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THEORETICAL ARTICLE

Adaptive joint call admission control scheme for LTE-A in mobile communication network and its performance analysis

Anupam Gautam[1] · **Selvamuthu Dharmaraja**[2]

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Abstract
In long term evolution-advanced (LTE-A) different radio access technologies coexist due to multi-node receivers and antennas. Under such a scenario, user experience, Quality of Service(QoS), and the loss becomes paramount goal. The main objective of this paper is to develop a new model such that it can serve a heterogeneous network environment and maintain a good Quality of Service. JCAC is a critical scheme for the acceptance in the decision process of accepting an incoming call, relies on certain criteria such as Quality of Service, user experience, and minimization of the cost. If accepted, JCAC decides on the RAT of the interface over which the connection is to be established. The JCAC scheme is introduced in this paper for three inter-RAT interfaces: Best Effort (BE), Non-Real Time (NRT), and Real-Time (RT), based on the measures such as, QoS and network load. To formulate the performance model of the proposed JCAC scheme efficiently, a framework of Generalized Stochastic Petri Nets (GSPNs) is employed. Performance assessment of this GSPN under various real life situations have been discussed, further steady state probabilities are obtained under these cases.

Keywords Joint call admission control (JCAC) · Generalized stochastic petri nets (GSPN) · Wireless networks · Load · Quality of service (QoS) · Resource allocation

1 Introduction

The Fifth Generation New Radio (5 G NR) serves as the evolutionary radio access technology succeeding the Fourth Generation (LTE Advanced), as defined by the Third Generation Partnership Project (3GPP). The primary objective of LTE-A is to

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✉ Anupam Gautam
anupam.gautam@nsut.ac.in

Selvamuthu Dharmaraja
dharmar@maths.iitd.ac.in

[1] Department of Mathematics, Netaji Subhas University of Technology, New Delhi 110078, India

[2] Department of Mathematics, Indian Institute of Technology Delhi, New Delhi 110016, India

enable users to seamlessly access vast amounts of information with enhanced reliability and minimal latency. Moreover, it facilitates data sharing at any time and location, connecting users and various devices or interconnected objects [1, 2].

Unmanned Aerial Vehicles (UAVs) can play a pivotal role in delivering communication services to ground users by either extending or substituting traditional mobile network infrastructure, particularly in disaster scenarios. Various proposals from different authors suggest the deployment of UAV-based networks, ranging from simpler configurations like aerial base stations connected to a 3 G backhaul to more complex hierarchical architectures involving a WiFi access network, a distribution network, and a 5 G backhaul [1].

RADIO Resource Management is responsible for overseeing the functions within the Radio Access Network. It consists of the coordination of the mobile users' links and operations with the core communications network. RRM is critical for maintaining high standards for QoS in wireless network systems [3, 4].

There are different schemes to manage radio resources, depending on the frequency/time handling they develop. Such schemes can include schemes for resource allocation, power and control allocation, and call admission control (CAC) [8]. One of the schemes presented in the array above deserves more attention compared to others due to its increased importance in wireless communication is CAC. The interest is increased by CAC's ability to provide Quality of Service (QoS), including the transmission rate, signal quality, packet delay, drop and call block probabilities, and loss rate.

A critical decision is at the heart of a CAC algorithm: should it accept a new call or handoff into a resource-limited network while maintaining service integrity level agreements given calls that are already admitted. These algorithms are designed to optimize the utilization of available radio resources while ensuring that QoS guarantees are met for all calls that are already admitted, [9].

The primary components of JCAC consist of admission and selection: In admission, the decision hinges on whether to accept new calls based on factors like resource availability and service requirements. In selection, the focus shifts to determining the appropriate Radio Access Technology (RAT) for serving the admitted call, considering factors like network load and Quality of Service (QoS).

A robust JCAC system aims to optimize network resource utilization while minimizing the blocking probability for incoming calls. However, achieving efficient QoS provisioning and resource utilization is particularly challenging due to the heterogeneous nature of networks and limited QoS support in LTE-A networks.

The proposed JCAC scheme outlined in this manuscript assumes a critical role in effectively guaranteeing QoS for each user throughout its traffic lifetime while judiciously managing scarce radio resources.

The rest of the paper is organized as follows. In Sect. 2, we delve into various approaches within JCAC schemes for selecting the best RAT. Then, in Sect. 3, we provide a concise overview of the GSPN modeling technique. Our proposed JCAC scheme takes center stage in Sect. 4. Moving forward to Sect. 5, we formulate a GSPN model and offer a numerical illustration to analyze how well our JCAC scheme performs. To wrap things up, Sect. 6 offers concluding remarks and outlines avenues for future research. Plus, we dive into results and discussions in Sect. 6 to paint a clear picture of our findings.

1.1 Related work

In the order literature, people read different fundamental design considerations for the development of JCAC, referred to as follows;

decentralization, optimization, criterion for the network cell selection, calling type, centricity and prediction, [10].

In like manner [10], a Markov chain model is used in the adaptive JCAC scheme as an example for the heterogeneous cellular networks.

The proactive JCAC proposed for the interface utilizing the interaction is as a result of the load on the RAT.

Data transmissions by non-adaptive JCAC technique in parallel with the heterogeneous wireless network are consequently contrasted in this methodology. In contrast to [12], the optimization model was developed with the semi-Markov decision-making process. UE was assumed to be in an idle mode. Their task was focused on solving RAT selection matters in wireless networks situated in close proximity.

Real-time and non-real-time services were their base and they served them all.

In [13], authors are proposing an optimal Joint Cell and Access Class Control (JCAC) solution for the inter-RAT cell reselection challenge, also known as initial RAT selection within closely situated wireless networks, accommodating both real-time and non-real-time services. The JCAC design is tailored for voice and video traffic, integrating two RAT interfaces-UMTS and LTE [14]. It is designed maintaining the QoS requirements and it is capable of balancing loads between the two. In [15], authors have proposed a CAC in a finite population micro-cell, with retrials of blocked new calls, impatience of subscribers and multiple guard channels dedicated to handoff calls. Steady-state probabilities of the corresponding Continuous Time Markov Chain (CTMC) is obtained, an efficient algorithm giving automatically the infinitesimal generator is formed, and various performance measures are investigated. In [16], a call admission control algorithm is introduced, leveraging inter-network collaboration within a Stackelberg game framework is tailored for cognitive heterogeneous networks. In [17], authors propose a call admission control scheme (CAC) to improve the performance of Coordinated multipoint transmission with the joint trasmission (CoMP-JT)-based cellular systems. In this CAC scheme, the CoMP-JT technique is applied to UEs located near the edge of a cell. To integrate all of these models into a single tool named - Comprehensive Call Admission Control Tool for Next Generation Wireless Networks-(CACTOR). The working of these models and usage of the tool for simulating these models are presented in [17].

The resource reservation is one of the key techniques to ensure the quality of service (QoS) of a multimedia application [18]. In [18], resource reservation and allocation with uncertain demands of mobile users is formulated as a robust optimization model. The conflict between mobility load balancing and mobility robustness optimization caused by the improper operation of the handover parameters is analyzed to achieve dynamical optimization of mobility load balancing in [19]. In [20], an appropriate model for using limited financial resources is proposed to provide better services to achieve a strategic and comparative advantage. These models can be implemented for resource management in CAC as well. An novel hierarchical model is proposed for LTE-A networks in [21]. This model discusses the reliability of LTE-A networks, which improves CAC in long run. In [22], the authors propose a performability model of multi-class CAC in cellular mobile networks. The probabilistic model checking is performed for the analysis of the performability model which is proposed in this work. A composite multidimensional Continuous Time Markov Chain (CTMC) is constructed for the considered CAC scheme containing both performance and failure-recovery events.

In the past, many proposed schemes have primarily focused on coexistence mechanisms, sometimes at the level of individual network elements, without fully optimizing the utilization of all available resources of network.

1.2 Motivation

The main objective of network operators is to optimize network utilization at the same time meeting the diverse communication needs of users by developing various strategies and algorithms. As contemporary and future wireless networks are required with catering to a wide array of user categories and traffic types, which are classified by standardization bodies [9], it becomes crucial to design an efficient CAC which is capable of considering the overall resource situation. It also involves prioritizing users based on their category level and the QoS require by them. Our primary objective is to design an effective CAC scheme which accommodates users with their varying categories and QoS demands.

However, a particular concern in the scenario illustrated in Fig. 1 is the potential bottlenecking of the WiFi access network, mainly due to its common MAC mechanism. Given this situation, if the volume of VoIP traffic surpasses the limit of the drone's Access Point (AP), it would result in a decline in the QoS for all users within the congested Wireless Local Area Network (WLAN). This point of saturation, often termed the Voice over IP (VoIP) capacity of the WLAN which not only requires signal coverage consideration but also, traffic of application-layer and the MAC sub-layer of the WLAN.

1.3 Contribution

This paper presents a novel approach known as JCAC (Joint Connection Admission Control) customized for heterogeneous networks integrating UMTS, LTE, and LTE-A, supported by evolved NodeB (eNB) interfaces. Diverse users and traffic types are methodically categorized within this framework. The efficacy of the JCAC scheme is evaluated through the usage of Generalized Stochastic Petri Nets (GSPN), a modeling technique with an inherent Markov process. Consequently, a Markov process-based JCAC scheme is introduced which employs GSPN modeling to analyze, taking into account the crucial factors such as Quality of Service (QoS), service class, and user experience.

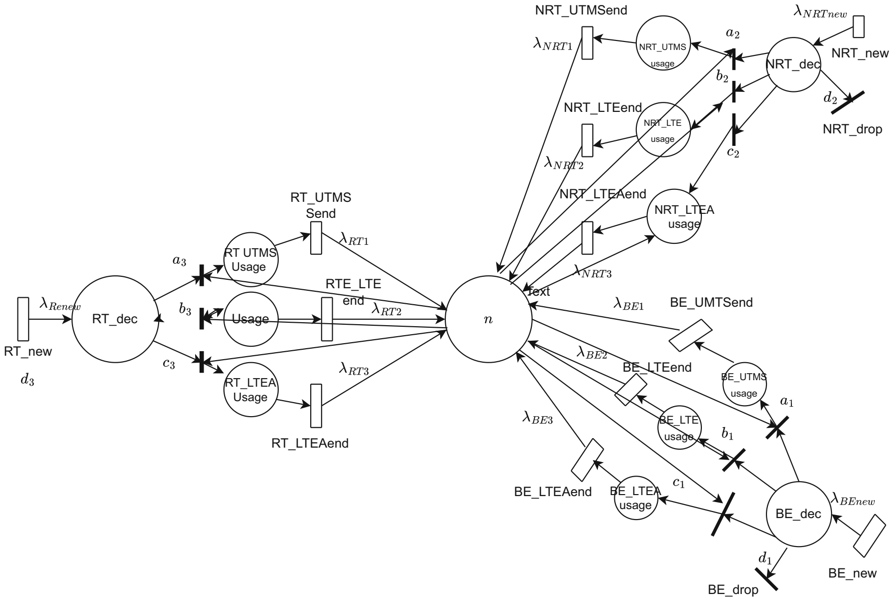


Fig. 1 GSPN model for the proposed adaptive JCAC scheme

To the authors' knowledge, there is a scarcity of literature exploring JCAC schemes employing GSPN modeling techniques, with the exception of reference [14]. However, the cited study does not have consideration for the three distinct data types, and further, it does not perform a thorough performance analysis of the proposed JCAC using GSPN modeling, overlooking to obtain the steady-state probabilities for the considered system.

2 Methods employed in JCAC schemes for RAT selection

Following are the generally used strategies in JCAC schemes: Service cost based, random selection, layer based, network load based, path loss based, cost/utility function based, service class based, computational intelligence based. In this work, the JCAC scheme is chosen to be depending upon the predominant selection based the following two approaches [9, 10]:

- *Network load based*: Based on the interface loads of the accessible RATs, a RAT interface is selected for incoming packets, a topic explored in detail in Sect. 5.
  Advantage: Promotes high network stability through balanced load distribution.
  Disadvantage: Tends to prioritize network needs over user satisfaction.
  To address the aforementioned drawback, a prioritization of RAT interfaces is implemented based on the type of traffic arrival, ensuring adherence to users' Quality of Service (QoS) requirements.
- *Service class based*: Dynamically modifying service classes across all available RATs to evenly distribute traffic load.

Advantage: It enhances the overall user experience
Disadvantage: Network load imbalance
However, the previously mentioned drawback is already taken into account by considering the proposed JCAC scheme, which operates on a network load-centric basis.

The determining factors for the RAT preferences include minimizing service costs, prioritizing security, ensuring optimal QoS, maximizing coverage, and minimizing power consumption. These factors collectively contribute to enhancing QoS and complete user experience.

QoS is of the basic importance from a user point of view. The following QoS requirements are taken into account for admitted calls:

- QoS requirements at the packet level are like latency, jitter, data rate, and packet loss probability.
- Connection level QoS demands, such as, the new call blocking probability, handoff call dropping probability.

Since to analyze the proposed JCAC scheme, a GSPN modeling technique is considered. Thus, before proceeding further, in the next section preliminaries of a GSPN model is discussed in the brief.

3 GSPN

gspn, an extension of Petri nets is a tool that revolutionizes performance analysis through graphical system presentation. While Petri nets adhere strictly to exponential distribution for transition firing times, GSPN introduces flexibility by allowing zero-value firing times, referred as immediate transitions. These immediate transitions hold priority over timed transitions, providing certainty in their execution. They serve to represent instantaneous actions, implement logical operations, and bridge time scale disparities effectively. Consequently, GSPN simplifies the analysis of detailed Petri net models, ensuring both accuracy and accessibility, [29].

In the case of immediate transitions, changes occur instantly. If a single immediate transition is enabled, it triggers, which leads to the corresponding modification in the marking. However, when multiple immediate transitions are enabled concurrently, a metric is essential to determine which transition will modify the marking. To address this, GSPNs assign weights to immediate transitions within the within the identical conflict set. These weights are normalized to obtain probabilities, considering all enabled transitions within the conflict set. As a result, specifying a weight independent of others within the same conflict set becomes impractical.

GSPNs have underlying CTMCs such that Stochastic Petri net models are isomorphic to underlying CTMC model. Hence, an ergodic petri net has ergodic CTMC which guarantees a steady state solution of the model. In this article, we utilize the software package known as SHARPE to derive the numerical results from the GSPN model corresponding to the proposed JCAC scheme, [30]. In the following section, we have discussed that how is this JCAC scheme proposed ?

4 The proposed JCAC scheme

In this study, we have explored a service class and network load-based JCAC scheme for three RAT interfaces: Best Effort (BE), Non-Real Time (NRT), and Real Time (RT). BE traffic, exemplified by peer-to-peer and email applications, it does not heavily prioritize QoS metrics like jitter, packet loss, and latency. In addition, RT traffic, such as online gaming and video calling, is highly sensitive to these QoS metrics and demands prioritization to minimize delays. Consequently, our scheme is customized to prioritize RT traffic over BE and NRT. Further, among BE and NRT, NRT is given precedence over BE.

Service class-based JCAC schemes acknowledge that different RAT interfaces are maade to support distinct service classes, assigning UMTS, LTE, and LTE-A for BE, NRT, and RT data traffic, respectively.

On the other hand, the network load-based scheme make its decisions based on the load present on the network interfaces. It selects the network interface based on the availability of bandwidth.

In this model, on the arrival of a new class of packet at the eNB, the availability of bandwidth is verified. Subsequently, the available bandwidth is assessed to determine if itis adequate for establishing a new connection or not? When the eNB approves the connection, it selects a communication interface mode (e.g., UMTS, LTE, and LTE-A) based on the load distribution on the different interfaces. Hence, the selection of the network interface, as per the proposed JCAC, adheres to Table 1 for admitting newly arriving packets.

Define

L^{s}_{UMTS} : Threshold for UMTS load
L^{s}_{LTE} : Threshold for LTE load
L^{s}_{LTEA} : Threshold for LTE-A load
L_{UMTS} : Load present on UMTS interface
L_{LTE} : Load present on LTE interface
L_{LTEA} : Load present on LTE-A interface

4.1 GSPN model for the proposed JCAC scheme

In Sect. 3, we have briefly introduced the GSPN modeling technique. The GSPN model developed for the proposed JCAC is illustrated in Fig. 1. Although transitions representing packet arrival and service at the RAT interfaces (e.g., $T_{BE_{UMTSend}}$, $T_{BE_{LTEend}}$, etc.) are characterized by various distributions as detailed in Table 2, for simplicity, we assume that they all follows an exponential distribution. This simplifying assumption enables us to model that all timed transitions are under the exponential distribution in the GSPN framework.

Immediate transitions, such as $t_{BE-drop}$, $t_{NRT-drop}$, and $t_{RT-drop}$, are activated when there are no tokens present at place n in the considered GSPN. To get the functionality of the GSPN models within the proposed JCAC scheme, detailed insights can be found in [30]. It is important to note that a token residing in the *bandwidth*

Table 1 Proposed adaptive JCAC scheme

Case	Condition for the selection of an interface	BE	NRT	RT
(i)	$L_{UMTS} < L^{s}_{UMTS}, L_{LTE} < L^{s}_{LTE}$ and $L_{LTE-A} < L^{s}_{LTE-A}$	UMTS	LTE	LTE-A
(ii)	$L_{UMTS} \geq L^{s}_{UMTS}, L_{LTE} < L^{s}_{LTE}$ and $L_{LTE-A} < L^{s}_{LTE-A}$	LTE	LTE	LTE-A
	or	LTE-A	LTE	LTE-A
(iii)	$L_{UMTS} < L^{s}_{UMTS}, L_{LTE} \geq L^{s}_{LTE}$ and $L_{LTE-A} < L^{s}_{LTE-A}$	UMTS	UMTS	LTE-A
	or	UMTS	LTE-A	LTE-A
(iv)	$L_{UMTS} < L^{s}_{UMTS}, L_{LTE} < L^{s}_{LTE}$ and $L_{LTE-A} \geq L^{s}_{LTE-A}$	UMTS	UMTS	UMTS
	or	UMTS	LTE	LTE
(v)	$L_{UMTS} \geq L^{s}_{UMTS}, L_{LTE} \geq L^{s}_{LTE}$ and $L_{LTE-A} < L^{s}_{LTE-A}$	LTE-A	LTE-A	LTE-A
(vi)	$L_{UMTS} \geq L^{s}_{UMTS}, L_{LTE} < L^{s}_{LTE}$ and $L_{LTE-A} \geq L^{s}_{LTE-A}$	LTE	LTE	LTE
(vii)	$L_{UMTS} < L^{s}_{UMTS}, L_{LTE} \geq L^{s}_{LTE}$ and $L_{LTE-A} \geq L^{s}_{LTE-A}$	UMTS	UMTS	UMTS
(viii)	$L_{UMTS} \geq L^{s}_{UMTS}, L_{LTE} \geq L^{s}_{LTE}$ and $L_{LTE-A} \geq L^{s}_{LTE-A}$	Packets dropped	Packets dropped	Packets dropped

Table 2 Different timed transitions and their respective rates

Timed transition	Rate	Value (ms^{-1})
$T_{BE-UMTSend}$	λ_{BE1}	0.1
$T_{BE-LTEend}$	λ_{BE2}	0.2
$T_{BE-LTEAend}$	λ_{BE3}	0.25
T_{BE-new}	λ_{BE4}	0.25
$T_{NRT-UMTSend}$	λ_{NRT1}	0.1
$T_{NRT-LTEend}$	λ_{NRT3}	0.2
$T_{NRT-LTEAend}$	λ_{NRT3}	0.25
$T_{NRT-new}$	λ_{NRT4}	0.25
$T_{RT-UMTSend}$	λ_{RT1}	0.1
$T_{RT-LTEend}$	λ_{RT2}	0.2
$T_{RT-LTEAend}$	λ_{RT3}	0.25
T_{RT-new}	λ_{RT4}	0.25

Table 3 Various immediate transitions and respective weights

Immediate transition	Weight	Value
t_{BE_UMTS}	a_1	3/7
t_{BE_LTE}	b_1	2/7
t_{BE_LTEA}	c_1	1/7
t_{BE_drop}	d_1	1/7
t_{NRT_UMTS}	a_2	1/7
t_{NRT_LTE}	b_2	3/7
t_{NRT_LTEA}	c_2	2/7
t_{NRT_drop}	d_2	1/7
t_{RT_UMTS}	a_3	1/7
t_{RT_LTE}	b_3	2/7
t_{RT_LTEA}	c_3	3/7
t_{RT_drop}	d_3	1/7

place signifies available bandwidth, which is tapped into three interfaces: UMTS, LTE, and LTE-A. On receiving indications of new packet arrivals, the network evaluates the load metrics of all RAT interfaces (UMTS, LTE, and LTE-A), and a selection is performed based on the criteria mentioned in Table 1.

In Table 1, L_{UMTS}, L_{LTE}, and L_{LTEA} represent the load of newly arriving packets, while L^S_{UMTS}, L^S_{LTE}, and L^S_{LTEA} denote the threshold load for the UMTS, LTE, and LTE-A interfaces, respectively. The meanings of all transitions are detailed in Tables 2 and 3.

Furthermore, the GSPN model in the proposed JCAC scheme employs the following notations:

$Bandwidth(n)$: total count of accessible channels within the system
$BE_{UMTSusage}$: total count of accessible ongoing BE data within the UMTS interface
$BE_{LTEusage}$: total count of ongoing BE data within LTE interface
$BE_{LTEAusage}$: total count of ongoing BE data within LTE-A interface
$RT_{UMTSusage}$: total count of ongoing RT data within UMTS interface
$RT_{LTEusage}$: total count of ongoing RT data within LTE interface
$RT_{LTEAusage}$: total count of ongoing RT data within LTE-A interface
$NRT_{UMTSusage}$: total count of ongoing NRT data within UMTS interface
$NRT_{LTEusage}$: total count of ongoing NRT data within LTE interface
$NRT_{LTEAusage}$: total count of ongoing NRT data within LTE-A interface
BE_{dec} : indicates the choice of an interface for data coming as new BE

NRT_{dec} : denotes the selection of an interface for data coming as new NRT
RT_{dec} : denotes the selection of an interface for data coming as new RT.

Various types of traffic typically demand distinct QoS supplies. Real-time services like voice and video requires minimal delay, prioritizing sensitivity to latency, while the main concern for delay-tolerant data service lies in its emphasis on throughput. Benefiting from a centralized architecture, LTE-A networks can serve real-time traffic, non-real time traffic and best effort traffic effectively. Therefore, the proposed JCAC scheme maintains QoS and delay requirements for different data types based on their priority. Such as, real-time data can't suffer delay in comparison to the best effort and non-real time data.

Now, we briefly discusses the operation of the GSPN model depicted in Fig. 1. The firing of markings, such as RT_{new}, signifies the generation of new data packets. In the subsequent section, we discusses the performance analysis of the proposed JCAC scheme. Furthermore, we numerically analyze the obtained performance measures.

5 Performance analysis of the suggested JCAC scheme

Consider the scenario when new Real-Time (RT) data arrives. For the incoming RT data, there are four possible options: it may be assigned to the UMTS, LTE, or LTE-A interface, or it could be dropped due to unavailability of bandwidth. The decision on which option to choose is depends on the load at each data interface, as mentioned in Table 1. To provide a numerical example, values for timed and immediate transitions are presented in Table 2 and Table 3, respectively.

Figure 2 illustrates the probability of the "Bandwidth" place (n) being empty at time t across different token values, particularly for $n = 1, 2, 3$. It indicates the absence of available bandwidth at time t within the corresponding JCAC framework, where unavailability signifies the lack of bandwidth at that moment. Notably, as time progresses, the likelihood of bandwidth unavailability rises.

Additionally, Fig. 3 depicts the anticipated number of tokens within the “Bandwidth” place at time t. Over time, there's a decrease in the expected token count

Fig. 2 Probability [In GSPN, place Bandwidth (n) is empty at time t]

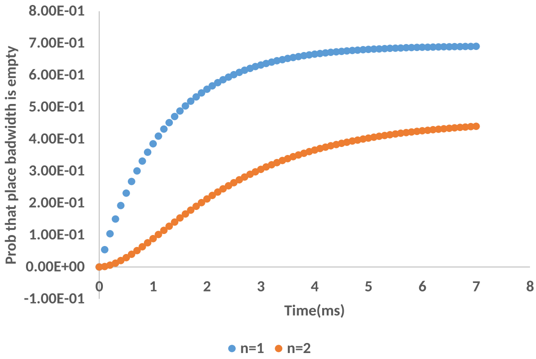
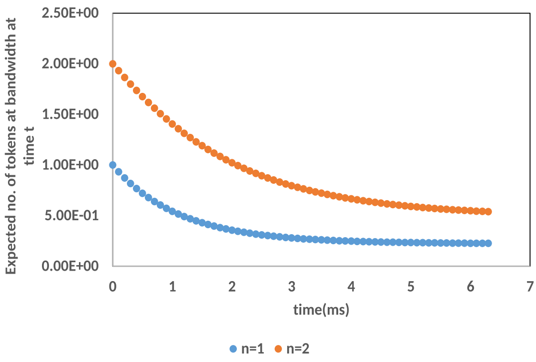


Fig. 3 Expected number of tokens at Bandwidth(n) versus time t



within place n. Furthermore, as the value of n increases, so does the token count within place n.

Consider

$$\begin{aligned} p_{(j)} &:= \text{Probability of new packet is} \\ &\quad \{ \text{ served in Case (j) in steady state, } \text{ where } j \in \{(i), \ldots, (viii)\} \end{aligned}$$

Let us consider a particular case as the following: When $n = 1$, i.e., at place Bandwidth, number of tokens(n) is 1.

- Case(i) When $L_{UMTS} < L^s_{UMTS}$, $L_{LTE} < L^s_{LTE}$ and $L_{LTE-A} < L^s_{LTE-A}$

$$\begin{aligned} p_{(i)} =& \frac{a_1}{a_1+b_1+c_1+d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{b_2}{a_2+b_2+c_2+d_2} \\ & \cdot \frac{1}{\lambda_{NRT2}} \times \frac{c_3}{a_3+b_3+c_3+d_3} \cdot \frac{1}{\lambda_{RT3}} \end{aligned} \tag{1}$$

- Case(ii) When $L_{UMTS} \geq L^s_{UMTS}$, $L_{LTE} < L^s_{LTE}$ and $L_{LTE-A} < L^s_{LTE-A}$

$$\begin{aligned} p_{(ii)} =& \frac{b_1}{a_1+b_1+c_1+d_1} \cdot \frac{1}{\lambda_{BE2}} \times \frac{b_2}{a_2+b_2+c_2+d_2} \\ & \cdot \frac{1}{\lambda_{NRT2}} \times \frac{c_3}{a_3+b_3+c_3+d_3} \cdot \frac{1}{\lambda_{RT3}} \\ & + \frac{c_1}{a_1+b_1+c_1+d_1} \cdot \frac{1}{\lambda_{BE3}} \times \frac{b_2}{a_2+b_2+c_2+d_2} \end{aligned}$$

$$\cdot \frac{1}{\lambda_{NRT2}} \times \frac{c_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT3}} \tag{2}$$

- Case(iii) When $L_{UMTS} < L^s_{UMTS}$, $L_{LTE} \geq L^s_{LTE}$ and $L_{LTE-A} < L^s_{LTE-A}$

$$\begin{aligned} p_{(iii)} = & \frac{a_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{a_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT1}} \times \frac{c_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT3}} \\ & + \frac{a_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{c_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT3}} \times \frac{c_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT3}} \end{aligned} \tag{3}$$

- Case(iv) When $L_{UMTS} < L^s_{UMTS}$, $L_{LTE} < L^s_{LTE}$ and $L_{LTE-A} \geq L^s_{LTE-A}$

$$\begin{aligned} p_{(iv)} = & \frac{a_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{a_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT1}} \times \frac{a_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT1}} \\ & + \frac{a_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{b_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT2}} \times \frac{b_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT2}} \end{aligned} \tag{4}$$

- Case(v) When $L_{UMTS} \geq L^s_{UMTS}$, $L_{LTE} \geq L^s_{LTE}$ and $L_{LTE-A} < L^s_{LTE-A}$

$$\begin{aligned} p_{(v)} = & \frac{c_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE3}} \times \frac{c_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT3}} \times \frac{c_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT3}} \end{aligned} \tag{5}$$

- Case(vi) When $L_{UMTS} \geq L^s_{UMTS}$, $L_{LTE} < L^s_{LTE}$ and $L_{LTE-A} \geq L^s_{LTE-A}$

$$\begin{aligned} p_{(vi)} = & \frac{b_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE2}} \times \frac{b_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT2}} \times \frac{b_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT2}} \end{aligned} \tag{6}$$

- Case(vii) When $L_{UMTS} < L^s_{UMTS}$, $L_{LTE} \geq L^s_{LTE}$ and $L_{LTE-A} \geq L^s_{LTE-A}$

$$\begin{aligned} p_{(vii)} = & \frac{a_1}{a_1 + b_1 + c_1 + d_1} \cdot \frac{1}{\lambda_{BE1}} \times \frac{a_2}{a_2 + b_2 + c_2 + d_2} \\ & \cdot \frac{1}{\lambda_{NRT1}} \times \frac{a_3}{a_3 + b_3 + c_3 + d_3} \cdot \frac{1}{\lambda_{RT1}}, \end{aligned} \tag{7}$$

- Case(viii) When $L_{UMTS} \geq L^s_{UMTS}$, $L_{LTE} \geq L^s_{LTE}$ and $L_{LTE-A} \geq L^s_{LTE-A}$

$$\begin{aligned} p_{(viii)} = & \frac{d_1}{a_1 + b_1 + c_1 + d_1} + \frac{d_2}{a_2 + b_2 + c_2 + d_2} + \\ & \frac{d_3}{a_3 + b_3 + c_3 + d_3} + \frac{d_4}{a_4 + b_4 + c_4 + d_4} \end{aligned} \tag{8}$$

6 Conclusion and future work

This paper discuss and presents a comprehensive analytical framework for the proposed Joint Connection Admission Control (JCAC). The proposed JCAC model considers and integrates three types of RAT interfaces (UMTS, LTE, and LTE-A) and three types of data traffic (BE, NRT, and RT). JCAC is formulated, on the basis of the service class and the considered network load. For $n = 1$, the closed-form steady-state probabilities are derived utilizing the GSPN model for the underlying CTMC. Model sensitivity analysis is presented visually through graphical representation. The primary objective of this work is to deal with the heterogeneous network environment and without compromising the QoS for the user in LTE-A network.

In the future, we plan to expand this research work by incorporating Phase Type distribution for service, particularly to accommodate the bursty nature of RT traffic, which is well-captured by Phase Type distribution due to its heavy-tail characteristics.

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