Prioritized Resource Sharing in WiMax and WiFi Integrated Networks

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***Abstract*—In order to ensure fair access and efficiency of bandwidth usage in wireless integrated networks, resource allocation algorithms should be well designed. In this paper, we briefly discuss the complete sharing, complete partitioning and Hybrid resource sharing approaches and their shortcomings in WiMax-WiFi integrated networks. To overcome these shortcomings we propose the *Prioritized Resource Sharing* algorithm for WiMax-WiFi integrated networks. In this algorithm, the channels are *prioritized* for different traffic classes rather than strict reservation or open access. The prioritized resource sharing algorithm is then extended to multiple integrated networks. Finally, we analyze the proposed algorithm by modeling it using two dimensional continuous time Markov chains. The simulation results indicate that the *Prioritized Sharing* model achieves the best system utilization compared to other algorithms. It is also observed that due to heavy traffic of one class of users, other class of users are not starved unlike in complete sharing.**

I. Introduction

The architecture for the next generation of wireless networks aims to integrate multiple networks and benefit from the resulting synergy. The most commonly studied integrated networks include cellular network combined with WLAN. Although 2.5 and 3G cellular data services offer wide area Internet connectivity, these services do not provide the broadband speeds to which users have become accustomed. WiMax on the other hand, can provide high speeds along with the quality of service. Service providers can offer their subscribers a more complete suite of broadband services in more places, by combining WiMax and WiFi technologies. However, due to the limited availability of spectrum and shared nature of wireless medium, design of efficient resource (channel) allocation mechanisms to provide the crucial quality-of-service (QoS) requested by the subscribers is a major issue involved in the integration of both these networks.

Although, multiple resource allocation schemes have been devised and studied, most of it deals with homogeneous networks [1]-[5]. The previous work includes various schemes such as Complete Sharing (CS) , Complete Partitioning (CP), Hybrid Sharing (HS), etc. Hybrid sharing has been studied to be more efficient than complete sharing and complete partitioning schemes by providing a trade-off between quality of service and channel utilization. But hybrid channel allocation scheme is affected by unbalanced loads although it's not as sensitive to load imbalance as fixed channel allocation [6].

Direct application of the above mentioned schemes in integrated networks involve greater challenges in terms of efficiently incorporating and coordinating the heterogeneity of different networks. However, some of the resource allocation schemes from homogeneous networks have been modified and tested in the integrated environment. Few of such adaptations to integrated network are discussed in [7]-[11] but their discussions are for general heterogeneous networks and not specific to WiMax-WiFi integrated networks. This paper is thus motivated to focus specifically on WiMax-WiFi integrated architectures.

Loose and tight coupling are the two widely studied WiMax-WiFi integration architectures. In a tightly coupled WiFi-WiMax architecture, the WiFi users connect to Internet through WiMax core network using a WiMax-WiFi bridge. The WiMax base station sees the WiFi-WiMax bridge as another subscriber station. Since each WiFi-WiMax bridge accomodates many WiFi users, the average traffic generated by the bridges are higher compared to WiMax subscriber stations. As a result, WiMax subscriber stations traffic will experience resource starvation. So controlled resource sharing between WiFi bridges and WiMax subsriber stations is required in such an architecture. [12] and [13] have addressed this issue based on game theoretic approach focusing more on optimal pricing efficientresource sharing, but the complexity of the model is high and it has dependencies between the different levels in hierarchy which could be a drawback interms of delay. [14] and [15] propose partial resource sharing for the same architecture but do not consider the starvation problem. So, in this paper we address the above mentioned issue by,

- Proposing a *Prioritized Sharing* (PS) algorithm for tightly coupled WiMax-WiFi architectures,
- Modeling the algorithm using two-dimensional continuous time Markov chains,
- and extending the *Prioritized sharing* algorithm to multiple integrated networks with tightly coupled architectures.

The rest of the paper is organized as follows: In section II, the system model and the *Prioritized resource Sharing* algorithm for tightly coupled WiMax-WiFi integrated networks are explained. The algorithm is then extended for mutiple integrated networks. The analytical modeling using Markov chains is presented in Section III. Section IV shows the simulation results and Section V concludes the paper.

II. SYSTEM MODEL

For our system model we consider a tightly coupled architecture based on WiMax and WiFi networks as shown in Fig. 1. In this architecture there is a WiMax base station encompassing multiple WiFi hotspots. The WiMax BS connects to the Internet and acts as the backbone to the WiFi network. The WiMax subscribers referred to as subscriber stations, communicate directly to the WiMax Base Station (BS) whereas the WiFi users have to use a special access point (AP) to communicate with the WiMax BS. This special access point is named as *WiFi -WiMax Bridge* (WWB) in this paper. The WiMax interface is used for communicating with the BS, and WiFi interface for communicating with WLAN stations. Since the range of WiFi users are much smaller than the WiMax counterparts and the access mechanism of WiFi (random) and WiMax (time slotted) are different, the WWB acts as a link for WiFi users to reach the WiMax BS. The WWB aggregates all the WiFi user traffic and requests the WiMax base station for a service. The traffic from WiFi-Wimax bridges are just referred to as WiFi users/traffic since they forward the aggregated WiFi requests and the traffic from WiMax subcriber stations is referred to as WiMax users/traffic. In the current work, the important issue we focus on is the prioritization of these two different traffics and the corresponding changes in channel utilization and blocking of traffic. We assume that each cell has a total of N channels. The admission control residing in the BS manages the resource N between the two types of traffics.

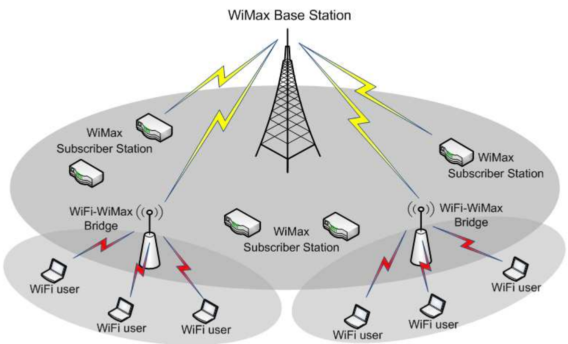

Fig. 1. System Model of WiMax and WiFi integration.

A. Channel Allocation Schemes

In this section the proposed Prioritized Resource Sharing algorithm in WiFi and WiMax integrated networks is described and modeled. Then the algorithm is extended to multiple integrated networks. Before describing this model, already existing allocation algorithms which are Complete sharing (CS), Complete Partitioning (CP) and Hybrid Sharing (HS) schemes are briefly explained below.

In CS allocation (Fig. 2a), WiFi and WiMax have their own queues and both of them share all the available channels. There is no prioritization and the users are served on first come first serve basis. If quality of service is defined as the minimum number of channels assured for a particular class of users, then there is no QoS guarantee in this scheme.

The CP allocation scheme (Fig. 2b) is a variant of CS scheme, where different resource utilization thresholds are assigned to WiFi and WiMax users based on each traffic priority. Higher number of channels are reserved for higher priority users, in this case WiMax users. QoS is achieved by reserving channels for each class of users.

HS scheme (Fig. 2c) is a combination of CS and CP schemes. There are a set of common channels which can be shared by both the class of users and the rest of the channels are reserved according to the priority of the class of users. In Fig. 2c, WiMax and WiFi are allocated three and two channels respectively and the rest three channels are common and are allocated on first come first serve basis. In this type of allocation, there is a trade-off between channel utilization and QoS.

B. Prioritized Sharing

The problem with the above schemes is that, in CP scheme the un-utilized channels of one class can not be used by other class of users and therefore the capacity is wasted. In CS, during unbalanced loads, the class of users with low traffic suffer resource starvation. In HS scheme the QoS for each class is guaranteed but this is achieved at the expense of inefficient total system utilization. Our proposed Prioritized Sharing (PS) takes these two problems into account.

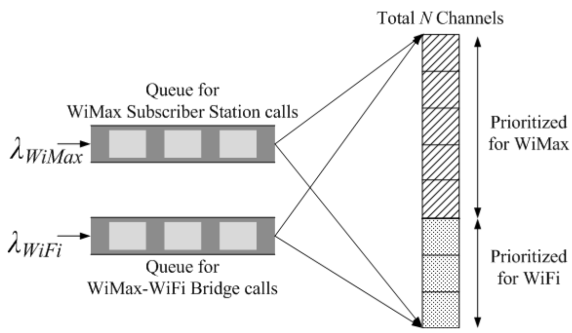

Fig. 3. Prioritized channel allocation Model.

In PS scheme as shown in Fig. 3, both the WiMax and WiFi users are allowed to access all the channels if they are free on first come first serve basis like in CS scheme. This allows the users to use the full capacity of the system. In PS scheme, Quality of Service is achieved by *prioritizing* the channels to WiMax and WiFi users according to their respective QoS requirements rather than strict reservation. In Fig. 3, WiMax has seven prioritized channels and WiFi has three, but all the ten channels can be accessed by any user if they are available. The calculation of number of prioritized channels for various class of users based on the given QoS requirements is out of the scope of this paper and will be considered as a future work.

It is important to note the difference between the terms *shared*, *reserved* and *prioritized*. *Shared* means that the chan-

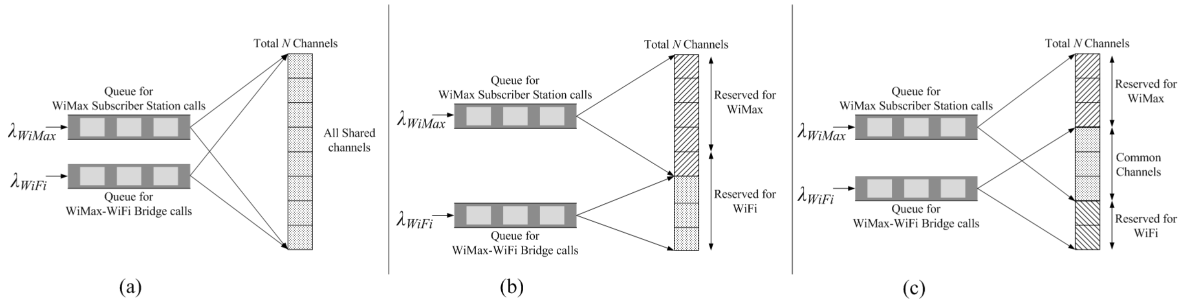

Fig. 2. a) Complete Sharing, b) Complete Partitioning, c) Hybrid Sharing.

nels can be accessed by anyone on a first come first serve basis. *reserved* means that the channels are allocated to a particular class and no use of any other class can access them. *prioritized* means that the channels can be accessed when they are free but a user can be terminated and queued to accommodate other class of users if certain pre-defined criteria is met. Channel reservation or prioritization does not mean that particular channels (band) are allocated to a class of users. It means that a certain number of channels are allocated and not any band in specific.

The criteria for call admission and forced termination for WiMax users in Prioritized resource sharing algorithm is stated as follows:

1) A WiMax call is admitted if the atleast one channel is free.
2) If all the channels are full but the number of channels occupied by WiMax users is less than the number of prioritized channels, then the WiFi user who has been most recently admitted is forced to terminate and is queued back until the next channel is free.
3) If all the channels are full and if the number of channels occupied by WiMax users is already greater than or equal to the number of prioritized channels the call is blocked.

The same procedure holds for WiFi traffic also. Since, the WiMax and WiFi are allocated a predefined number of prioritized channels, those many channels are assured at the least in any traffic conditions. Hence, QoS of service is achieved as in CP case as will be observed in the simulation results.

C. Prioritized Sharing for Multiple Networks

Prioritized sharing (PS) channel allocation model can be easily extended to more than two networks. A service request from a class i network is admitted if the atleast one channel is free. If all the channels are full, but the number of channels occupied by users of i^{th} class is less than the number of prioritized channels for that class, then the user who has been most recently admitted among those classes of networks which have exceeded their prioritized channels, is forced to terminate and is queued. If all the channels are full and if the number of occupied channels by class i users is greater than or equal to the number of its prioritized channels, the call is blocked.

Suppose there are K networks represented as $\{\chi_1, \chi_2 .., \chi_K\}$ with $\{\eta_1, \eta_2 .., \eta_K\}$ number of prioritized channels respectively and $\{\omega_1, \omega_2, .., \omega_K\}$ be the number of channels occupied by the respective class of users. The psuedocode for the channel allocation procedure of PS for K networks is shown in Table I.

TABLE I
PSEUDOCODE FOR PRIORITIZED RESOURCE SHARING FOR K INTEGRATED NETWORKS

```
For a Channel Allocation Request from Network k_i
  If sum_{i=1}^{K} ω_i < N
    Allocate the free channel
    ω_i = ω_i + 1
  ElseIf ω_i < η_i
    G = {χ_j | ω_j > η_j}
    Queue the most recent request among the networks in G
  Else
    The request is blocked.
  End
```

The analytical model of PS algorithm is discussed in the following subsection.

III. Analytical Model and Performance Measures

Two dimensional Markov chain is used to model PS algorithm. The corresponding Markov state diagram is illustrated in Fig. 4. Each state, in the Markov chain represents the number of occupied channels of which i and j represent number of WiMax and WiFi users respectively. $P(i, j)$ represents the probability of i WiMax users and j WiFi users in the system. The WiMax and WiFi traffics are assumed to follow a Poisson arrival process with mean rates λ_{WiMax} and λ_{WiFi} respectively. They have a negative exponential service time distribution with mean rate $1/\mu_{WiMax}$ and $1/\mu_{WiFi}$ respectively. For the sake of clarity, λ_{WiMax} and λ_{WiFi} are represented as λ_b and λ_a respectively in the figure and the following equations. There are a total of N channels of which s are prioritized to WiMax traffic and the rest to the WiFi traffic.

By applying the flow-equilibrium analysis on the model in Fig. 4, the state probability $p(i, j)$ can be derived as shown in Eq.1 with the initial condition as shown in Eq.2.

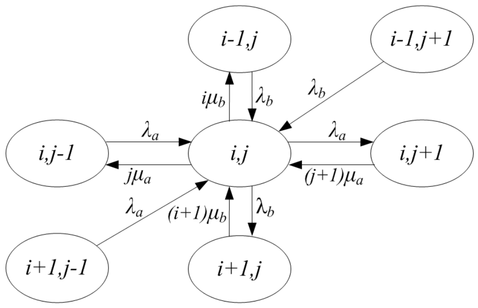

Fig. 4. Markov Model of WiMax and WiFi integration using prioritized channels.

TABLE II
DEFINITIONS OF BOOLEAN VARIABLES

Condition	Boolean variable values
If $i = 0$	$\delta_3 = 0$ else $\delta_3 = 1$
If $j = 0$	$\delta_4 = 0$ else $\delta_4 = 1$
If $(i + j) \neq N$	$\delta_1 = 0$, $\delta_2 = 0$
If $(i + j) = N$ && $i < s$	$\delta_1 = 1$, $\delta_2 = 0$
If $(i + j) = N$ && $i > s$	$\delta_1 = 0$, $\delta_2 = 1$
If $(i + j) = N$ && $i = s$	$\delta_1 = 1$, $\delta_2 = 1$

$$\begin{aligned} p(i,j) &= \left[p(i-1,j)\lambda_b + \delta_1 p(i-1,j+1)\lambda_b\right]\delta_3 \\ &+ \left[p(i,j-1)\lambda_a + \delta_2 p(i+1,j-1)\lambda_a\right]\delta_4 \\ &+ \left[(i+1)p(i+1,j)\mu_b + (j+1)p(i,j+1)\mu_a\right](1-\delta_1) \\ &(1-\delta_2)/\left[\lambda_a(1-\delta_1) + \lambda_b(1-\delta_2) + j\mu_a + i\mu_b\right] \end{aligned} \quad (1)$$

where δ_1, δ_2, δ_3, δ_4 are Boolean variables defined in Table II.

$$\sum_{i=1}^{N}\sum_{j=1}^{N-i} p(i,j) = 1 \quad (2)$$

Performance Parameters

The performance parameters to evaluate the proposed scheme are Blocking probability and Channel Utilization.

Blocking probability is a measure of QoS of service offered by the allocation algorithm. Suppose that the set S contains all the possible states, $S = \{(i,j)|(i,j) \leq N\}$. Since s channels are prioritized to WiMax traffic, WiMax will suffer blocking only in those states in which WiMax users have occupied more than s channels. Suppose, all the states where WiMax users suffer blocking are represented as $H_{WiMax} = \{(i,j)|(i,j) \in S, i \geq s\}$ and the states where WiFi users suffer blocking are, $H_{WiFi} = \{(i,j)|(i,j) \in S, i \leq s\}$.
Then the Blocking probability of WiMax users is given by the expression,

$$B_{WiMax} = \lambda_{WiMax} \sum_{(i,j)\in H_{WiMax}} p(i,j) \quad (3)$$

and the expression for Blocking probability of WiFi users is,

$$B_{WiFi} = \lambda_{WiFi} \sum_{(i,j)\in H_{WiFi}} p(i,j) \quad (4)$$

Channel utilization is the measure of how efficiently the band is shared using the specified allocation algorithm. It is defined as the average number of occupied channels and can be derived as,

$$U_{Total} = N \times 100 \sum_{(i,j)\in S} (i+j)p(i,j) \quad (5)$$

The percentage of occupied channels shared by WiMax users and WiFi users are referred to as WiMax Channel utilization and WiFi Channel Utilization respectively and are derived as shown in Eq. 6 and 7. Such a measurement is important to see if one class of traffic is chocked due to the heavy traffic of other class of users.

Percentage of WiMax Channel Utilization,

$$U_{WiMax} = \frac{N \times 100}{U} \sum_{(i,j)\in S} ip(i,j) \quad (6)$$

Percentage of WiFi Channel Utilization,

$$U_{WiFi} = \frac{N \times 100}{U} \sum_{(i,j)\in S} jp(i,j) \quad (7)$$

The performance parameters will be used in simulations to evaluate the proposed algorithm in the next section.

IV. SIMULATION RESULTS

In this section, the Prioritized Sharing scheme is compared with complete sharing, complete partitioning and hybrid sharing. The blocking probabilities and the channel utilization of these allocation schemes are studied. The definitions of these performance parameters are provided in Eq.3 to Eq.7.

A. Simulation Parameters

WiMax and WiFi network integration architecture is considered as shown in Fig. 1. The traffic from WiFi-Wimax bridges are just referred to as WiFi traffic and the traffic from WiMax subcriber stations is referred to as WiMax traffic as mentioned earlier. Both the traffics are assumed to have Poisson arrivals with average arrival rates of λ_{WiFi} and λ_{WiMax} for WiFi and WiMax traffic respectively. λ_{WiFi} and λ_{WiMax} are varied from 0 to 1. The average service rates are $\mu_{WiFi} = \mu_{WiMax} = 0.005$ all through the simulations. The total number of channels, N is equal to 10. Channel accessiblity for WiMax and WiFi traffic for the simulations is summarised in Table. III. 'Shared channels' mean that the channels are accessible by any type of users. 'Reserved channels' mean that the channels are allocated for a particular class of users and others can't access them. 'Prioritized channels' mean that the channels are accessible by all users but priority is given to the particular type of users to whom the channels are prioritized as discussed in Section II.

TABLE III
CHANNEL ALLOCATION

Allocation Algorithm	WiMax Accessible Channels	WiFi Accessible Channels
Complete sharing	10 shared	10 shared
Complete Partitioning	7 reserved	3 reserved
Hybrid Sharing	4 reserved, 3 shared	3 reserved, 3 shared
Prioritized Sharing	10 shared, 7 prioritized	10 shared, 3 prioritized

B. Results and Discussion

1) Blocking probability: The first graph, Fig. 5 shows the blocking probability of WiMax users with varying WiFi users traffic. WiMax arrival rate, λ_{WiMax} is set to 0.5. It can be observed that the blocking probability of PS scheme is the least. In CS scheme, as the WiFi traffic increases, more channels are allocated for WiFi traffic and the so the WiMAX user traffic suffers higher blocking. In CP Scheme, as the seven reserved WiMax channels can not be accessed by the WiFi users, the blocking probablity remains constant and this scheme is considered to provide ideal QoS by assuring seven channels for WiMax users. Since, PS scheme also assures seven channels for WiMax traffic if needed, the blocking probability is almost the same as CP scheme. It is infact lower than in CP, because the WiFi channels are also accessible to WiMax users when needed. So PS scheme assures QoS better than other allocation methods.

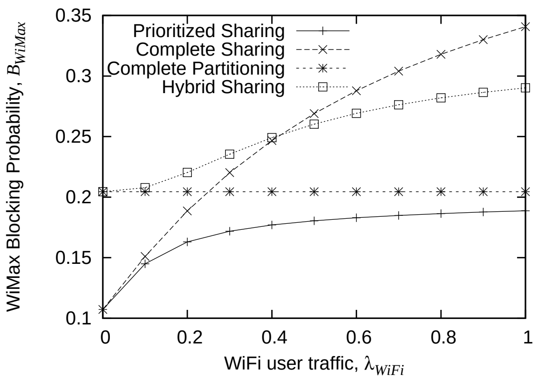

Fig. 5. Blocking probability of WiMax Users with varying WiFi user traffic.

The second graph, Fig. 6 shows the blocking probability of WiFi users for varying WiFi traffic and constant WiMax traffic. In this case CS should provide the least blocking, because all the channels can be used by the WiFi users. Since PS allocation also allows the WiFi users to access all the channels and also since they have priority over three channels, it has lesser blocking than CS scheme. Similarly, as WiMax traffic is varied and WiFi traffic is constant, PS offers least blocking to WiFi users as shown in Fig. 7. In both these cases, CP has the highest blocking because only three channels are accessible by WiFi users.

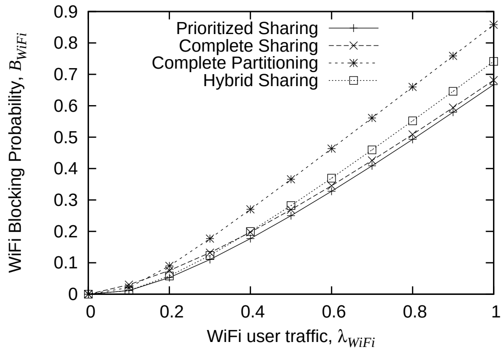

Fig. 6. Blocking probability of WiFi Users with varying WiFi user traffic.

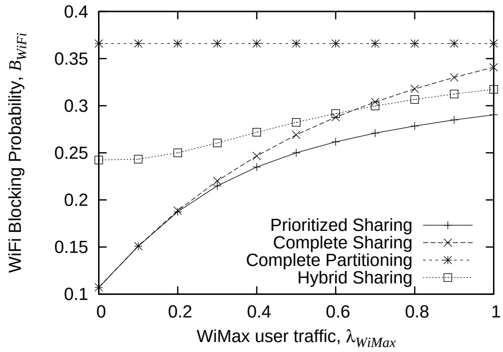

Fig. 7. Blocking probability of WiFi Users with varying WiMax user traffic.

Fig. 8 shows the blocking probability of WiMax users as their traffic is varied keeping the WiFi traffic constant. Again, CS should have provided the least blocking because all the ten channels are accessible to the WiMax users. But, due to prioritization of channels in PS allocation, PS scheme offers the least blocking than any other allocation method.

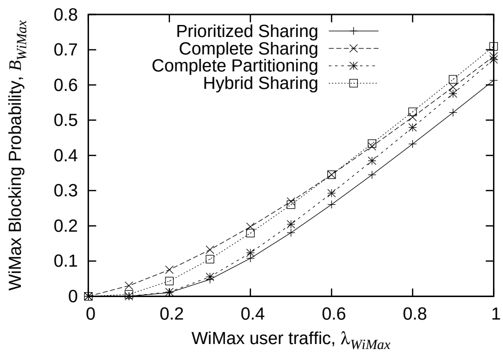

Fig. 8. Blocking probability of WiMax Users with varying WiMax user traffic.

2) Channel Utilization: In this section, the total percentage channel utilization and the WiMax, WiFi channel utilization as defined in section III are studied. Fig. 9 shows the Total channel utilization of the channels as WiFi user traffic is varied and WiMax traffic constant. As was discussed, total channel utilization of CS scheme is ideal since all classes of users can access all channels. Since, PS carries the same property that any channel can be accessed by any class of users when they are free, the channel utilization is exactly equal to CS. Complete partitioning has the least channel utilization because free channels of one class of users can not be utilized by other class of users and hence they lay idle.

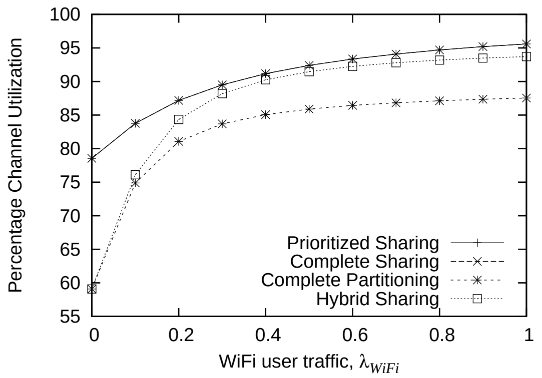

Fig. 9. Total Percentage Channel Utilization with varying WiMax user traffic.

Fig. 10 summarizes the advantages of PS by showing the Total and WiMax channel utilization together. Each bar represents the total channel utilization and the shaded region of each bar represents the WiMax share of the utilized channels. The shaded region of CS shows that as the WiFi traffic is increased the WiMax users are chocked and their share of the channels goes down. In CP, though the WiMax traffic share is preserved due to reservatio, the channel utilization is reduced. The hybrid allocation scheme has intermediate values. The PS allocation method chooses the best out of CS and CP schemes and has the channel utilization of CS and WiMax share as of CP, both of which are achieved by prioritization of channels.

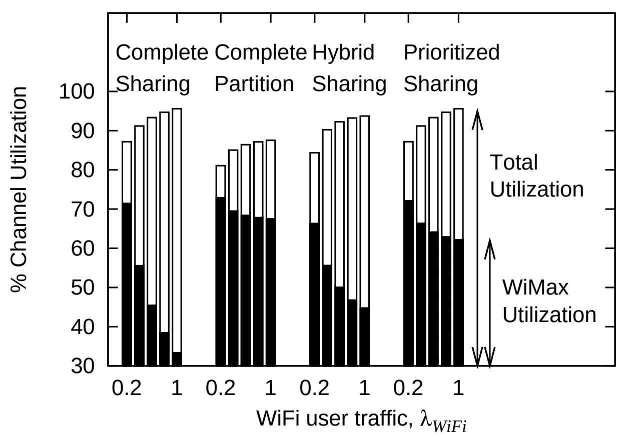

Fig. 10. Total Percentage Channel Utilization with varying WiMax user traffic.

V. Conclusion

Design of efficient resource allocation algorithms are very important in integrated networks in order to ensure efficient bandwidth usage and fair access to all the participating networks. In this paper, *Prioritized Sharing* (PS) algorithm is proposed for resource sharing in WiMax-WiFi integrated networks and later extended to application in multiple integrated networks. The Complete Sharing (CS) approach which is well studied in literature offers best channel utilization and Complete Partitioning (CP) approach assures minimum quality of service to each class in terms of allocated channels. *Prioritized Sharing* algorithm is designed such that the best of the two algorithms is achieved. The algorithm was modeled and analyzed using two dimensional continuous time markov chains. It is observed through simulations that PS resource sharing algorithm offers least blocking probabilities and highest channel utilization for WiMax and WiFi users compared to other models.

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