Priority-Scaled Preemption of Radio Resources for 3GPP LTE Networks

S. M. Chadchan and C. B. Akki

Abstract—**The preemption technique plays an important role in the radio resource management (RRM) of 3GPP Long Term Evolution (LTE) networks. In preemption handling methods, the resource allocation to high priority bearer requests is done by preempting the resources either partially or fully from the low priority preemptable active bearers (LP PABs). The paper proposes the priority-scaled (PS) preemption technique using Allocation and Retention Priority (ARP). The proposed technique suggests the priority-scaled (PS) preemption of resources up to minimum quality of service (QoS) level from all LP PABs. This is in contrast with conventional preemption technique, wherein high priority bearer requests preempt resources completely up to minimum QoS level, with PABs selected in sequence from lowest priority onwards. The paper investigates performance of the proposed technique in terms of number of active bearers dropped and blocked to accommodate higher priority bearer requests. The PS preemption technique reduces the dropping of LP PABs compared to conventional technique for subsequent arrivals of new low priority radio access bearer (RAB) requests, at the cost of QoS by higher priority bearer services. However, the QoS sacrifice made by the high priority PABs is limited to minimum QoS level.**

Index Terms—**LTE, RRM, ARP, CAC, preemption.**

I. Introduction

The Third Generation Partnership Project (3GPP) launched the standardization activity of Long Term Evolution (LTE)/System Architecture Evolution (SAE) to build the framework for 3G evolution towards 4G. The motivation came from the huge traffic requirements of next generation mobile services: high-speed internet access, multimedia online gaming, Fixed-Mobile Convergence (FMC), wireless DSL and mobile TV. The 3G evolution aimed at providing wireless broadband to support all these applications at reduced cost and better performance, besides maintaining seamless mobility, service control and maximizing network capacity with limited spectrum resources [1]-[6]. In release 8, the standardization work has resulted in the specification of the Evolved Packet System (EPS), which contains Evolved Packet Core (EPC) and Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) or LTE Radio Access Network (RAN). EPC constitutes an all-IP, end-to-end architecture for supporting mobile access networks, while LTE RAN performs all radio interface related functions for the terminals. The main objectives of LTE include high data rate, low latency, spectral flexibility, improved coverage, better battery lifetime and cost effective deployment. The design targets for LTE are specified in [7]. To achieve the performance objectives, the 3GPP LTE employs several enabling technologies which include Orthogonal Frequency Division Multiple Access (OFDMA) [8], Single Carrier Frequency Division Multiple Access (SC-FDMA) [9] and Multiple Input Multiple Output (MIMO) [10].

The QoS provisioning has been a key issue in the mobility management of wireless networks, which include wireless LAN, wireless ATM [11], cellular networks [12]-[14] etc. The 3GPP has standardized QoS concept of the EPS in Release 8. The motivation for this concept is highlighted in [15]. It enables service and subscriber differentiation with a set of tools provided to access network operators and service operators. These tools control the packet flow treatment corresponding to a service and a subscriber group. While the service differentiation includes public Internet, VPN, P2P sharing, video streaming, IMS and non-IMS voice, mobile TV etc., the subscriber differentiation includes pre-paid/ post paid, business/standard, roamers etc. [16].

The QoS level of granularity in 3GPP EPS is a Bearer. The data traffic mapped to a bearer is granted identical QoS treatment. The EPS QoS concept is based on two key principles: Network initiated and Class based QoS control. In the network-initiated QoS control, only the network can make the decision to establish or modify a bearer. The network-initiated QoS control paradigm specifies a set of signaling procedures for managing bearers and controlling their QoS assigned by the network. In class based EPS QoS, each bearer is assigned a QoS Class Identifier (QCI). The QCI specifies the user-plane treatment for packets associated with bearer. The network-initiated and class-based QoS concept of the EPS has been aligned with 3GPP's Policy and Charging Control (PCC) framework [17]. It improves the operator’s control over all QoS functions that are distributed across different network nodes.

In order to provide quality of service (QoS) in wireless networks, the role of radio resource management (RRM) is very important. The performance of RRM techniques not only has an impact on the performance of individual user, but also on the overall network performance. The important task of RRM includes – call admission control (CAC), scheduling, rate policing and power control. The CAC, in part of RRM

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decides the acceptance or rejection of service requests, to ensure the QoS of the ongoing calls. The preemption methods are used in case of limited resource conditions. The ARP parameters provide the key attributes for governing preemption of resources. The conventional preemption techniques involve preemption of resources from LP PABs in two phases. The first phase allows preemption of resources by reconfiguring LP PABs up to minimum QoS, with PABs selected in sequence from lowest priority onwards. The second phase allows total preemption of resources from LP PABs, after all of them are reconfigured to minimum QoS. The proposed preemption algorithm suggests the priority-scaled preemption up to minimum QoS during first phase, while the second phase allows the total preemption of resources. The paper discusses the performance of the proposed algorithm in terms of dropping of active bearers and blocking of new bearer requests under different conditions.

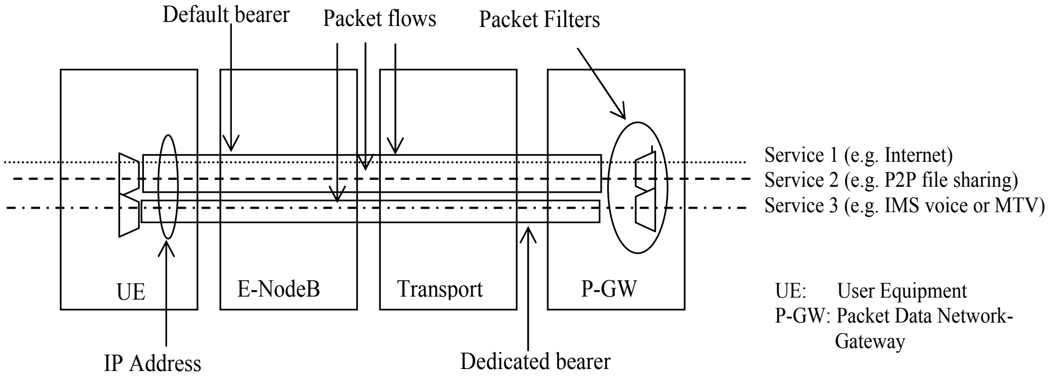

Fig. 1. EPS bearer.

The organization of this paper is as follows. Section II discusses the QoS concepts of 3GPP EPS. It also explains the RRM model and the importance of CAC in QoS provisioning. Section III discusses the preemption handling technique for RRM in LTE. It discusses the conventional preemption method, concepts of the proposed PS preemption method and the detailed algorithm. Section IV deals with the results and discussions. Section V concludes the paper.

II. QoS Concepts and Radio Resource Management in 3GPP EPS

A. 3GPP EPS Bearer

A bearer is the level of granularity in the QoS provisioning of 3GPP EPS and it carries data between user equipment (UE) and packet data networks (PDN) Gateway as in Fig.1. The packet flows mapped to a bearer receives the same packet forwarding treatment, which are specified by - scheduling policy, queue management policy, rate shaping policy, link layer configurations etc. One bearer exists for each combination of QoS class and IP address of UE. To support multiple applications with different QoS specifications, multiple EPS bearers are to be setup in EPS system.

There are two types of bearers: guaranteed bit-rate (GBR) and non-guaranteed bit-rate (n-GBR) bearers. A GBR bearer confirms the value of QoS parameters associated with it and the corresponding service assumes that the congestion related packet losses do not occur. A non-GBR bearer does not confirm bearer QoS values and the corresponding service should be prepared for congestion related packet losses. A GBR bearer is established “on demand”, because it blocks the resources by reserving them during admission control, while a non-GBR bearer does not block resources; hence it can remain for longer duration [16].

The bearer can be either a default or a dedicated bearer. The default bearer is a non-GBR bearer that provides basic connectivity, whose QoS level is based on the subscription data. The dedicated bearer can be either a non-GBR or a GBR bearer. The operator can control mapping of packet flows onto the dedicated bearer and the assigned QoS level through policies that are provisioned into the network policy and charging resource function (PCRF) [17]. The EPS bearer architecture is shown in Fig.2 [18]. While EPS bearers are established between UE and P-GW, the Radio bearers exist between UE and eNodeB. There exists a one-to-one mapping between EPS bearer and Radio Bearer.

B. 3GPP EPS QoS Parameters

The QoS parameters associated with a bearer include: QoS Class Identifier (QCI), Allocation and Retention Priority (ARP), Guaranteed Bit-rate (GBR), Maximum Bit-Rate (MBR)/Aggregate Maximum Bit-Rate (AMBR).

QCI is a scalar value that refers to a set of access node-specific parameters which determine packet forwarding treatment. The standardized QCI characteristics associated with QCI are specified by the parameters: bearer type (GBR or non-GBR), priority, packet delay budget, and packet error loss rate [19]. The standard QCI characteristics ensure same minimum level of QoS for the services mapped to a QCI.

The ARP enables the EPS system to differentiate the control plane treatment related to establishment and retention of bearers. It resolves the conflict in case of demand for network resources. The ARP contains the information: the Priority level, the Pre-emption Capability Indicator (PCI) and the Pre-emption Vulnerability Indicator (PVI). ARP priority level is used to decide whether to accept or reject a request for establishment or modification of bearer in a limited resource condition. The PCI flag indicates whether the bearer request can preempt the resources from the LP PABs. The PVI flag defines whether an active bearer can be preempted by a preemption capable high priority bearer

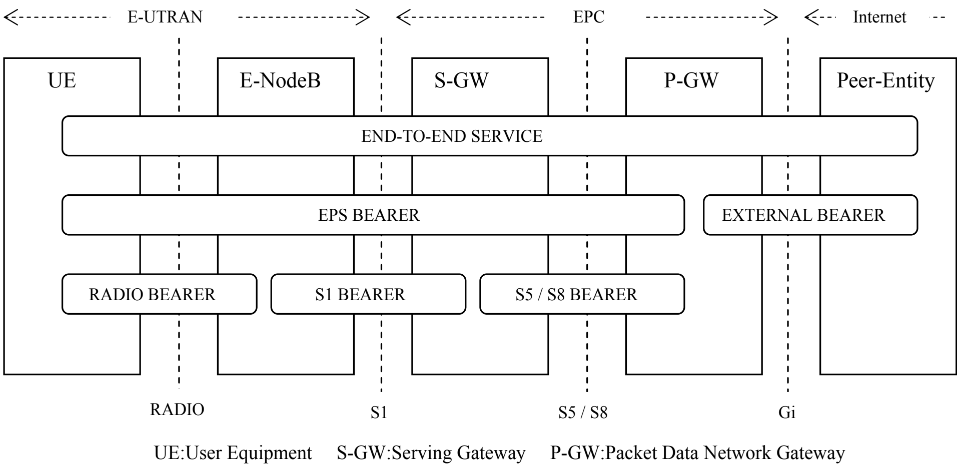

Fig. 2. EPS bearer architecture.

The MBR and GBR are defined only for GBR bearers. While GBR specifies the bit-rate that can be expected to be provided by a GBR bearer, MBR specifies the maximum bit-rate the GBR bearer can support. The Aggregated Maximum Bit-Rate (AMBR) is defined for a group of non-GBR bearers and is intended to enable operator to limit the total bit rate consumed by a single subscriber. AMBR is a session level QoS parameter defined for every PDN connection. Multiple EPS bearers for the same PDN connection can share the same AMBR value. Potentially each non-GBR bearer within a group can utilize whole AMBR, when other EPS bearers are not involved in any data transfer. Thus, the AMBR restricts the total bit rate of all the bearers sharing this AMBR and enables better utilization of bandwidth [16].

C. Radio Resource Management Model

Radio resource management (RRM) plays a major role for QoS provisioning in wireless networks. The RRM in LTE aims at providing multi-class services such as data, audio, video, etc., which have different QoS requirements. The schemes for RRM can be categorized into three categories: The first category includes frequency/time resource allocation schemes such as channel allocation, scheduling, transmission rate control, and bandwidth reservation schemes. The second category includes power allocation and control schemes, which control the transmitter power of the terminals and the base stations. The third category includes call admission control, handoff algorithms, which control the access port connection [20].

As shown in Fig. 3 [20], arriving calls are accepted or rejected access to the network by the call admission control (CAC) scheme based on predefined criteria, taking the network loading conditions into consideration. Traffic of admitted calls is then controlled by other RRM techniques such as scheduling, power and rate control schemes. The Call Admission Control (CAC) [20]-[26] is one of the key components of RRM that limits the number of connections to the system capacity and guarantee the QoS of ongoing calls.

The CAC decides the acceptance of new bearer request, taking into account resource situation in the cell, QoS needs of the new bearer request, QoS levels of active sessions, priority levels of the new requests and the active sessions. A new bearer request is granted resource only if its QoS requirements can be guaranteed, besides providing acceptable service to the ongoing sessions in the cell having same or higher priority. In LTE, eNodeB performs radio admission control to allocate the radio resources.

The preemption technique plays a vital role in the radio admission control of LTE networks, in case of limited resource condition. In preemption handling methods, the resource allocation to high priority bearer requests is done by preempting the resources either partially or fully from the LP PABs. The ARP parameters play a key role in preemption decision making. On successful establishment of a bearer, ARP has no impact on bearer-level packet forwarding treatments (e.g. for scheduling and rate control). Such packet forwarding treatments are determined by the other bearer level QoS parameters such as QCI, GBR and MBR/ AMBR.

III. Preemption Handling Technique for Radio Resource Management

A. Conventional Preemption Handling Algorithm

The Radio resource management based on pre-emption techniques using Allocation Retention Priority (ARP) information are explained in explained in [27, 28]. Whenever a new bearer request arrives, if free resources are available,

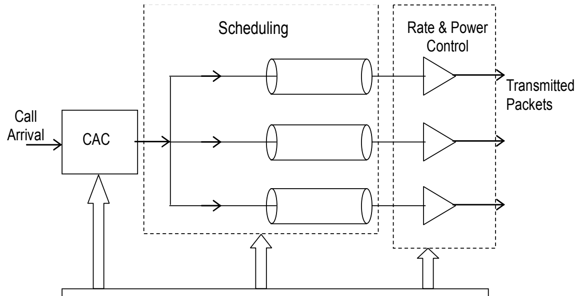

Fig. 3. Radio resource management model.

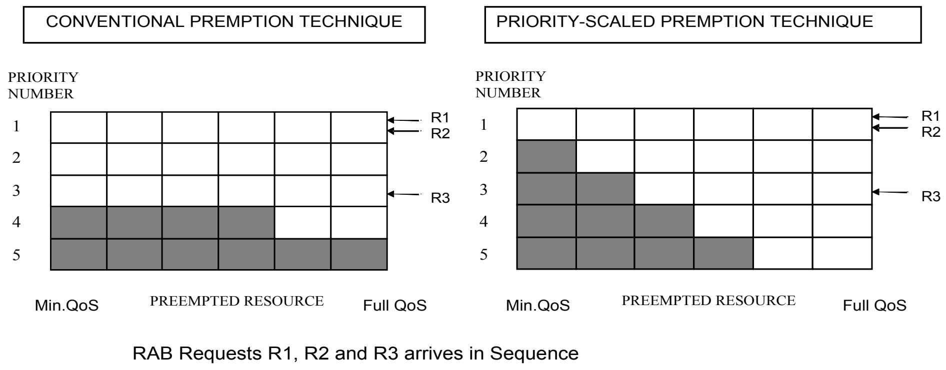

Fig. 4. (a) Conventional preemption technique (b) concept of PS-preemption technique

then resource allocation is done to the new requests by establishing new bearers. If sufficient free resources are not available, the preemption method is employed. In the resource preemption method, the resource allocation to a new preemption capable radio access bearer (RAB) request is done by fully/partially preempting resources from the low priority preemptable active bearers (LP PABs). The conventional preemption technique can be explained with the following steps [27]:

1) Identify PABs (with PVI=1 in ARP) on the network and select the lowest priority bearer among them according to predefined selection criteria. The priority level can be determined by considering priority parameter of ARP value sent by core network.
2) Estimate the gain in radio resources obtained by partial reconfiguration of the selected LP PAB, such that the resource allocation to this PAB reaches minimum predetermined QoS (e.g. minimum bit-rate).The resources from the selected PABs are preempted only if the estimated gain in the resources obtained after partial reconfiguration exceeds the reconfiguration threshold. The purpose of defining the reconfiguration threshold is to limit the number of bearer reconfigurations. The gain obtainable from the PABs is listed in a reconfiguration list.
3) Check if the gain obtained by the preemption of all LP PABs included in the reconfiguration list is sufficient to support the new request.
4) In case of sufficient resource availability, the new RAB request is accepted, by reconfiguring all the LP PABs in the reconfiguration list. Otherwise, repeat steps 1) to 3), until the gain obtained is sufficient to provide the resources necessary to support new RAB request or until all the low-priority bearers are evaluated for minimum QoS.
5) If the total gain obtained by reconfiguration of all LP PABs is not sufficient to support new RAB request, then the option of total preemption of low priority PABs is to be considered.
6) In total preemption option, the LP PABs are selected one-by-one starting from lowest priority one, until the sufficient resource gain is obtained to support new RAB request or till all low-priority active bearers are evaluated for total preemption.
7) If the gain obtained by total preemption of all the selected PABs is sufficient to support new RAB request, the new RAB request is accepted. The new request is rejected if the gain obtained by total preemption of all LP PABs is not sufficient to support new RAB request.

B. Concept of Priority Scaled Preemption of Radio Resources

The conventional preemption technique discussed in previous sub-section, suggests the preemption of LP PABs in two phases. First, preemption of resources from LP RABs by reconfiguring them to minimum QoS, with PABs selected in sequence from lowest priority. Second, adopt total preemption of resources (in case of non-availability of sufficient resources after reconfiguration of LP PABs) by dropping LP PABs, selected in sequence from the lowest priority. Because of complete preemption of resources up to minimum QoS, from LP PABs, the subsequent arriving lower priority RAB requests may possibly face shortage of resources within minimum QoS range as shown in Fig.4.(a).

The illustration in Fig.4 assumes the priority levels ranging from 1 to 5, and the requirement of each RAB to be 5 units. The earlier arriving higher priority RAB requests (R1, R2 of Fig.4.) preempt the resources completely up to minimum QoS from the LP PABs (starting from the lowest priority one). It can possibly leave no room for later occurring lower priority RAB requests (R3) as in Fig.4.(a), to gain resources by reconfiguring LP PABs to minimum QoS. In such case, further LP PABs are to be dropped to accommodate new RABs. It is desirable to avoid the dropping of bearers. This can be achieved to certain extent in the Priority-scaled preemption method.

The PS-preemption method employs the preemption of resources from all LP PABs in a scaled manner based on priority up to minimum QoS level as shown in Fig. 4 (b). This can possibly provide room for later occurring lower priority RAB requests (R3) as in Fig. 4 (b), to reconfigure LP PABs to minimum QoS. It prevents the dropping of LP PABs at the cost of QoS sacrifice by the higher priority bearers. However, the QoS sacrifice of the higher priority bearers is limited upto minimum QoS range only.

C. Proposed Priority-Scaled Preemption Handling Algorithm for 3GPP LTE

The proposed algorithm is based on the invention in [27]. The overview of the proposed PS-preemption handling algorithm for RRM in LTE is shown in Fig. 5. Table-I lists the descriptions of all notations used in algorithm.

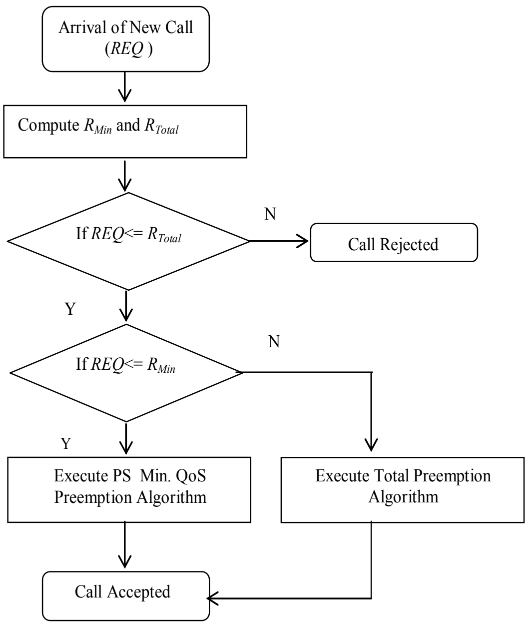

Fig. 5. Preemption handling algorithm for RRM in LTE.

When a new call arrives, the algorithm computes two parameters: R_{Total} and R_{Min}. R_{Min} is the amount of resource that can be obtained by reconfiguring all LP PABs to minimum QoS. R_{Total} is the amount of resource that can be obtained by total preemption of all LP PABs. When a new bearer request with requirement REQ arrives, it is rejected (or blocked) if R_{Total} is not sufficient to satisfy its QoS needs. If the gain obtained by reconfiguration, (i.e, R_{Min}) is sufficient to support new request, then Priority-Scaled (PS) Minimum QoS Preemption Algorithm (PS-MQPA) is executed.

In PS-MQPA (Algorithm-1), the amount of resources preempted from LP PABs is in proportion to their priorities. More resources are preempted from lower priority bearers than higher priority ones, in order to ensure better QoS provisioning to higher priority bearers than lower priority ones. If the gain R_{Min} is not sufficient to support requirements of new bearer request, but the requirements of new request is less than R_{Total}, then Total Preemption Algorithm (TPA) is executed (Algorithm-2). In TPA, the resources are gained by total preemption (by dropping) of LP PABs. In each of the iterations, the algorithm selects the PABs with lowest priority and highest resource, in the list for total preemption.

Algorithm 1: PS Minimum QoS Preemption Algorithm

Step 1: Initialize variables m=15, R=0, C=1.

Step 2: Compute the preemption coefficient for bearer priority "i". $\alpha_i = (i-L)/(m-L)$, for $i = L$ to m.

Step 3: Compute the Gain estimate

$$R_{Gain} = R + \sum_{i=L}^{m} \alpha_i \; R_i$$

Step 4: If REQ > R_{Gain} Then

R=R+ R_m

m= m–1

Goto Step 2

Step 5: If REQ <= R_{Gain} Then

$$C = (REQ - R) \,/\, \left(\sum_{i=L}^{m} \alpha_i \; R_i\right).$$

$$R_{Gain} = REQ$$

TABLE I: DESCRIPTION OF NOTATIONS USED IN THE ALGORITHM.

Notations	Description
$b_i(k)$	Bit-rate to support Min. Qos for k^{th} bearer in i^{th} priority list. (The i^{th} priority list is sorted in descending order for k=1 to n_i).
$B_i(k)$	Bit-rate in excess of Min. QoS for k^{th} bearer in i^{th} priority list.
n_i	Number of bearers in i^{th} priority list.
L	Priority level of new bearer request.
$R_i = \sum_{k=1}^{n_i} B_i(k)$	Total bit-rate in excess to Min. QoS available with all bearers at priority level 'i'.
$r_i = \sum_{k=1}^{n_i} b_i(k)$	Total bit-rate available with total preemption of all bearers reconfigured to Min. QoS at priority level 'i'.
$R_{Min} = \sum_{i=L+1}^{15} R_i$	Total bit-rate available after reconfiguring all LP PABs to Min. QoS.
$R_{Total} = R_{Min} + \sum_{i=L+1}^{15} r_i$	Total bit-rate available after total preemption of all LP PABs.
R_{Gain}	Gain obtained after preemption.
α_i	Preemption coefficient for bearers of priority 'i'. The fraction of resource to be preempted from bearers of priority 'i' during priority scaling.
REQ	Resources required by new bearer (in terms of bit-rate).
$MinQoS$	Minimum QoS expressed as a fraction of total QoS requirement.

Step 6: Reconfiguration of resources and updation of parameters

$\alpha_i = C\alpha_i$, for $i = L$ to m

if m<15, $\alpha_i = 1$, for $i = m$+1 to 15

$B_i(k)$= $(1-\alpha_i)B_i(k)$, for k =1 to n_i , $i = L$ to 15

Step 7: Admit new bearer and update parameters

$n_L = n_L + 1$

$b_L(n_L) = MinQoS \times R_{Gain}$

$B_L(n_L) = (1-MinQoS) \times R_{Gain}$

Algorithm 2: Total Preemption Algorithm

Step 1: Obtain $R_{Gain} = R_{Min}$

Step 2: Sort the arrays $b_i(k)$ in descending order, for k = 1 to n_L in each list of bearers of priority 'i', for i = L+1 to 15.

Step 3: Total Preemption of LP PABs:

$i = 15$

Label1:$k = 1$

Label2:$R_{Gain} = R_{Gain} + b_i(k)$

$b_i(k) = 0$

If $R_{Gain} > REQ$ then go to Step 4

$k = k + 1$

If $k <= n_i$ go to Label2

$i = i - 1$

Goto Label1

Step 4: Admit new bearer and update parameters

$n_L = n_L + 1$

$b_L(n_L) = MinQoS \times R_{Gain}$

$B_L(n_L) = (1-MinQoS)$ x R_{Gain}

Step 5: The excess resource (R_{Gain}–REQ) is redistributed proportional to priority among all active bearers.

IV. Results and Discussions

This section investigates the performance of the proposed algorithm. The experimental results show the effect of priority on dropping and blocking of bearer service [Fig. 6], the effect of change in minimum QoS on dropping of bearer services [Fig. 7], and the effect of priority-scaling of resource preemption on dropping of bearers [Fig. 8]. Several assumptions are made in experiments.

1) All new bearer requests and active existing bearers are preemption capable (*PCI*=1) and preemption vulnerable (*PVI*=1).
2) The priority of bearers range from 1 (Highest priority) to 15 (lowest priority).
3) Initially the entire resource of the system is assumed to be occupied by bearers. Each bearer is mapped to a single service data flow.
4) The number of bearers with a priority value is 10. Hence for priority values ranging from 1 to15, total number of active bearers in the system equals 150.
5) The resource requirement of each bearer is assumed to be fixed (eg., 64 kbps).

A. Effect of Priority on Dropping and Blocking of Bearer Services.

To study the effect of priority, a sequence of bearer requests of a constant priority are input (e.g., priority 12, 8 and 4). The minimum QoS of all the bearers is assumed to be 0.8 (i.e., 80% of the required bit-rate). In an example plot corresponding to priority 12 in Fig. 6, the new RAB requests are accepted by the reconfiguration of LP PABs to minimum QoS for 6 requests, and by the dropping of LP PABs till 30 requests. Thereafter, the new requests are blocked. The higher the priority (as in priority number 8 and 4) of the new RAB requests, the dropping of LP PABs and blocking of new bearer requests are reduced, due to more resources available for preemption from the LP PABs.

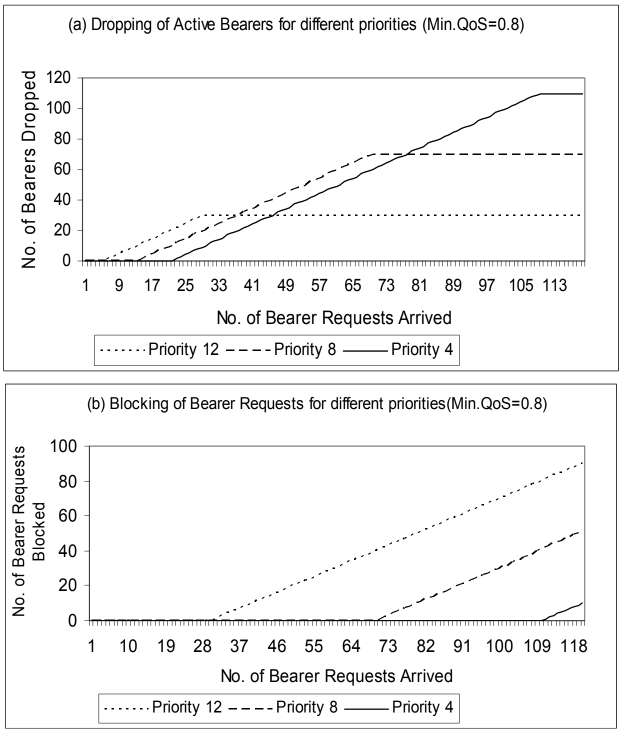

Fig. 6. Effects of priority on (a) dropping and (b) blocking of bearer services.

B. Effect of Minimum QoS on Dropping of Bearers.

To study the effect of variations in minimum QoS, the bearer requests of a constant priority (i.e., priority 8, 12) are input in sequence as in Fig.7. The dropping of bearers begins with the arrival of bearer request numbers 7, 13 and 19, of priority 12, for minimum QoS values 0.8, 0.6 and 04 respectively. The higher the minimum QoS value, the lesser is the resource available for reconfiguration; hence the dropping of the bearer starts earlier.

C. Effect of Priority Scaled Preemption of Resources on Dropping of Bearers.

The input consists of a sequence of bearers of priority 1 to 15. As seen in Fig. 8, the dropping of LP PABs in case of conventional preemption method starts with the arrival of bearer request number 8 and 11 for minimum QoS values 0.9 and 0.8 respectively. In case of PS preemption method, dropping starts at bearer request number 9 and 12 for minimum QoS values 0.9 and 0.8 respectively. It is seen that the dropping of the bearer begins earlier in conventional preemption technique than in PS-preemption technique. This is due to more resource availability in LP PABs in the PS-preemption than in conventional preemption method, which is due to QoS sacrifice made by higher priority bearers.

V. Conclusion

The preemption handling technique has a key role in the radio resource management (RRM) of 3GPP LTE networks to guarantee QoS requirements of user services. The paper proposed the priority-scaled (PS) preemption technique using Allocation and Retention Priority (ARP). The proposed technique suggests the priority-scaled (PS) preemption of resources up to minimum QoS level, from all LP-PABs,

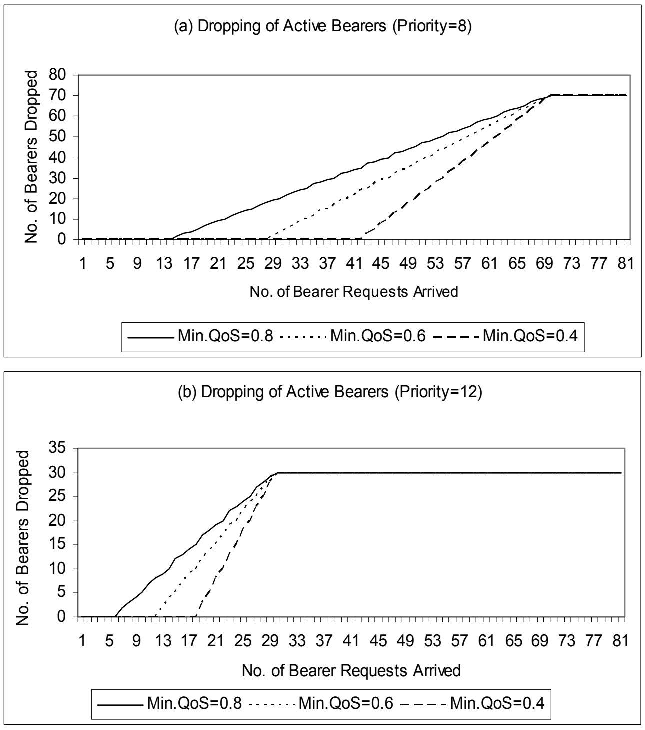

Fig. 7. Effects of Minimum QoS on dropping of bearers for the arrival of bearer requests of (a) Priority = 8 (b) Priority = 12.

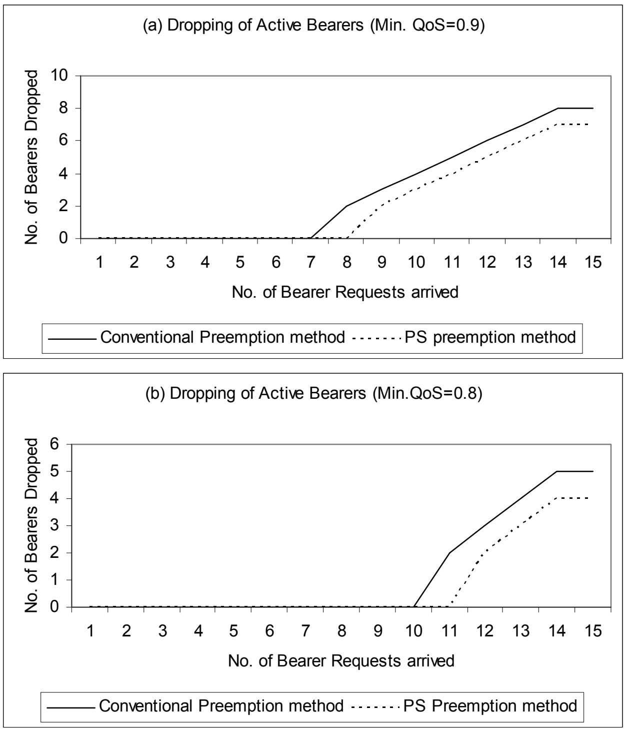

Fig. 8. Effects of priority-scaled preemption of resources on dropping of bearers for (a) Min. QoS = 0.9 (b) Min. QoS= 0.8.

instead of complete preemption of resources up to minimum QoS level (as in conventional method). The performance of the proposed technique is investigated in terms of numbers of active bearers dropped and blocked to accommodate higher priority bearer requests. It also discussed the effect of variations of minimum QoS and priority scaled preemption on dropping of active bearers. The PS preemption technique shows better performance in terms of dropping of bearers than conventional technique, in case of subsequent arrivals of new low-priority RAB requests. It costs the QoS of higher priority bearer services, which is limited to minimum QoS level.

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