Channel Allocation for Broadband Fixed Wireless Access

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Abstract

Existing channel allocation methods are usually implemented for voice oriented services where the aim is to reduce the call blocking and call dropping rate. In this paper, we will investigate channel allocation schemes appropriate for data oriented services in a Broadband Fixed Wireless Access network where the aim is to reduce interference and improve overall packet throughput. A Fixed Channel Allocation (FCA) scheme employing a Genetic Algorithm (FCA-GA) that is not constrained by a compatibility matrix is proposed. The performance of the proposed FCA-GA scheme is simulated in a small network with a static interference environment and these results are used as a benchmark for three other distributed Dynamic Channel Allocation (DCA) schemes namely, the Random Channel Allocation (RND), Least Interfered Method (LI) and DCA using a Genetic Algorithm DCA-GA. It is shown that the Signal to Interference Ratio (SIR) performance of the DCA-GA scheme is reasonably close to that achieved by FCA-GA. The performance of LI is inferior to that of DCA-GA and RND has the worst performance of all.

Keywords

Dynamic Channel Allocation, Genetic Algorithm

I. INTRODUCTION

Broadband Fixed Wireless Access (BFWA) is one of many last mile solutions available. It has the advantage that it can be deployed quickly, covering a large geographical area at a low cost compared with a wireline solution. The primary BFWA system components are the Subscriber Unit (SU), the Access Point (AP) and the Control Server (CS). The SU is mounted at the subscriber's premises and uses a directional antenna to communicate with the AP. An AP uses a sectored antenna to cover the geographical region where the SUs are deployed. Several APs are connected to a CS where authentication and management functions are provided. The CSs are further connected to a central facility where network monitoring, billing and connection to a gateway occur. A typical BFWA system has limited spectrum and hence to cover a large geographical area, the channels are reused. Channel reuse causes co-channel and adjacent channel interference and this will lower the capacity of the system. Channel allocation is used to reduce interference and thereby improve the overall Signal to Interference Ratio (SIR).

The channel allocation problem is defined as allocating a total number of channels in the system, C, to M APs where each AP has a specified traffic demand. In order to allocate a channel, information either in the form of current measurements or from prior estimates concerning the interference or traffic environments are required. The more timely the information that is gathered the better the channel allocation decision is likely to be. However, gathering information may cause delay, consequently the information needs to be gathered and used efficiently. The existing channel allocation methods can be classified using a Channel Allocation Matrix [1], which categorizes the schemes according to the methods employed in obtaining interference and/or traffic information. Citations to channel allocation schemes in each quadrant of the Channel Allocation Matrix are shown in Figure 1.

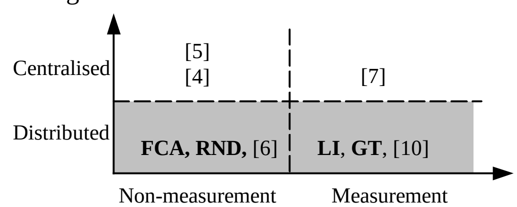

Figure 1. Channel Allocation Matrix

In most publications, channel allocation is applied to voice based system where the aim is to minimize the call blocking and call dropping rate. In contrast the aim of channel allocation in a data oriented service is to improve the overall data throughput by reducing the interference power at each AP and SU.

In order to ensure an acceptable interference level at each AP, most channel allocation schemes conform to a compatibility matrix. A compatibility matrix specifies the channel (e.g. frequency) spacing required between two APs so that co-channel and adjacent channel interference is acceptable. Channel allocation is classified as a NP-complete problem and an optimal solution may not be found in a large network of APs. For a given network conforming to a specific compatibility matrix, a solution may not be found even in a small network [5]. The compatibility matrix is usually assumed to be given and in cases where it is not given, it needs to be constructed.

In this paper we look at channel allocation for a data oriented service in a BFWA network. The Media Access Control (MAC) layer of the BFWA system under consideration is described in Section II. We will focus on the lower (distributed) half of the Channel Allocation Matrix shown shaded in Figure 1. The channel allocation schemes considered in this paper do not require a compatibility matrix and are used to reduce the interference power at each AP. The channel allocation schemes considered are the proposed Fixed Channel Allocation (FCA) scheme using a Genetic Algorithm, and 3 DCA methods namely, Random Channel Allocation (RND), the Least Interfered Method (LI) and DCA using a Genetic Algorithm (DCA-GA). These schemes are described in Section III. Section IV details the simulation and results and Section V gives the conclusion.

II. SYSTEM DESCRIPTION

The APs in the BFWA network under consideration are assumed to be asynchronous with each other. Asymmetric time division duplex (TDD) with Packet Reservation Multiple Access (PRMA) is used as the MAC layer [8]. The structure of single MAC frame is shown in Figure 2. When DCA is employed the SCAN portion of the MAC frame is used by the AP to measure the interference power of say N channels. The DCA scheme then selects one channel to be used. In the transmit portion, the AP and SUs take turns to transmit depending upon their traffic load. The length of the transmit portion for AP j in a single MAC frame is defined as $\mu_j(t)$ at time t.

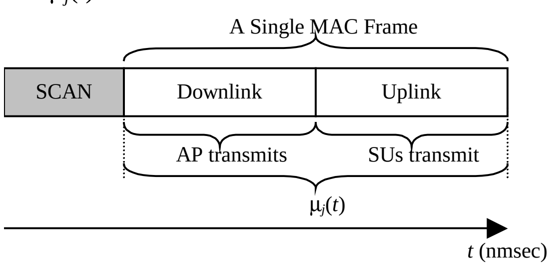

Figure 2. A single MAC frame structure

The channel selected for use after a SCAN has been performed is used for F MAC frames. The period between two consecutive SCANs is defined as T. Time is measured in normalized seconds (nmsec) where a nmsec is the transmission delay of a data packet by an AP or SU. In this paper, a data packet is of fixed size (an ATM cell).

III. CHANNEL ALLOCATION METHODS

Channel allocation is a NP-complete problem and hence an optimal solution for a large network may not be feasible. In this paper we aim to find a sub-optimal solution for a small network in a static interference environment.

A. FCA Using Genetic Algorithm (FCA-GA)

In FCA a channel is permanently allocated to an AP for all time. The FCA method lies in the lower-left quadrant of the Channel Allocation Matrix, hence it does not make use of any current interference information. However, it uses a-priori knowledge of the network and assumes that it does not change when the network is operational. Hence FCA is unable to adapt to interference changes, which is critical particularly in a network operating in unlicensed spectrum. However we will assume that the interference environment does not change and consequently FCA has global knowledge of the entire network and so will perform better than the DCA methods – where each AP has only partial and local knowledge of the interference environment. Also, we are looking at a small network where the FCA-GA is able to find a good sub-optimal solution. The performance of FCA-GA will thus acts as a benchmark for the other DCA methods.

The a-priori information used in this method (FCA-GA) is the number of APs M, the positions of the APs and SUs, the antenna radiation pattern of the AP and the propagation model of the wireless channel.

Channel utilization is defined as the average number of APs using a particular channel and the aim is to achieve uniform channel utilization. If the utilization is not uniform across the channels, the APs using the highly utilized channel may experience higher levels of interference. Hence, to be fair to all APs, the APs are divided equally among the C channels in the system. This can be represented as the string shown in Figure 3, where C = 3 and M = 9. The elements in the string are the AP identities. In the example of Figure 3, AP 5, AP 2 and AP 8 are assigned to Channel 1. The string is also a possible channel assignment and this can be a daunting combinational problem for larger values of C and M. A genetic algorithm is employed to search for a sub-optimal string (i.e. a channel assignment).

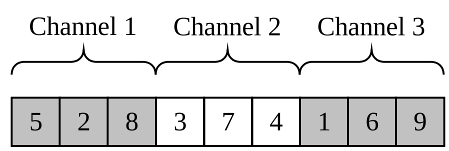

Figure 3. String representation of a channel assignment

In a genetic algorithm [9], an initial population of individuals is subject to an iterative process consisting of Selection, Crossover and Mutation operations as shown in Figure 4.

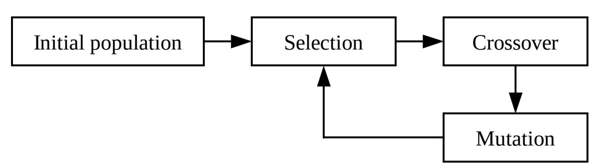

Figure 4. Operations in a genetic algorithm

Each individual is represented by a string as shown in Figure 3 and each individual is assigned a fitness value. The fitness function at the t^{th} iteration is given as:

$$F(t) = \sum_{i=1}^{C} F_i(t) \tag{1}$$

Where i is the channel number ranging from 1 to C and $F_i(t)$ is given as:

$$F_i(t) = \sum_{j=1}^{c_i} \sum_{\substack{k=1 \\ k \neq j}}^{c_i} \begin{bmatrix} P_{Aj,Ak}(t) + P_{Aj,Sk}(t) + \\ P_{Sj,Ak}(t) + P_{Sj,Sk}(t) \end{bmatrix} \quad (2)$$

In a TDD system, interference can arise in 4 ways: AP to AP, AP to SU, SU to AP and SU to SU. The fitness function takes into account these mechanisms so, $P_{Aj,Ak}(t)$ is the received interference power at AP j from AP k at iteration t and c_i is the total number of APs using channel i. $P_{Aj,Ak}(t)$ depends upon the antenna pattern and the positions of AP j and AP k. Similarly, $P_{Aj,Sk}(t)$ is the received interference power at AP j from SU k, $P_{Sj,Ak}(t)$ is the received interference power at SU j from AP k, and $P_{Sj,Sk}(t)$ is the received interference power at SU j from SU k. This is a negative fitness function where the lower the value the better the assignment. Hence the APs using the same channel will be placed as far apart as possible from each other so that the interference power is minimized.

Tournament selection is used whereby two individuals are selected randomly from the population and the individual with the lower fitness value has a probability p_k of being selected for the next operation.

A partially mapped crossover method [10] is used to avoid two channels being used by the same AP. Each individual is subjected to mutation with a probability p_m, where two random elements in the string are swapped.

The final channel assignment is selected from the individual with the best fitness after G iterations.

B. Random Channel Allocation (RND)

RND is also located in the same quadrant as FCA-GA and hence does not require measured or centralized knowledge of the network in order to allocate a channel. Unlike FCA methods, RND does not require a-priori knowledge of the network.

In RND, a channel is randomly selected based on a uniform distribution at the start of every MAC frame without any measurement (i.e. $N = 0$). This method is simple and very effective for a system with a high number of available channels.

C. Least Interfered Method (LI)

In the LI method, each AP measures the interference power of all available channels (i.e. $N = C$) and selects the channel with the lowest interfered power [2]. In this BFWA network, the selected channel is used for X MAC frames such that the period between two SCANs is T. The period T is selected so that its packet throughput (irrespective of the SIR) is equivalent to that in DCA-GA.

D. DCA Using Genetic Algorithm (DCA-GA)

The DCA-GA [1] has two subsystems. The first subsystem is at the AP and is responsible for measuring the interference power of the channels in an ordered list and selecting a channel. The second subsystem is at the CS and is responsible for creating the ordered list for each of the APs belonging to it.

The AP needs only to measure $N = N_S$ out of C available channels and selects the first channel that has an interference power below a threshold. The interference power measurements are sent to the CS.

The CS selects N_S out of the available C channels and ranks these channels for each AP. This can be a large combinational problem and therefore the CS uses a genetic algorithm to form the ordered lists for each AP. The genetic algorithm is performed when the network is operational and it uses the interference power measurements from the AP and a memory of each AP's previous channel ordered list. The fitness function balances whether to explore different channel lists or to exploit the current channel list that is performing well.

The APs do not wait for updates from the CS to make a channel allocation decision but use the existing ordered lists. The system uses partially centralized information and this reduces the number of measurements required by each AP. Since the APs and CS operate asynchronously the AP has the speed of a distributed system with the advantage of partially centralized knowledge. The system is able to achieve long-term frequency coordination among the APs.

IV. SIMULATION AND RESULTS

The performances of FCA-GA, RND, LI and DCA-GA are compared via a simulation using OPNET Modeler. The scenario considered in this paper is a small network with 50 APs and 277 SUs non-uniformly distributed over 7 cells with the layout shown in Figure 5. This gives rise to a non-uniform traffic distribution among the cells. The cell radius is 0.5 km and the interference environment does not change during the simulation. The results are collected from the 3 shaded cells shown in Figure 5.

An ON-OFF model using Pareto distribution is used to generate self-similar traffic typical of a packet data network in both the AP and SU [1]. The minimum OFF and ON periods are selected such that it resembles an assumed average file size of 13.9 kbytes, which is typical in web browsing applications [3].

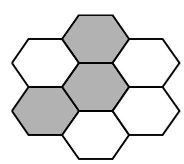

Figure 5. Simulation cell layout

A Random Height path loss model [1] is used to represent the BFWA wireless channel. This propagation model has a path-loss exponent of 2 for distances up to 1km and an exponent of 3.8 thereafter. The lognormal shadow standard deviation is 3.5 dB. Only co-channel interference and thermal noise (at the receiver) are considered in this simulation. The total number of channels C is 15.

Figure 6 shows the performances of the channel allocation schemes in terms of received SIR cumulative distribution functions (CDFs). The curve shown is the combined downlink and uplink performance for all the shaded cells in Figure 5. It can be seen that FCA-GA has the best SIR performance while RND has the worst SIR performance. FCA-GA has prior knowledge of the entire network, which remains the same during network operation and as a consequence it is able to make better allocations compared to RND, which does not make use of prior or current information concerning the interference environment. The SIR performance of LI and DCA-GA lie between that of FCA-GA and RND since LI and DCA-GA have only partial and local knowledge of the interference environment. In LI and DCA-GA, the channel selected by an AP may affect other APs and therefore frequency coordination among each other is difficult. However, DCA-GA is able to use partial centralised knowledge and knowledge of the interference environment to achieve better frequency coordination among the APs. This gives it a better performance than LI. Hence, the performances of the distributed DCAs that have access to partial information of the environment is bounded by that of RND and FCA-GA.

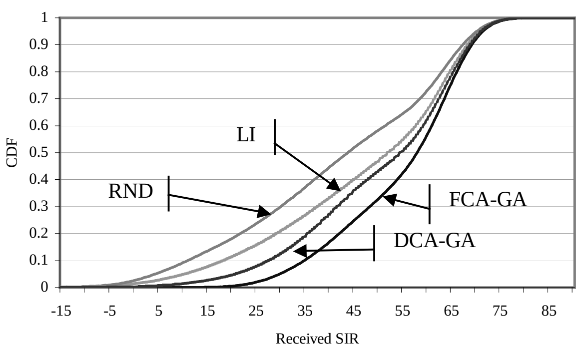

Figure 6. Received SIR CDF

Table 1 lists the 1-percentile SIR and average packet throughput for the channel allocation schemes. The 1-percentile SIR means that there is a 0.01 probability that the received SIR is below this value. The average packet throughput, π_{AVG} is the number of successful data packets that can be transmitted per AP per nmsec. A data packet is considered to be successfully transmitted if its received SIR is at least 21 dB. FCA-GA has a 1-percentile SIR gain of at least 14.5 dB over the best DCA method. This is due to the good SIR performance of FCA-GA. DCA-GA has the second best 1-percentile performance at 8 dB and RND has the worst 1-percentile performance at –4.5 dB. LI and DCA-GA need to spend time measuring the interference power of the environment and hence will lose efficiency compared with FCA-GA and RND. However, due to the poor SIR performance of RND, it has a lower successful throughput π_{AVG} than LI and DCA-GA.

Table 1. One percentile SIR and average throughput

	FCA-GA	RND	LI	DCA-GA
1% SIR	22.5 dB	-4.5 dB	-1.5 dB	8 dB
π_{AVG}	0.993	0.808	0.848	0.922

Although the average total packet throughput of DCA-GA and LI are arranged to be the same, DCA-GA is able to achieve frequency coordination among the APs and consequently has a better SIR performance than LI. Hence DCA-GA has a higher π_{AVG} than LI.

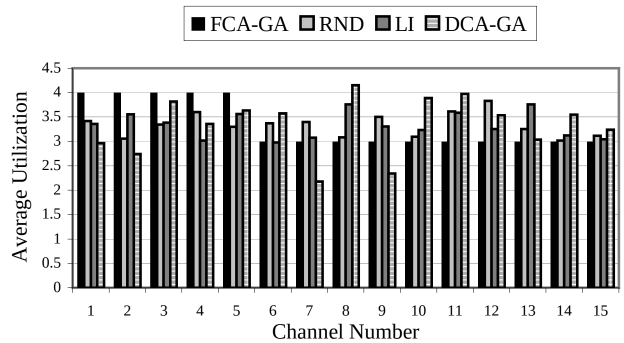

Figure 7. Channel utilization - Average APs per channel

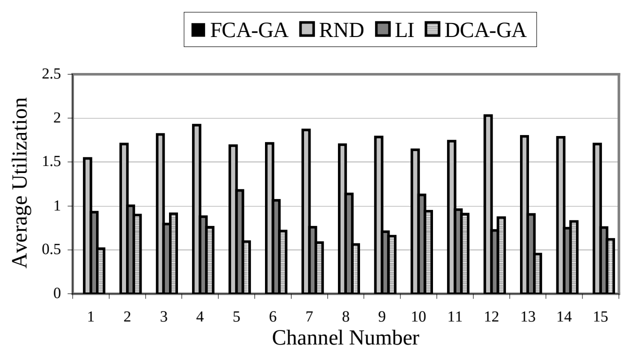

Figure 8. Channel fluctuation - Standard deviation

Figure 7 is the channel utilization for each channel allocation method. Channel utilization is defined as the average number of APs per channel. Figure 8 shows the channel fluctuation for each channel allocation method. Channel fluctuation is defined as the standard deviation of the channel utilization. In FCA-GA the number of APs per channel is fixed at the beginning and never changes thus its channel fluctuation is zero. RND and LI channel utilization is uniform across all channels. However, RND has an average channel fluctuation of 1.76 compared to 0.91 in LI. The higher channel fluctuation in RND is expected and is caused by the frequent channel changes at every MAC frame. LI is able to settle upon a channel for a longer period of time. DCA-GA has a channel fluctuation of 0.72, which is lower than that of LI. This is because DCA-GA was able to achieve frequency coordination among the APs and hence converges to a channel usage thereby causing less channel fluctuation.

In a measurement based DCA, the measured interference power performed during the SCAN portion may change significantly during the transmit portion if the channel fluctuation is high. Hence, it is desirable to have low channel fluctuation in a measurement based DCA.

V. CONCLUSION

Channel allocation schemes conforming to a compatibility matrix may not have an optimal solution and schemes that adapt to traffic changes (i.e., which require more than the minimum number of transceivers to be deployed at each AP) may not be economically feasible. A FCA method using a genetic algorithm (FCA-GA) is introduced and its performance is used as a benchmark for the DCA schemes to give a measure of the sub-optimality of the DCA solutions. The methods considered do not require a compatibility matrix and are used in a BFWA network offering data based services. The methods introduced are used to minimize overall interference rather than to adapt to traffic variations.

It is shown that the performance of the channel allocation schemes is dependent on the amount of information available. FCA-GA has complete prior knowledge of the entire network. Therefore in a static environment FCA-GA has the best SIR and packet throughput performance compared to the DCA schemes with a 1-percentile SIR gain of at least 14.5 dB and a packet throughput at least 7% higher than the best performing DCA scheme. RND does not make use of prior or current interference information and hence gives the worst performance. LI and DCA-GA have partial and local interference information and their performances lie between that of RND and FCA-GA. However, LI fails to achieve long term frequency coordinate and hence performs worse than DCA-GA. DCA-GA makes use of partial centralized information and partial measured information and so is able to achieve long term frequency coordination that leads to a SIR performance that is close to that of FCA-GA.

FCA-GA has zero channel fluctuation while RND has the highest channel fluctuation. For measurement based DCA methods DCA-GA, which has a lower channel fluctuation, performs better than LI since the APs are able to predict each other channel usage.

Channel allocation is a NP-complete problem and hence in FCA schemes its complexity increases with the size of the network. Therefore FCA may not provide a good solution in a large network, particularly those that do not have a static interference environment. In contrast distributed DCA methods are able to adapt to interference changes, they do not require prior planning and their complexity is the same regardless of the size of the network. However, due to partial information of the environment, distributed DCA methods may not produce a good SIR performance even for a small network as shown by the results obtained using RND and LI.

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