Enhancing Service Provisioning within Heterogeneous Wireless Networks for Emergency Situations

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Abstract. Emergency situations where lives are at stake, such as natural disasters, accidents, or serious fire, require low reaction times. Especially in sparsely populated areas the distance between the nearest emergency station and its disaster location may be quite large. In order to minimize reaction times, emergency communication is to be prioritized with respect to other network services. For enabling efficient and privileged usage of available network resources for emergency services, we propose to handle diverse service requests, ranging from emergency voice calls to bandwidth-consuming streaming services for emergency news, collaboratively by a Joint Call Admision Control (JCAC) and Dynamic Bandwidth Adaptation (DBA) approach. Therefore, we introduce a novel utility definition of services. It represents a generic measurement of the provided level of importance of the emergency service with respect to the common utility, i.e. the utility of service provisioning for the population. The designed JCAC and DBA algorithms cooperatively manage resources of heterogeneous wireless networks and aim at supporting a maximum number of requested services. Further, system utilization is optimized by improving the QoS characteristics of the already granted, elastic services. Simulation results show an improvement in the overall gained utility for emergency services compared to other research approaches.

Keywords: Joint Call Admission Control, Dynamic Bandwidth Adaptation, Utility, Heterogeneous Wireless Networks.

1 Introduction

Common Radio Resource Management (CRRM) is a key concept for efficiently managing radio resources of co-deployed heterogeneous Radio Access Technologies (RATs), yielding enhanced Quality of Service (QoS) provisioning and system utilization. In the proposed concept, two of the main CRRM functionalities are considered: Joint Call Admission Control (JCAC) and Dynamic Bandwidth Adaptation (DBA). In contrast to Call Admission Control (CAC) in homogeneous RATs, JCAC does not only determine whether an incoming service is

R. Popescu-Zeletin et al. (Eds.) AFRICOMM 2011, LNICST 92, pp. 14–23, 2012.

admitted or not, it is moreover able to decide in which RAT the respective service should be deployed. However, JCAC has to take different service and RAT characteristics into account, while ensuring a minimum level of QoS of the admitted services. JCAC and DBA have been in the focus of many research projects in recent years, e.g. [1], [2]. In [3], a generic approach for admission control is presented that mainly focuses on bandwidth adaptation. QoS parameters are taken into account by the bandwidth usage $b_{service}[\frac{\mathrm{bit}}{\mathrm{sec}}]$ and the utility function is represented by a mapping of the utility vs. the perceived service performance. In [4], a novel approach for combined JCAC and bandwidth adaptation is proposed which enhances the average system utilization, QoS, and reduces blocking and dropping rates in heterogeneous wireless systems. It is based on a Markov chain model and shows an improvement of up to 20% in terms of system utilization compared to a system without JCAC. However, none of these approaches takes emergency situations into consideration. We propose a novel JCAC and DBA approach that aims to improve the overall common utility increasing the overall system utilization and that takes the different QoS demands of various services, such as elastic, best-effort traffic or non-elastic, voice communication, into consideration. An example for elastic best effort services are streaming services with emergency announcements and an example for fixed bandwidth voice services are conventional emergency calls. The main objectives of the proposed approach are to maximize the common utility of all deployed services and the system utilization of co-deployed RATs by dynamically adjusting the conceded QoS demands of elastic services. Furthermore, our approach aims at achieving a homogeneous traffic load distribution among the deployed RATs and avoiding RAT overload, while ensuring minimum QoS requirements on the connection level for admitted services. This makes it possible to serve a large number of emergency-related services.

The present paper is organized as follows. Section 2 presents the joint JCAC and DBA approach. In section 3, the simulation platform, which has been developed to evaluate the proposed algorithms, is described. The applied simulation parameters are included, and an evaluation of simulation results is given. Finally, the paper concludes with section 4.

2 Joint JCAC and DBA

The following section introduces the designed concepts. It depicts prerequisites and the simulation model, the developed JCAC and DBA algorithms, and their collaboration.

2.1 Prerequisites and System Modeling

In the present work, we assume a scenario in which the cells of 2 heterogeneous RATs, that partly share the same core network entities, such as High Speed Packet Access (HSPA) and Long Term Evolution (LTE), are co-deployed in the same service area. The radio resources of all Radio Access Networks (RANs) are managed commonly by a central entity. Each of the considered RATs uses different radio transmission schemes for service data transmissions, and manages and allocates different types of radio resources. In order to generalize these RAT-specific radio resources and to create a basis for common radio resource management decisions, an *effective bandwidth usage* measure is introduced. Each cell can provide a maximum effective bandwidth that can be allocated to the requested services. Spatially co-deployed cells of different RANs form a group of co-located cells, a so-called *cell area*, that is used as target for new or handover services.

In our model, mobile terminals are characterized by their prioritization class, a randomly chosen dwell time that expresses the duration it is located within one cell, and the number and types of requested services. In the following, we assume that all mobile terminals are multi-mode terminals that are capable of supporting all deployed RATs in the service area. Mobile terminals are able to suuport different services that are required for emergency situations, like conventional cellular phones that are used by first-aid services up to screens that are used to display the latest information of the emergency area.

Further, two kinds of services are considered: *elastic services* and *non-elastic services*. The QoS characteristics of the latter ones are expressed by a range of effective bandwidth values in the range of $b_{min} \leq b_{desired} \leq b_{max}$. The minimum effective bandwidth value b_{min} expresses the minimum value that is required to deploy a service, specified by the minimum QoS demand of the application; whereas b_{max} describes the maximum effective bandwidth value the RAN grants to a service. $b_{desired}$ is defined by the application and describes the level of effective bandwidth that is required to execute the service at a satisfactory Quality of Experience (QoE) level. In contrast, the non-elastic services are fixed with respect to their QoS requirements and, thus, with respect to their required effective bandwidth, i.e. $b_{non-elastic} = b_{min}$. Further, each service class is defined by its service duration and its pause time which expresses the time between two service requests of the same application class.

2.2 Utility Concept

The basic ideas of the utility concept are taken from the field of micro-economics. The term *utility* represents a measure of relative satisfaction and is modeled by the consumption of different goods or services. In the present work, it represents a generic measurement of the overall provided utility of the different services that are required in an emergency situation. In the present case one Mobile Network Operator (MNO) is in charge of the respective RANs. All parameters are related to the Service Level Agreement (SLA) between the devices and the MNO, that also defines services that can be deployed within the network. It is assembled by utility functions that need to take several factors into consideration, which are set by the policies of the MNO and the services requested by the terminal. In general, the utility $u_{i,j}$ for service j deployed in RAN i can be stated as follows:

$$u_{i,j} = U(a_j, \pi_j, \rho_i), \quad (1)$$

where

- a_j: application utility function, that depends on the QoS parameters of the requested service and the current effective bandwidth usage b
- π_j: priority factor, that represents the priority level of the User Equipment (UE) defined by the SLA
- ρ_i: RAN factor that is to be set by the MNO policies; the higher the value the higher the utility for the session in the specific RAN

In the considered scenario, the utility function is assembled by the following utility function

$$u_{i,j} = a_j(b) \cdot \pi_j \cdot r_j, \tag{2}$$

where the utility function of the service depends on the service properties (cf. [3]). Elastic services follow an exponential function (see equation 3), whereas non-elastic services are represented by a step function (see equation 4):

$$u_{elastic}(b) = 1 - e^{-\frac{k \cdot b}{b_{max}}} \tag{3}$$

$$u_{non-elastic}(b) = \begin{cases} 1 & b \geq b_{min} \\ 0 & b < b_{min} \end{cases} \tag{4}$$

2.3 Overall Concept

The handling of all incoming and handover service requests is performed in a bundled manner, i.e. the incoming and handover service requests are queued and the DBA and JCAC algorithms are performed each $TTI_{semipersistent}$ for all cell areas in a central entity. $TTI_{semipersistent}$ denotes the time interval between two runs of the joint DBA and JCAC algorithms. The sequence of algorithm steps is as follows:

1. DBA, *Bandwidth Adaption Arrival:* Check if enough resources are available in the system for the incoming requests (new services and handover services)
2. JCAC, *Serve Handover Services:* Handle the queued handover services first
3. JCAC, *Serve New Services:* Handle the new queued services secondly
4. DBA, *Bandwidth Adaption Departure:* Assign the remaining capacity to the services with elastic traffic in order to increase system utilization

2.4 JCAC Algorithm

The following section introduces the suggested JCAC algorithm that is handled as a General Assignment Problem (GAP).

The GAP belongs to the class of bin packaging problems in which N items (S) need to be assigned to M bins (B) (knapsacks). Each bin i has a certain capacity c_i and each item j has a weight $w_{i,j}$ and utility $u_{i,j}$, respectively, depending on the bin. The objective is to find a subset of $U \subseteq B$ of items that can be placed in the bins B, in a way that the overall utility z is maximized. The mathematical definition of the problem is:

$$z = \max \sum_{i=1}^{m} \sum_{j=1}^{n} u_{i,j} \cdot x_{i,j} \tag{5}$$

$$\text{s.t.} \sum_{j=1}^{n} w_{i,j} \cdot x_{i,j} \leq c_i \ \ \forall i \in M = \{1, \ldots, m\} \tag{6}$$

$$\sum_{i=1}^{m} x_{i,j} = 1 \ \ \forall j \in N = \{1, \ldots n\} \tag{7}$$

$$x_{i,j} = \{0, 1\} \ \ \forall i \in M, j \in N \tag{8}$$

$x_{i,j}$ indicates whether item j is assigned to knapsack i ($x_{i,j} = 1$) or not ($x_{i,j} = 0$).

In the present work, the cells represent the bins, where their capacity c_i is represented by the maximum amount of effective bandwidth. Services are considered as items. The weight of a service is represented by the effective bandwidth usage of the service, which is an input parameter for the utility calculation for the referring service. These relationships allow for reusing existing approximative algorithms with good run-time characteristics. We choose the approach of [5] as a suitable solution. The algorithm itself is split in two main parts: an *outer* and an *inner* algorithm. The first one (see algorithm 1) decomposes the GAP into M 0-1 knapsack problems for which a variety of approximative algorithms exists, see [6] for more information. It requires capacity information of all cells, C, the weight and utility information that depends on the respective RAN for every bearer, W and P, respectively, and returns the assignment vector T which contains the index of the cell in which the respective service is to be deployed. The M 0-1 knapsack problems are solved by the *inner* algorithm that, in principle, can be any algorithm capable of solving 0-1 knapsack problems. It requires the utility and weight vectors of the bearers to be assigned for the considered cell, P_i and W_i, respectively, and the current remaining capacity c_i as input. In turn, the algorithm provides assignment and updated capacity information.

In case the 0-1 knapsack algorithm exhibits an approximation ratio of α, the approximation ratio of the GAP algorithm is $(1 + \alpha)$. In the present work, a simple *Greedy* algorithm is chosen, since it offers the best run-time performance at an eligible approximation ratio, see algorithm 2.

In order to avoid overload situations that occur due to the greedy characteristic of the underlying 0-1 knapsack algorithm, an additional *prioritization* factor is introduced. In case the load of one cell within a cell area is above a certain threshold $\eta_{cell} > \eta_{cell,overload}$, an additional prioritization factor for the respective services is calculated. This factor is accounted for in the utility that is used for the underlying 0-1 knapsack algorithm and decreases with an increasing cell load which in turn leads to a smaller utility value for the knapsack decision. The actual utility value is calculated without this prioritization factor.

Algorithm 1. Outer GAP solver

```
Input: C, W, P
Output: T, C
  for i = 1 to M do
    {Create price vector}
    for j = 1 to N do
      if T(j) == -1 then
        do P_i(j) = p(i, j)
      else
        do k = T(j)
        do P_i(j) = p(i, j) - p(i, k)
      end if
      KNAPSACK(P_i,W_i,c_i)
    end for
  end for
```

Algorithm 2. Greedy Knapsack Solver

```
Input: P, W, C
Output: T, C
  SORT(P, W)
  for j = 1 to N do
    if w_j > C then
      t_j = -1
    else
      t_j = i
      c = c - w_{i,j}
      z = z + p_{i,j}
    end if
  end for
```

2.5 DBA Algorithm

The DBA algorithm is split into two main stages: the *Arrival Algorithm* is performed before and the *Departure Algorithm* after the JCAC.

Arrival Algorithm. First, the *Arrival Algorithm* acquires as much as resources as are required by the queued services in the considered cell area. For that purpose, it degrades already deployed elastic services in order to release sufficient resources. At the beginning of each cycle, the total demand of effective bandwidth of the queued services is calculated $B_{req} = \Sigma_{\forall i} b_i$, whereas b_i holds the bandwidth of service i. The already deployed elastic services are sorted in ascending order according to their *utility slope*

$$u'_j = \frac{\Delta u_j}{\Delta b_j},$$

i.e. $u'_1 < u'_2 < \ldots < u'_n$. In case not enough resources are available in the considered cell area, services could not be served by a single RAN. Hence, the already deployed services are degraded until all incoming services can be admitted or until all admitted elastic services have already been degraded to a minimum. This leads to a minor overall utility loss, since the elastic services, that suffer the least of utility degradation, are degraded first.

Departure Algorithm. First, elastic services are sorted in descending order according to their utility slope

$$u'_j = \frac{\Delta u_j}{\Delta b_j},$$

i.e. $u'_1 > u'_2 \ldots > u'_n$. In case there are resources available, i.e. the system is not completely utilized in the considered cell area, the already deployed elastic services are assigned more resources in order to increase the overall system utilization and level of service provisioning. They will be upgraded until their desired effective bandwidth $b_{desired}$ is reached and in case the bearer is already served with $b = b_{desired}$, they will be upgraded until $b = b_{max}$. This allows for improving the gain of bandwidth adaptation, since the services with the steepest slope will be upgraded first. The services are upgraded until the system reaches its maximum capacity or all elastic services are upgraded to their maximum bandwidth.

3 Evaluation

The following section introduces the developed simulation platform that is used to evaluate the proposed approach, followed by the applied simulation parameters, and obtained simulation results.

3.1 Simulation Parameters

In the following, the parameters that were used for the simulations of all relevant components are presented. All mobile terminals (in the following called UEs) are characterized both by their *UE class* and their *UE utility factor* π_j, see table 3. The first one denotes the service types that are requested by a UE of the respective UE class, whereas π_j represents the utility factor of the randomly assigned SLA class values. Table 1 states the characteristics of the applications that are supported by the system. Application 1 and 2 represent non-elastic services that are fixed with respect to their QoS characteristics, i.e. Voice over IP (VoIP) and streaming services, respectively. In contrast, application 3 and 4 represent elastic services, that are variable with respect to their QoS characteristics, i.e. best-effort services, such as web applications or file transfers. A cell area consists of a HSPA and a LTE cell, each characterized by a maximum available bandwidth and a RAN factor presented in table 2.

Table 1. Service Parameters

App. ID	BW Req. [Mbps]	Active Time [s]	Pause Time [s]
1	$b_{min} = 0.030$	$\mu_{Duration} = 90$	$\mu_{Pause} = 1800$
2	$b_{min} = 0.256$	$\mu_{Duration} = 300$	$\mu_{Pause} = 1800$
3	$b_{min} = 0.0$ $b_{desired} = 0.25$ $b_{max} = 1.00$	$\mu_{Duration} = 50$	$\mu_{Pause} = 420$
4	$b_{min} = 0.0$ $b_{desired} = 1.5$ $b_{max} = 10$	$\mu_{Duration} = 120$	$\mu_{Pause} = 420$

Table 2. Cell Parameters

RAN	B_j [Mbps]	ρ_j
HSPA	14.4	0.6
LTE	80.23	1.0

Table 3. UE Class Parameters

UE Class	A	B	C	D
Applications	{1}	{1,3}	{1,3,4}	{2,3,4}
Distribution	0.2	0.5	0.2	0.1

3.2 Simulation Results

In the following section, performance results of the proposed JCAC and DBA approach with respect to the blocking and dropping rates, the system utilization in the HSPA and LTE cells, and the overall gained utility of all deployed services are given. The proposed approach, which is denoted as *DBAJCAC*, is compared to the *AJCAC* scheme presented in [4] and an approach that does not take JCAC and dynamic bandwidth adaptation into consideration at all.

Blocking and Dropping Probability. The simulation results show that the blocking probabilities of new and the dropping probabilities of handover services are on an acceptable low level for both approaches using JCAC, even at a high number of initial users per cell, see figure 1. In case no JCAC is applied both rates increase in an enormous way at a high number of initial users per cell.

Overall Utility. The overall gained utility, depicted in figure 2, is up to 6% higher using the proposed *DBAJCAC* approach and the distance to the gained overall utility of the *AJCAC* increases for a higher number of initial users per cell. This is due to the greedy characteristic of the underlying GAP solver. In case no JCAC is applied the utility increases too, however at a lower slope.

Cell Load. Figure 3 illustrates the relative cell load statistics both for LTE and HSPA cells, respectively, for all considered algorithms. Apparently, more services are deployed in the LTE cells for both algorithms using an JCAC algorithm up to a number of initial users per cell of $n = 70$. For DBAJCAC, this is due to the utility factor of the RAN, ρ_j, which has a higher value for LTE cells (cf. table

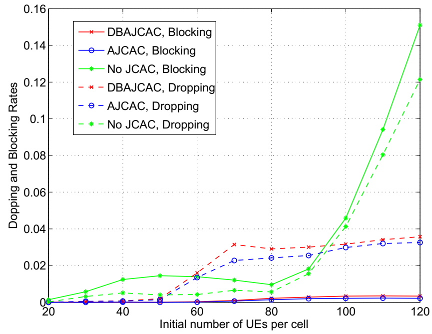

Fig. 1. Dropping and Blocking Probability (mean)

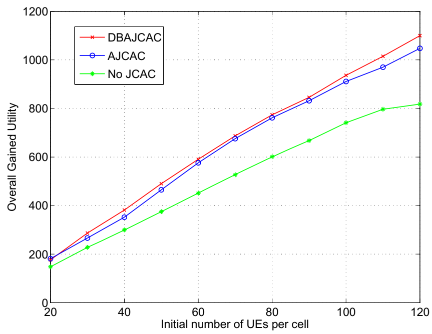

Fig. 2. Overall Gained Utility (mean)

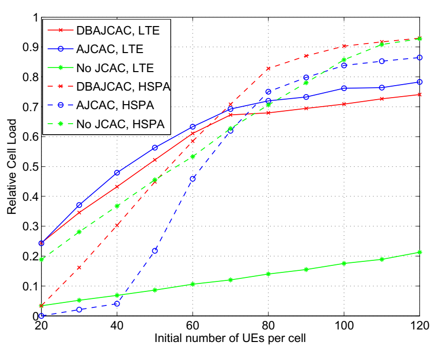

Fig. 3. Cell Load of HSPA and LTE Cells (mean)

2). If the number of initial users per cell increases even further, the cell load of the HSPA cells rises as well. For DBAJCAC, this is due to the load balancing characteristic of the prioritization factor, which is set to $\eta = 0.6$. This leads to a relative increase of the utility used for the underlying 0-1 knapsack algorithm for the HSPA cells. In case no JCAC is applied the LTE cells are only loaded to a minimum whereas the HSPA cells are loaded to a great amount which is a result of not taking JCAC into consideration at all. Thus, all UEs remain in the same RAN during the whole simulation time.

4 Conclusion

The presented work introduces a novel approach for joint JCAC and DBA that enhances resource sharing and service provisioning in emergency situations while taking QoS requirements of services into account. The JCAC task is mapped to a general assignment problem which is well-suited for the resource sharing of different services for emergency use cases. Further, the utility-based definition of services provides a generic measurement of the importance of the service for the community in emergency situations. The performance of the proposed concept is compared to other research approaches and shows an improvement of the achievable utility of approximately 6% with respect to other JCAC approaches, while key performance indicators, such as blocking and dropping rates, are kept at an acceptable level.

Acknowledgment. This work has been funded by the Federal Ministry of Education and Research of the Federal Republic of Germany (Förderkennzeichen 01 BU 1116, SolarMesh - Energieeffizientes, autonomes großflächiges Sprach- und Datenfunknetz mit flacher IP- Architektur). The authors alone are responsible for the content of the paper.

References

1. Niyato, D., Hossain, E.: Connection Admission Control Algorithms for OFDM Wireless Networks. In: Proceedings of the IEEE GLOBECOM, St. Louis, MO, vol. 5, pp. 2455–2459 (2005)
2. Altman, E., Jimenez, T., Koole, G.: On Optimal Call Admission Control in Resource-Sharing System. IEEE Transactions on Communications 49(9), 1659–1668 (2001)
3. Lu, N.: Utility-based Bandwidth Adaptation for QoS Provisioning in Multimedia Wireless Networks, Ph.D. dissertation, Queen Mary University of London, London, United Kingdom (2007)
4. Falowo, O.E., Chan, H.A.: Adaptive Bandwidth Management and Joint Call Admission Control to Enhance System Utilization and QoS in Heterogeneous Wireless Networks. EURASIP Journal on Wireless Communications and Networking 2007 (July 2007)
5. Cohen, R., Katzir, L., Raz, D.: An Efficient Approximation for the Generalized Assignment Problem. Information Processing Letters 100, 162–166 (2006)
6. Martello, S., Toth, P.: Knapsack problems. Wiley, Chichester (1990)