CHAPTER V

AN EFFICIENT APPROACH TO ALLOCATING SERVICE IN INTEGRATED CELLULAR NETWORKS

5.1 BACKGROUND

In the preceding chapter, the EEM approach was designed, and it had the ability to come up with allocating resource allocations that were fair with respect to numerous applications in varying types of networks. Every network was in a position to allocate a specific bandwidth to various users, and was also able to maximize a portion of the utility function in a distributed fashion. It was able to bring about optimization with regard to various users’ utilities, along with reduction in the blocking probability in a manner that was much more efficient. With the help of EEM, Bandwidth optimization [34] was carried out among various applications which didn’t happen with regard to service providers. The concept of resource optimization can be extended among various service providers using the Two-level game Framework.

With regard to heterogeneous wireless networks, allocation of bandwidth for service classes that are not identical becomes quite crucial for any service provider to fulfill their main objective which involves balancing the quality of service and its profit. The challenge grows manifold when is a dynamic competition emanates between the service provider [43] and its users. This chapter attempts to addresses this issue that arises, by proposing a framework that utilizes the two-level game concept. This concept has its basis on the concept of replicator dynamics, while modeling the underlying dynamic service selection is carried out utilizing the evolutionary game theory. The modeling of any competition that could arise among various service providers is achieved by formulating an upper bandwidth allocation differential game. In this scenario, the upper differential game’s state would be described based on the underlying evolutionary game distribution of service selection. The solution that results in the linear state differential game is achieved by taking into consideration an open loop Nash equilibrium [48]. As no information broadcasting is required, the model that has been proposed in this chapter can be implemented with least communication cost. It is also observed that by maximizing the
social welfare component, it is possible to modify the selfish behavior that service providers demonstrate.

It is only but natural that there arises a twofold issue that influences both the user and the service provider in an environment that not only operates wirelessly, but is also heterogeneous in nature. The first issue concerns rational users whose choice is the access network along with the service class from various service providers based on the observation of the performance of every service class that was available. The network’s decision (i.e., strategy) and selection of service selection is carried out in a dynamic manner, which maximizes individual utility as a result. The second issue concerns allocation by service providers of network capacity (i.e., bandwidth) that is available to service classes that have been offered. As users behave in a dynamic manner, the allocation of bandwidth also has to be performed in a manner that is dynamic so as to maximize profit.

In order that the twin issues of service selection and bandwidth allocation be addressed, the development of a game framework that is a hierarchical (i.e., two-level) game framework has been resorted to, which would help fulfill the joint strategies of both the users and service providers. Dynamically deciding on service selection by users has been modeled by utilizing an evolutionary game that takes into account the bandwidth allocation control of the service providers. As a result, the service providers can now observe the users’ service selection and then allocate the bandwidth in a dynamic manner, which can then be modeled in the manner of a differential game [41].

The novelty factor of the two-level game framework is that it takes into account decision making that is dynamic in nature. Various parameters of the system include users choosing access service class that possess a dynamic nature, which may not allow for the attainment of a steady state network. As a result, dynamic optimal control is the suitable approach when it comes to assessing the dynamic decision making process of service providers that are rational in heterogeneous wireless networks.

The remainder of the following chapter has the following organization. In Section 5.2, the system model has been presented. The key basis of selecting a service in wireless networks that are heterogeneous in nature is formulated as an evolutionary game in Section 5.3. On the other hand, taking into consideration the selection of both the dynamic
network and service selection has been formulated as a differential game in Section 5.4. Numerical studies are presented in Section 5.5.

5.2 SYSTEM MODEL

Figure 5.1 depicts a heterogeneous wireless access environment that consists of an IEEE 802.11 wireless LAN (WLAN), a CDMA cellular network and IEEE 802.16 wireless MAN (WMAN) radio interfaces. A simultaneous connectivity to these radio access networks is made possible with a mobile possessing numerous radio transceivers, namely, software radios. Every mobile that this system presents possesses varying interfaces so that connection to these networks is feasible.

![Figure 5.1: Multi-class Heterogeneous Wireless Network model](image)

Figure 5.1 depicts a geographical area whose entire coverage is by a WMAN base station, and partial coverage by a cellular base station along with a WLAN access point (AP). In order that the available transmission rate is uniform across the coverage area, perfect power control is assumed so that a mobile can be connected to all the networks if it corresponds to its area of coverage. In the system model that has been considered in this study, a mobile has the ability to subscribe to differing service classes, where every class’
requirement of bandwidth is not the same. Determining the subscription class occurs when connection is commenced by the mobile, and it is assumed that until termination has occurred, a connection that was ongoing stays in the same class. The aim of the admission control that has been proposed is to ensure total transmission rate that the new connection had requested, while at the same time, the bandwidth allocation algorithm attempts in allocating bandwidth from each and every network in such a way that can be considered as fair. In other words, there exists cooperation among all these networks to ensure that the maximum bandwidth service is offered to a new connection. As a result, the Two-level game Framework can be considered as a special type of Evolutionary game is utilized here in order for the solution to be obtained with regard to the problem of bandwidth allocation prevailing in a heterogeneous wireless access network.

It is assumed that the specific service area $s$ existing while covering an environment that is heterogeneous in nature, consists of $M$ access networks and $N(t)$ active users at any time $t$. Required parameter are list in Table 5.1. Not providing for any loss of generality, it is assumed that every service provider owns every access network. Service provider $i \in \{1,2,\ldots,M\}$ is in a position to provide $K_i$ service classes to its users in order that the varying Quality of Service (QoS) demands will be satisfied. The total number of service classes is denoted as

$$K = \sum_{i=1}^{M} K_i$$

(5.1)

There are certain characteristics of wireless channels that include interference and fading, along with the wireless users’ mobility, the capacity of the system (bandwidth $B_i$) and the number of users in a specific area ($N$), that usually vary with time. All users that are particularly registered to a particular service class shares the bandwidth that is available in an equal manner. The bandwidth of user $k$ that was obtained from service class $j$ of service provider $i$ at time $t$ can be represented as

$$\tau^i_j(t) = \frac{\text{Allocated BW of SC } j \text{ from SP } i (B_{ij}(t))}{\text{Total No. of users choosing SC } j \text{ of SP } i \text{ at } t (N_{ij}(t))}$$

(5.2)

where
\[
\sum_{i=1}^{M} \sum_{j=1}^{K_i} N_{ij}(t) = N(t)
\]  

Here, \(B_i(t)\) and \(N(t)\) are smooth functions with respect to \(t\).

5.3 SERVICE SELECTION EVOLUTION

Every user in area \(a\) starts competing in order to select access networks that exist from the list of candidate service providers that are available. The selection is carried out with the main objective of maximizing satisfaction, namely the utility, with respect to QoS performance. At any instant of time, every individual user will be in a position to adapt their service selection strategies that will be founded on the observed network’s performance that is time-varying and depends on the prevailing status of congestion.

The formulation of an underlying evolutionary game modelling the dynamic competition of service selection among users is carried out, and this becomes the lower-level game of the two-level game framework. In this lower-level evolutionary game model, the \(N(t)\) active users in the area \(a\) at any time \(t\) are constituted by the players. In the context of an evolutionary game, the population is constituted by a group of users. The strategy of a player is framed by the choices of a particular service class from certain service providers (i.e. Available access networks). The payoff of a player consists of the utility that represents the QoS satisfaction level. Let \(x_{ij}(t)\in[0,1]\) denote the proportion of users in area \(a^2\) that choose service class \(j\) from service provider \(i\) at time \(t\). As a result, bandwidth is allocated to each and everyone from this proportion of users at time \(t\) and is given by

\[
\tau_{kij}(t) = \left(\frac{B_{ij}(t)}{N(t)x_{ij}(t)}\right)
\]

and the utility of user \(k\) is

\[
u\left(\tau_{kij}(t)\right) = \alpha \tau_{kij}(t)
\]

Where \(\alpha\) is a constant that denotes the utility’s increasing rate. The population’s average utility is obtained as follows:
\[ \vartheta(t) = \sum_{i=1, j=1}^{M, K_i} x_{ij}(t)u(t_k^i(t)) \]

The following differential equations describe the replicator dynamics that are being used to model the evolutionary process of service selection strategy for all \( i \in \{1,2,\ldots,M\}, j \in \{1,2,\ldots,K_i\} \)

\[ \frac{\partial x_{ij}(t)}{\partial t} = x_{ij}(t) \left( u(t_k^i(t) - \vartheta(t)) \right) \sum_{i=1, j=1}^{M, K_i} x_{ij}(t) = 1 \]  \hspace{1cm} (5.7)

that possesses initial condition \( \tilde{x}(0) = \tilde{x}_0 \in \chi \), where \( \tilde{x}(t) = [x_{11}(t), \ldots, x_{ij}(t), \ldots, x_{MK}(t)]^T \) is a vector that describes the population state, \( \delta \) is the population’s learning rate, and \( \chi \subseteq \mathbb{R}^K \) denotes the set that contains every possible state.

### 5.4 DRA WITH RESPECT TO SERVICE CLASS

Service providers can allocate bandwidth in an optimum fashion which would help in attaining maximum profit, mainly is due to the users’ dynamic service selection behavior. On the other hand, the service provider’s overall profit reduces due to the access network’s capacity that is limited, and as a result, the bandwidth being allocated to other services classes is reduced, when bandwidth that has been allocated to one service class is increased. Here, a service provider’s differential game model with respect to bandwidth allocation has been formulated, and it constitutes the upper level game in the two-level game framework that has been proposed, by taking into account the users’ dynamic service selection.

#### 5.4.1 Allocating Service Using Open Loop Strategy

When the bandwidth allocation strategy is controlled, each of the \( M \) non-cooperative service providers starts to compete in order to ensure that the objective function’s current value that was derived over an infinite time horizon was maximized. Simultaneously, a play differential game that could assist in achieving this objective can be formulated as follows:
The set of players comprises all the various service providers of the access networks that are available. The strategy required where in a service provider behaves in the manner of a player, is that the dynamic control of the bandwidth’s proportion which had been allocated to various service classes needs to be carried out. The proportion of bandwidth of service provider $i$ allocated to service class $j$ at time $t$ is denoted as $\varphi_{ij}(t)$. A service provider’s control strategy $i$ is denoted by vector $\vec{\varphi}_i(t)$, which is implemented as follows:
Assume that the value of $\varphi_{ij}(t)$ is between 0 and 1
for (i=1;i<=M;i++)
    for (j=1;j<=K;j++)
    
    $\bar{\varphi}_i(t) = \varphi_{ij}(t)$
    Basically $\varphi_{ij}(t) = 1$
    $B_{ij}(t) = B_i(t)\varphi_{ij}(t)$ \(// t \in [0, +\infty]\)

$\bar{\varphi}_i(t) \in R^K$

Resorting to similar notations that finds usage in game theory, $\Phi = \{\varphi_i(t), \varphi_{-i}(t)\}$
denotes this differential game’s strategy profile, and $\varphi_{-i}(t)$ is a vector containing
strategies of every player excluding player $i$.

<table>
<thead>
<tr>
<th>Hardware Specification</th>
<th>Service Class</th>
<th>Service Provider</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11b Access Point</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>IEEE 802.16 Base Station</td>
<td>2</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

There are two ways by which service providers can be represented that is based on
various informational structure assumptions: 1) open-loop control strategy (doesn’t
require any feedback information from the system), and, 2) closed-loop control strategy
(utilizes feedback information in order to adjust the control process). It is observed that
utilizing a closed-loop strategy requires a system structure with a greater level of complexity.
In the model that has been proposed, the open-loop control strategy of the service
provider is taken into consideration due to the simplicity in its implementation, as there is
no need for a centralized controller which perfectly suits a wireless network that is
heterogeneous in nature and loosely coupled. The bandwidth allocation differential game, ensures that every service provider (player) choose their bandwidth allocation control strategies simultaneously, thus being able to influence not only the evolution of the state of the differential game, but also the objective functions of both, their opponent and their own.

The differential game’s state is represented by the population state $\bar{x}(0)$ of the underlying service selection game. Differential equations (5.3) pertaining to replicator dynamics describe the extent to which the current state $\bar{x}(0)$ and the service providers’ control $\varphi_i(t)$ at time $t$ influence the state’s rate of change at time $t$. With respect to a service provider, it now becomes an optimal control problem, subjected to constraints such as state evolution differential equations, when other service providers’ control strategies are known. The instantaneous payoff of a service provider $i$ when selecting a control strategy $\bar{\varphi}_i(t)$ is

$$U(\bar{\varphi}_i(t), \bar{\varphi}_{-i}(t))$$

For (j=1;j<=K;j++)

{ // $\theta_j \rightarrow$ Cost Factor

$$P_{ij}N(t)x_{ij}(t) - \theta_j(\varphi_i(t)B_i(t))^2$$

$P_{ij} \rightarrow$ Cost charged by SP i for SC j per user

}

Regarding non-cooperative bandwidth allocation $i$, the optimal control with respect to each and every rational service provider is expressed as follows:

$$U(\bar{\varphi}_i(t), \bar{\varphi}_{-i}(t)) = \int_0^\infty e^{-\rho t} U(\bar{\varphi}_i(t), \bar{\varphi}_{-i}(t))dt$$ (5.8)

subject to equation (5.7), where $\rho$ is the discounting rate of utility of SP

### 5.4.2 Nash Equilibrium

Most research in game theory focuses on how groups of people interact. There are two main branches of game theory: cooperative and non-cooperative game theory. Non-cooperative game theory deals largely with how intelligent individuals interact with one another in an effort to achieve their own goals. In cooperative game theory, players can
make binding agreements before playing the game, e.g. how to share pay-offs. In non-cooperative game theory, agreements are not binding. Non-Cooperative game theory support dynamic and also optimistic bandwidth allocation. That why we focused on this approach. When considering Non-Cooperative game theory, Nash equilibrium is the origin of fundamental concept in the theory of games and the most widely used method of predicting the outcome of a strategic interaction in the social sciences.

Pontryagin's maximum (or minimum) principle is used in optimal control theory to find the best possible control for taking a dynamical system from one state to another, especially in the presence of constraints for the state or input controls. Here we adopt the pontryagin principle to optimize the resource and to maximize the network utility.

Generally the principle states that the Hamiltonian must take an extreme value over controls in the set of all permissible controls. Whether the extreme value is maximum or minimum depends both on the problem and on the sign convention used for defining the Hamiltonian. The normal convention, which is the one used in Hamiltonian, leads to a maximum hence maximum principle is used in the thesis.

Obtaining the solution to the bandwidth allocation differential game that has been stated above, leads to determining the Nash equilibrium.

Definition : 1

The optimal bandwidth allocation control path \( \gamma_i^*(t) \) for service provider \( i \) exists if the inequality condition \( J_i(\gamma_i^*(t), \gamma_{-i}(t)) \geq J_i'(\gamma_i(t), \gamma_{-i}(t)) \) holds true for all feasible control paths \( \gamma_i(t) \) in the non-cooperative bandwidth allocation differential game.

Definition : 2

Let \( \gamma_i(t) \) denote the open-loop bandwidth allocation strategy of service provider \( i \). The strategy profile \( \Phi = \{ \phi_i(t), \phi_{-i}(t) \} \) becomes an open-loop Nash equilibrium, if for each service provider \( i \in \{ 1, 2, ..., M \} \), \( \gamma_i^*(t) \) becomes an optimal control path on the condition that the remaining service providers’ control strategies are \( \gamma_{-i}^*(t) \).

To determine the open-loop Nash equilibrium, every service provider solving an optimal control problem becomes essential. Here, the Pontryagin’s maximum principle can be utilized. To achieve it, definitions pertaining to the Hamiltonian function \( HF \), the
maximized Hamiltonian function $H_{F}^{*}$, and the adjoint equation $\dot{\lambda}(t)$ required for the bandwidth allocation differential game are given as:

**Step 1**: Compute the Hamiltonian function of SP $i$ denoted by $H_{F_{i}}$ as follows:

$$
H_{F_{i}}(\tilde{x}(t), \overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t), \lambda_{ij}(t), t) = U(\overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t)) + \sum_{i=1, j=1}^{M, K_{i}} \lambda_{ij}(t) \cdot \left( \frac{\partial x_{ij}(t)}{\partial t} \right)
$$

where $\lambda_{ij}(t)$ is the co-state variable associated with $\tilde{x}(t)$.

**Step 2**: The corresponding maximized Hamiltonian function $H_{F}^{*}$ from the above equation and Utility SP is determined from the following definition:

$$
H_{F}^{*}(\tilde{x}(t), \lambda_{ij}(t), t) = \max \{ H_{F_{i}}(\overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t), \lambda_{ij}(t), t), \overrightarrow{\varphi_{i}}(t) \in [0, 1] \}
$$

**Step 3**: The adjoint equation is computed as follows:

$$
\overrightarrow{\lambda}(t) = \rho_{\lambda}(t) - \frac{\delta H_{F}^{*}(\tilde{x}(t), \lambda_{ij}(t), t)}{\delta x_{ij}(t)}
$$

**Step 4**: In order to obtain the derivative, Hamiltonian functions and the linear utility function are used.

$$
\left( \frac{\delta(H_{F_{i}}(\tilde{x}(t), \overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t), \lambda_{ij}(t), t))}{\delta x_{ij}(t)} \right) = P_{ij}N(t) - \frac{\alpha \delta B(t) \lambda_{ij}(t)}{N(t)}
$$

where $B(t) = \sum_{i=1}^{M} B_{i}(t)$. Thus, the above equation becomes

$$
\left( \frac{\delta^{2}(H_{F_{i}}(\tilde{x}(t), \overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t), \lambda_{ij}(t), t))}{\delta x_{ij}^{2}(t)} \right) = 0
$$

In a similar manner we solve

$$
\frac{\delta^{2}(H_{F_{i}}(\tilde{x}(t), \overrightarrow{\varphi_{i}}(t), \overrightarrow{\varphi_{-i}}(t), \lambda_{ij}(t), t))}{\delta x_{ij}(t)\delta \lambda_{ij}(t)} = 0
$$
Figure 5.2: Service Selection

Step 4, leads to the following property: The bandwidth allocation differential game being defined in step 1 & step 2 is a linear state differential game possessing the property of the open-loop Nash equilibria and are Markovian perfect. To determine a solution providing optimal control strategy, the first order condition is defined as follows:

$$
\frac{\partial HF_i}{\partial \phi_{ij}(t)} = \lambda_{ij}(t)\partial \alpha \frac{B_i(t)}{N(t)} - 2 \varphi_{ij}(t)B_i(t)\theta_j = 0 \quad (5.9)
$$

We thus obtain

$$
= \frac{\lambda_{ij}(t)\partial \alpha}{2 B_i(t)N(t)\theta_j} \quad (5.10)
$$
5.5 PERFORMANCE MEASURES

In this study, a wireless network that is heterogeneous in nature is considered, that contains the following: an IEEE 802.11b access point, along with an IEEE 802.16 base station that provides two service classes to 20 users within a specific area $a$, which has been depicted in Figure 5.1. The assumption made over here is that the IEEE 802.11b-based WLAN’s maximum saturation throughput is 7 Mbps, while it is assumed to be 5 Mbps for an IEEE 802.16 network covering an area $a$ considering that the other users share in the same cell share the bandwidth [Table 5.2]. To enhance easier understanding, the service providers with respect to the WLAN network and WiMAX have been named service provider 1 and service provider 2, respectively.

The two service providers have their fixed connection fees with respect to the two service classes set as $P_{11} = 0.2$, $P_{12} = 0.1$, $P_{21} = 0.3$ and $P_{22} = 0.25$. On the other hand, when it comes to replicator dynamics, the settings corresponding to the learning rate is $\delta = 0.6$. Other settings include $\alpha = 0.2$ for user utility, $\rho = 0.1$, and $\theta_1 = \theta_2 = 0.01$. 

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Figure 5.3: Control Strategies under different N Users
with respect to the discounting rate and cost factors for the objective function of service providers. The proportion of users who initially choose two service classes of the two service providers are as follows: $x_{11}(0) = 0.2$, $x_{12}(0) = 0.3$, $x_{21}(0) = 0.1$ and $x_{22}(0) = 0.4$.

Figure 5.4 (a): Example of Bandwidth Allocation in Normal Case

Figure 5.2 depicts investigations that were undertaken relating to the dynamic behavior of not only the users’ service selection falling under the control of bandwidth allocation, but also strategy adaption trajectory obtained from the selection distribution carried out initially. The trajectory reveals the convergence of the dynamics to a particular selection distribution allowing each and every all the user falling under area $a$ to obtain a utility identical to the population’s average utility. On the basis of the optimal control strategy, it is seen that service provider 1 and service provider 2 had allocated a much bigger bandwidth to service class 1 as a result of the higher price being offered, resulting in more users opting for service class 1 as shown in Figure 5.2.
Figure 5.4 (b): Example of Bandwidth Allocation when the cellular network becomes congested.

Varying the total number of users in an area $a$ with respect to time can be implemented due to user mobility. Figure 5.3 depicts the consequence of the variation in the number of users with respect to optimal bandwidth allocation control. As the number of users in area $a$, is increased, it leads to the congestion of the two access networks, and this can be controlled by the service providers by adjusting the proportion of bandwidth being allocated to the service class that possessed a higher price in a dynamic fashion. The observation is that the bandwidth’s proportion allocated to service class 1 by service provider 1 is larger than that of service provider 2, as a result of the service classes’ price differentiation with respect to service provider 1 being much higher.

In the system that has been considered in this study, it is assumed that three classes of mobile subscription exist, and their corresponding bandwidths with respect to these subscription levels are 200, 350 and 500 Kbps respectively. In order to calculate the bandwidth being offered, it is assumed that $b_{k, wt} = 200$, $b_{k, ce} = 150$, $b_{k, wmn} = 250$ for all
and it is also assumed that $r = 0.85$. Moreover, it is assumed that 50, 30, and 20 percent of new connections in the entire coverage areas are found in the corresponding subscription classes 1, 2, and 3. It is assumed that the connection arrival process follows a Poisson distribution, and the connection holding time is exponentially distributed.

Figure 5.5 (a): Average Number of Connections under Unequal Arrival Rate

It is followed by varying the quantity of the bandwidth requested, and every network’s resultant allocation is depicted in Figure 5.4(a) in a normal situation and in Figure 5.4(b) in the congested situation of a cellular network. Expectedly, while satisfying the requirement of bandwidth requirement for a connection that is new, an increase in the amount of bandwidth that has been allocated follows an increase in the bandwidth that was requested originally.

In Figure 5.4(a), bandwidth allocation, that has its basis the amount of bandwidth requested and is thus broken into four intervals (i.e., $[0, 150)$, $[150, 400)$, $[400, 600)$ and $[600, \infty)$). The first interval allocates bandwidth to each and every network in an equal manner, since the complete quantity of bandwidth that was requested is in a position to be
accommodated by each and every network. It is only but fair that bandwidth allocation is measured in equal quantities for each network.

Figure 5.5 (b): Bandwidth Utilization for Unequal Arrival Rate

With respect to the second interval, as the bandwidth that was requested turns out to be larger than the bandwidth offered by a particular network, there is a variation in the bandwidth allocation for each network. Regarding the third interval, the variations that exist with respect to the bandwidth allocated with respect to every network has increased as the bandwidth that was requested is now greater than the bandwidth that is being offered to both the networks. As the bandwidth requested keeps on increasing and now turns out to be much bigger than the bandwidth offered among all networks, the bandwidth allocated then becomes constant. Figure 5.4(b) depicts the instant congestion in the cellular network occurs, implying that the bandwidth that the network offers has now attained 50 Kbps. It is observed that the trend regarding bandwidth allocation in every network resembles that of Figure 5.4(a).
5.5.1 Analysis under Unequal Arrival Rate

Here, the performance of the proposed bandwidth allocation is presented. Considering the network as depicted in Figure 5.1, there is a triple division of mobiles that have its association with service area 1 (i.e., mobiles that come under the WLAN, cellular network and WMAN’s coverage), 2 (i.e., mobiles that come under the cellular network and WMAN’s coverage), and 3 (i.e., mobiles coming only under the WMAN’s coverage). The intensity of traffic, namely, the connection arrival rate per minute is based on the evaluation scenario, while the assumption of the connection holding times for those connections situated in areas 1, 2 and 3 are 20, 10, and 25 minutes respectively. Figure 5.5 (a), (b) and (c) depicts the average number of ongoing connections, bandwidth utilization and connection blocking probability under various traffic intensities. Moreover, the connection blocking probability that is provided by the opportunistic network
selection, namely the instance when a mobile selects the network that possesses the greatest available bandwidth, has also been depicted for comparison purposes.

![Figure 5.6 (a): Average Number of connections under Equal Arrival Rate](image)

In particular, from Figure 5.4, one observes area 1’s connection arrival rate equals the traffic intensity as depicted in the X-axis, which reduces to half and one-third respectively, for areas 2 and 3 with respect to the particular traffic intensity. On expected lines, as there is an increase in traffic intensity, every area’s average number of connections, every network’s bandwidth utilization, and the connection blocking probability is also found to increase. But on the other hand, the connection blocking probability for the algorithm that has been proposed here has reduced when compared to the opportunistic scheme.

### 5.5.2 Analysis under Equal Arrival Rate

Figure 5.6 (a) depicts the same performance measures with respect to the situation when, in every area, the connection arrival rates and the traffic intensity are the same. It must be noted that, this situation is utilized in evaluating performance with a high traffic load.
Observations in Figure 5.5 were similar, showing every performance measure increasing with increasing traffic intensity. On the other hand, it is observed that in the instances of traffic intensity being quite high, namely, when traffic intensity is higher than 6 connections per minute, the number of connections in area 3 decreases, while at the same time it still shows an increase in area 1.

As WMAN’s traffic load attains the point of saturation, it is not possible to increase the number of connections in this area. But, the bandwidth allocation algorithm is able to distribute the requested bandwidth from WLANs and cellular networks to WMAN, resulting in bandwidth availability to connections in area 3 to decreases, while increasing in area 1, resulting in the reduction in the number of connections in area 3, which have been confirmed by the utilization of higher bandwidth in the WMAN air interface in Figure 5.6 (b) & (c) when compared to that in Figure 5.5(b) & (c). Once more, with regard to the proposed algorithm, its connection blocking probability is less than that of the opportunistic scheme.
As the demand for mobile communication has grown remarkably in the past few years, mobile networks should be able to utilize the limited resources, which lacks of incoming Calls, Bottleneck problem, increase Call dropping probability, system utility, and to prevent system underutilization. The radio frequency spectrum that is currently available is limited in nature and thus can no longer be counted on to support the ever increasing number of mobile users’ demand, and hence, the required Quality of Service (QoS) is no longer attainable until an optimum solution is obtained.

Therefore, a different approach that combines the acceptable efficiency of the above critical problems, the proposed scheme focus mainly of Network Performance and to satisfy users’ needs which reduces performance degradation. In the context of a general resource allocation framework for dynamic, open systems we have developed several algorithms aimed to optimize bandwidth allocation in wireless networks. We propose several allocation schemes that use these utility functions for allocating and reallocating bandwidth to connections, aiming to maximize the accumulated utility of the system. In

Figure 5.6 (c): Connection Blocking Probability under Equal connection Arrival Rate.
order to fulfill this requirement, there arose the need for a proper load balancing method. As a result, the bandwidth allocation problem of such systems, had the concepts of a differential game and an evolutionary game as its basis, which would then have the potential to achieve optimal bandwidth allocation with respect to wireless networks. Whereas the analysis of the strategy of the evolution process was achieved utilizing replicator dynamics.

5.6 SUMMARY
This chapter presented a bandwidth allocation algorithm along with an admission control algorithm for heterogeneous wireless access networks wherein a mobile had the capability to connect to multiple radio interfaces, namely WLANs, cellular networks, and WMANs at the same time. In order to fulfill this requirement, there arose the need for a proper load balancing method. As a result, in this chapter, the bandwidth allocation problem of such systems, based on a two-level game framework had been formulated, that had the concepts of a differential game and an evolutionary game as its basis, which would then have the potential to achieve optimal bandwidth allocation with respect to wireless networks. In this chapter, the dynamic service selection behavior of the various users was modeled on the basis of an evolutionary game, whereas the analysis of the strategy of the evolution process was achieved utilizing replicator dynamics. Additionally, bandwidth allocation among different service classes after taking into consideration the users’ dynamic service selection, was formulated using the concepts of a linear state differential game. The solution provided by this differential game could be considered as the open-loop Nash equilibrium. The fact that social welfare maximization can be achieved using the open-loop Nash equilibrium has also been demonstrated in this chapter.