac{(\rho_{ij})^{m_{ij}}}{m_{ij}!} \qquad \forall\ s \in S, \quad (5)$$

Where P_o is a normalization constant given by Equation (6).

$$P_o = \sum_{s\in S}\prod_{i=1}^{I}\prod_{j=1}^{J}\frac{(\rho_{ij})^{m_{ij}}}{m_{ij}!}. \quad (6)$$

The average utilization of the network can be obtained by summing up for all the admissible state, s (s ∈ S), the product of the system utilization in a particular state U_s (s ∈ S), and the probability P_s of the heterogeneous network being in state, s. The average utilization U of the heterogeneous cellular network can be expressed as follows:

$$U = \sum_{s\in S} U_s\ x\ P_s. \quad (7)$$

where U_s is total amount of resources (bbu) allocated to all the services admitted into the heterogeneous network at a particular state, s, and P_s is obtained from equation (5). The normalised utilization is obtained by dividing the average utilization (U) by the total resources available in the heterogeneous networks.

IV. Results

In this section, the performance of the network selection algorithm in the mixed deployed NSA 5G-NR and SA 5G-NR network is evaluated with respect to normalized average network utilization through simulation. In the simulation, two types of services are considered, namely, MBB (video streaming) and eMBB (virtual reality). It is assumed that the spectrum efficiency of the 5G NR network is 2 times that of LTE. Thus, in our simulation two SCs (each of 180 kHz) are needed for the MBB service in the LTE network whereas one SC of 180 kHz is needed for MBB service in the 5G NR. Moreover, in the 5G NR, one SC (with bandwidth = 4 x 180 kHz) is needed for the eMBB service. Without loss of generality, it is assumed that the SCs assigned to a service flow will be available for other service flows when the transmission session of the flow has ended [7].

Figure 4 shows the effect of subscribers upgrading their UE1 to UE2 in the heterogeneous network. In this scenario, all the subscribers use MBB service with B_L is 20 MHz, B_N is 80 MHz, and B_S is 100 MHz. As shown in Figure 4, when all the subscribers use UE1, the normalized utilization of the heterogeneous network is very low because UE1 subscribers are confined to the LTE network. However, as more subscribers upgrade their UE1, the normalized utilization of the heterogeneous network increases because the subscribers with UE2 can connect to LTE and NSA networks. Figure 4 shows that after 75% of the subscribers have upgraded their UE1, there is no further significant increase in the utilization of the heterogeneous network.

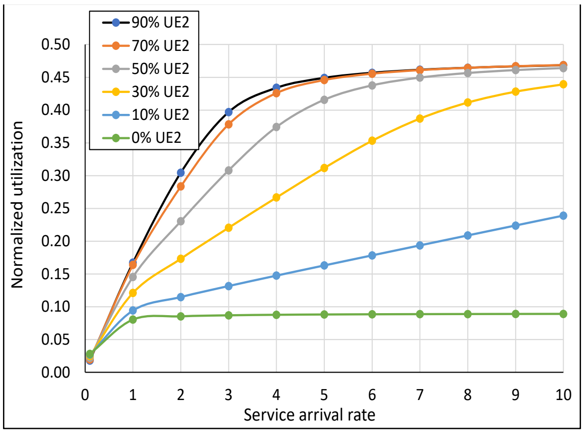

Fig. 4. Effect of subscribers' upgrading UE1 to UE2 on the heterogeneous network utilization.

Figure 5 shows the effect of subscribers upgrading their UE1 to UE3 in the heterogeneous network. In this scenario, all the subscribers use MBB service and B_L is 20 MHz, B_N is 80 MHz, and B_S is 100 MHz. As shown in 5, when all the subscribers use UE1, the normalized utilization of the heterogeneous network is very low (similar to Figure 4) because UE1 subscribers are confined to the LTE network. However, as more subscribers upgrade their UE1, the normalized utilization of the heterogeneous network increases because subscribers having upgraded devices can connect to LTE, NSA, and the SA networks. Figure 5 shows that when 90% of the subscribers have upgraded their UE1 to UE3, the normalized utilization of the heterogeneous network doubles when compared to the scenario in Figure 4, where 90% of the subscribers upgraded their UE1 to UE2.

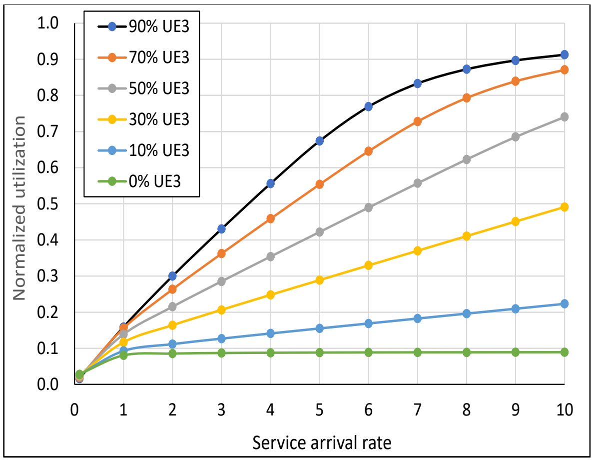

Fig. 5. Effect of subscribers' upgrading UE1 to UE3 on the heterogeneous network utilization.

Figure 6 shows the effect of subscribers upgrading their UE2 to UE3 in the heterogeneous network. In this scenario, all the subscribers use eMBB service, B_N is 80 MHz, and B_S is 100 MHz. As shown in 6, when all the subscribers use UE2, the normalized utilization of the heterogeneous network is very low (about 0.26) because UE2 subscribers having eMBB service are confined to the NSA 5G network. However, as subscribers upgrade their UE2 to UE3, the normalized utilization of the heterogeneous network increases because subscribers having upgraded devices can connect to NSA and the SA 5G networks. Figure 6 shows that after 50% of the subscribers have upgraded their UE2 to UE3, the utilization of the heterogeneous network almost remains the same.

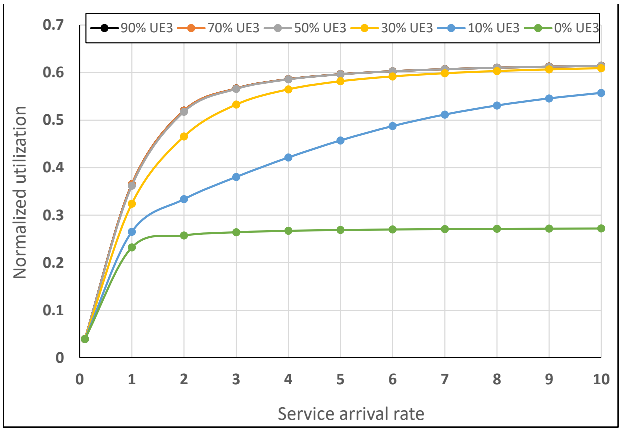

Fig. 6. Effect of subscribers' upgrading UE2 to UE3 on the heterogeneous network utilization.

V. Conclusion

This paper has investigated the effect of users' equipment capability in a heterogeneous network consisting of a mixed deployment of NSA and SA 5G network. A Markov model has been developed to investigate the effect of users' equipment capability on average utilization in the heterogeneous network, considering users with different equipment capabilities. Simulation results show that users' equipment capability significantly affects average utilization in the heterogenous network. Results show that when 90% of the users upgraded their LTE-only-capable devices to devices that support LTE, NSA, and SA networks, the average utilization of the heterogeneous network doubles when compared to the scenario where 90% of the users upgraded their LTE-only-capable devices to devices that support LTE and NSA networks. The study provides useful insight and underscores the importance of upgrading UEs to enhance the average utilization of heterogeneous networks.

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