Dynamic Channel Allocation for Interference Avoidance in a Broadband Fixed Wireless Access Network

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***Abstract*— Existing Dynamic Channel Allocation (DCA) methods are usually applied to systems carrying connection oriented voice calls. In this paper DCA using a Genetic Algorithm (GA) is applied to a Broadband Fixed Wireless Access (BFWA) network that provides data services. The performance of the GA method is compared using a simulation with two other DCAs namely the Least Interfered (LI) and Channel Segregation (CS). It is shown that while the GA method converges to a SNR in excess of 20 dB, LI and CS fail to convege. Also GA has the highest throughput and is capable of adapting to interference and reconverging to a new stable state.**

I. Introduction

BFWA can be deployed rapidly and easily from scratch as compared to wireline especially in situations where cable cannot be easily or quickly installed. Fig. 1 shows a typical BFWA layout and components. The Subscriber Unit (SU) communicates with an Access Point (AP) using a directional antenna. An AP uses a sectored antenna to communicate with the SUs covered by it. Several APs can be connected to a Control Server (CSVR) where management and authentication are provided.

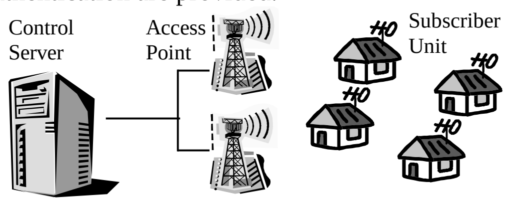

Fig. 1. Broadband fixed wireless access components and layout.

The channels in a BFWA network are usually reused and this causes co-channel and adjacent channel interference, giving rise to a low average Signal to Noise Ratio (SNR). Frequency planning is thus required to reduce these interferences. However this process is usually time consuming and not flexible. DCA can be employed in a BFWA network to reduce the frequency planning process by having the APs adapt to the interference environment. DCA can be used to avoid an interferer especially in a BFWA operating in an unlicensed band.

Most existing channel allocation methods have been applied to systems carrying voice calls. This paper looks into channel allocation methods for a data oriented network. Section II describes two existing DCA methods namely the Least Interfered (LI) and Channel Segregation (CS) and proposes a new DCA method using a Genetic Algorithm (GA). A simulation is performed to evaluate the performance of these DCA methods and the results are presented in Section III. Section IV gives the conclusion.

II. DCA Methods

In this paper three DCA methods – CS, LI and GA are considered for use in a BFWA network for data service. The simulation assumes an asynchronous BFWA network using asymmetric time division duplex (TDD) with packet reservation multiple access (PRMA) [4]. The BFWA Medium Access Control (MAC) frame structure is shown in Fig. 2.

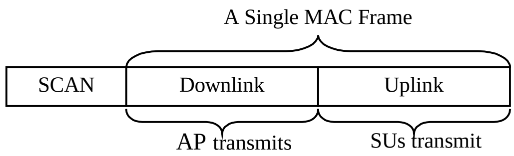

Fig. 2. A single MAC frame structure.

The AP broadcasts data packets to its SUs using the Downlink portion of the MAC frame and the SUs use the Uplink portion of the MAC frame to transmit data packets to their AP. The AP measures the interference power of the frequency channels during the SCAN portion of the MAC frame. The AP uses the measured interference power to select a single channel – based on one of DCA methods – to be used for the entire current MAC frame. The selected channel is assumed to reach all the SUs belonging to this AP. This process is repeated for every MAC frame.

In the LI method [1], the AP scans all available channels and selects the channel with the lowest interference power. If more than one channel shares the same lowest interference power, the channel used previously will be selected and if none were used previously, the channel with the lowest number is selected.

In the CS method [2] an ordered list is given to each AP and this list is updated according to interference conditions. The AP will scan the interference power for the highest priority channel in the ordered list and if the scanned interference power is below a threshold, this channel will be selected and the scanning process ends. If the highest priority channel does not meet the requirement, the next highest priority channel in the list is considered. If no such channel exists the lowest interfered channel is selected. The priority, P of each channel in the list is updated as follows:

$$P = \frac{N_A}{N_T} \qquad (1)$$

Where N_A is the number of successful uses of the channel and N_T is the total number of trials for the channel. The initial priority list can be arbitrary and is set to follow the channel number. When the system converges to a priority list, the amount of scanning can be reduced to one channel for every MAC frame.

The GA method has two subsystems – one responsible for scanning and selecting a channel and the other responsible for ranking the channels in a priority list having N_S channels per AP where N_S is a percentage of the total available channels. In the first subsystem, the AP scans a fixed number of channels N_S and selects the highest priority channel on the basis that the interference power is below a threshold. If no such channel is found, the highest priority channel is chosen to be that with the lowest interference power. The measured interference powers of these N_S channels are sent to the CSVR. The CSVR uses a genetic algorithm to select N_S channels out of the total number of available channels and then ranks these selected channels for each AP. The set of ordered lists are then sent to the corresponding APs. In the GA method, the APs do not wait for updates from the CSVR to make a channel allocation decision but use their current priority list. Each CSVR is connected to a fixed number of APs forming a cluster without overlap (i.e. no one AP communicates with two CSVRs as compared with the situation where centralisation up to the interference neighbourhood is employed).

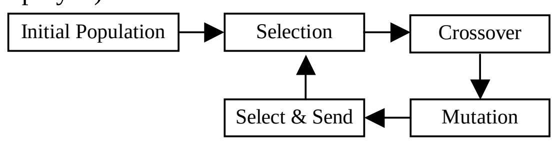

Fig. 3. Genetic Algorithm used by CSVR.

The CSVR uses the process shown in Fig. 3, which has an initial population and an iterative process consisting of Selection, Crossover, Mutation and Select and Send operations. These processes are found in a typical genetic algorithm [5].

The Control Server has a population of individuals N_P where each individual is a string that represents a concatenation of each AP's channel priority list. Each element in the string is a channel number. An example of an individual's string is shown in Fig. 4, where it is assumed that 3 APs are connected to a CSVR and each AP scans 5 channels (N_S = 5). The priority in each priority list decreases moving from left to right for *each* AP. The initial population is generated randomly.

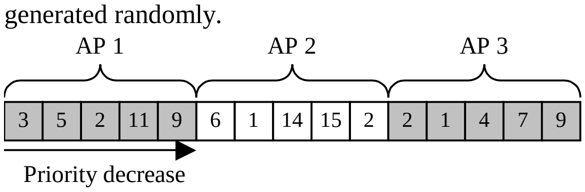

Fig. 4. An example of an individual's string representation.

The fitness value is evaluated for each of the N_P individuals using a fitness function. The fitness value is a measure of how good an individual is i.e. how good the channel priority order list is. Firstly, in a specific generation t, the fitness for the i^{th} priority order in the channel priority list is evaluated using (2).

$$F_i(t) = A\sum_{m=1}^{K} I_{i,m}(t) + B\sum_{m=1}^{K}\sum_{n=m+1}^{K} D_{i,m,n}(t) + C\sum_{m=1}^{K} S_{i,m}(t,t-1) \tag{2}$$

Where $1 \le i \le N_S$ and K is the total number of APs connected to the CSVR. Function $I_{i,m}(t)$ is the averaged measured interference power (in dBm) for the channel in the i^{th} priority position of AP m in the t^{th} generation. Function $D_{i,m,n}(t)$ is 1 if the channel number in the i^{th} priority position of AP m and AP n are different otherwise it is 0. This is to encourage the APs within the same CSVR to use different channels. Function $S_{i,m}(t,t\text{-}1)$ is 1 if the channel number in the i^{th} priority position of AP m at generation t and t-1 are the same otherwise it is 0. This is to encourage each AP to use previous channel. A, B and C are constants which weight the importance of functions $I_{i,m}(t)$, $D_{i,m,n}(t)$ and $S_{i,m}(t,t\text{-}1)$ respectively. Constant A is a negative value since we require the fitness value to be a positive monotonically increasing function. When C is set to a high value, the algorithm will tend to exploit the current channel combinations and thus will not cause the channel used for transmission to fluctuate. This enables APs associated with other CSVRs to better predict its channel usage. However, the network will converge quickly to a local optimum that may give poor SNR performance. On the other hand, if the constant C is low, the algorithm tends to explore different combinations that may produce a better SNR performance. This causes the transmission channel to fluctuate and so is less predictable causing instability. The constant C should be set to balance between exploration and exploitation. The overall fitness value for an individual at generation t is thus:

$$F(t) = \sum_{i=1}^{N_S} W_i F_i(t) \tag{3}$$

Where W_i is constant, which weights the importance of each element (i.e. priority order in the list). An example fitness function calculation for the string in Fig. 4 is shown in Fig. 5.

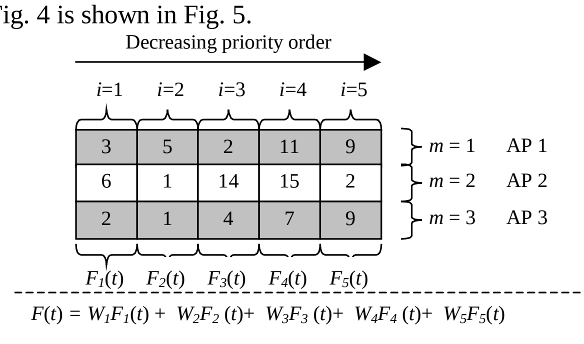

Fig. 5. An example fitness function calculation

After the fitness of each individual is evaluated, the Selection operation picks the top 50% of the fittest individuals for the Crossover operation. The Crossover operation uses a partially mapped crossover method [6]. In the Mutation operation, every element in each individual is subjected to mutation with a small probability p_m, where the channel number of each element is randomly changed. This is to encourage different channels to be explored.

At the Select and Send operation in Fig. 3, a new generation of individuals is produced and the fitness value for each of them is evaluated. The channel priority order lists for each AP is taken from the best individual's string and is sent to update the respective AP.

III. Simulation and Results

The three DCA methods are simulated using OPNET Modeler. A scenario with 37 cells is used with the layout as shown in Fig. 6, where each cell has a radius of 3 km. The simulation has 137 APs where each cell has from 2 to 6 APs giving a non-uniform traffic distribution. Boundary effects are reduced using this layout and measurements taken from the centre cell (with 6 APs) shown shaded in Fig. 6. A total of 920 SUs are distributed randomly in the layout. There are 14 CSVRs with a maximum of K = 10 APs per CSVR and N_S = 5 (in the GA method). At the start of the simulation, all of the APs transmit using the same channel causing the worst-case interference amongst themselves and consequently the APs need to adapt to this situation. The packet throughput (packet/normalised second) and received SNR response as a function of time are recorded for the shaded cell. A normalised second (nmsec) is the time required for an AP and/or SU to transmit an average packet (which has a fixed size in an ATM network).

In order to investigate the response of the network employing the GA to interference, two continuous wave (CW) sources each using an omni-directional antenna are placed in the shaded cell and after 14400 nmsec or 4 normalised hours (i.e. when the network has reached a stable state) they begin to transmit in channels already in use by two of the APs in the shaded cell. The interferer's EIRP is set to be 9 dB lower than the EIRP of the APs and they continue to transmit using these channels until the end of the simulation.

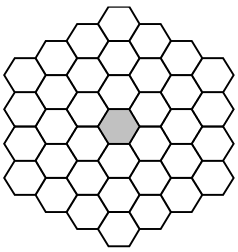

Fig. 6. Simulation layout

An ON-OFF model using a Pareto distribution is used to generate self-similar traffic typical of a packet data networks in both the AP and SU [7]. Pareto's probability distribution function is given by,

$$p(t \mid t > \beta) = \frac{\alpha\beta^{\alpha}}{t^{\alpha+1}} \tag{4}$$

Where β is the minimum OFF (or ON) period and $1 < \alpha < 2$. The values for α are 1.7 for ON-periods and 1.2 for the OFF-periods [7]. The value of β depends upon the data rate and average file size, which is assumed to be 13.9 kbytes for web browsing applications [3].

The radio propagation is assumed to follow the Random Height path loss model [8], which 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 are assumed in the simulation. The number of available channels is 15 each having a bandwidth of 15 MHz operating in the 5GHz U-NII band.

The temporal response for the uplink received SNR for the CS, LI and GA methods are shown in Fig. 7, 8 and 9 respectively. The CS and LI methods do not exhibit convergence in the received SNR since these methods do not achieve long-term frequency coordination among APs. Comparing Fig. 7 (CS) and Fig. 8 (LI) it can be seen that LI gives a better performance than the CS method with fewer received packets having a SNR below 20 dB. Fig. 9 shows that the GA method converges to a SNR in excess of 20 dB after about 1200 nmsec (0.33 normalised hours). For a system running at 25 Mbps, a normalised second is equivalent to 0.01696 ms (i.e. time required to transmit 424 bits or 1 ATM cell). Hence the centre cell takes 20 ms to converge to a stable state using the GA method.

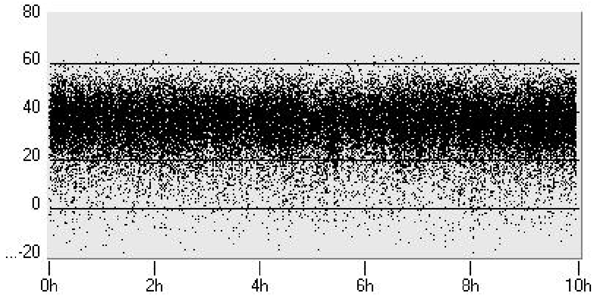

Fig. 7. CS - temporal response for uplink received SNR.

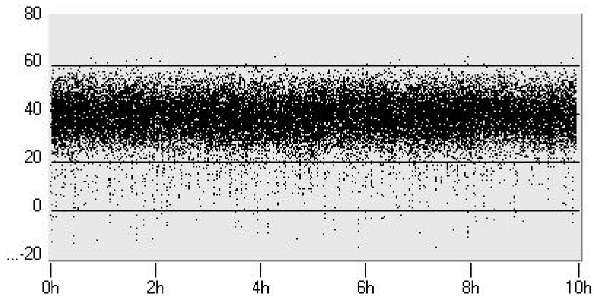

Fig. 8. LI - temporal response for uplink received SNR.

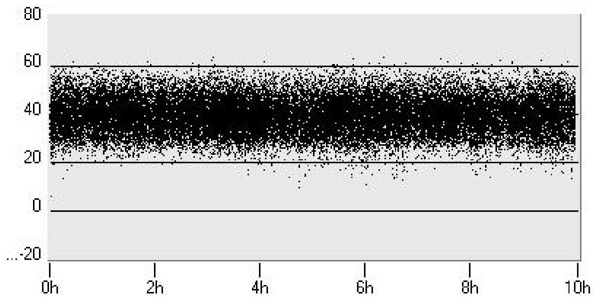

Fig. 9. GA - temporal response for uplink received SNR.

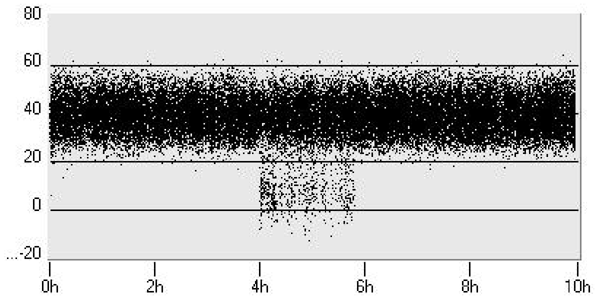

Fig. 10. GA - temporal response for uplink received SNR with 2 interferers.

TABLE I shows the packet throughput (packet/ normalised second) for uplink packets received by APs in the centre cell that have a SNR exceeding 18 dB [1]. The GA method has a 23% higher packet throughput than the LI method because the LI method needs to measure all channels before selecting one for transmission thereby causing packet delay and lowering packet throughput. In contrast the GA method scans a portion of all available channels thus raising throughput compared to the LI method. The CS method after settling upon a priority list needs only to scan one channel and hence has a higher packet throughput than the LI method. However, the CS method does not have a good SNR performance thereby more packets are received with a SNR below 18 dB resulting in a 4.3% lower packet throughput than the GA method.

TABLE I
PACKET THROUGHPUT FOR ALL APS IN CENTRE CELL (PACKETS/NORMALISED SECOND)

	CS	LI	GA
Throughput	1.143	0.916	1.194

Fig. 10 is the uplink received SNR as a function of time for the GA method with two interferers activated in the centre cell. The interferers cause the SNR performance to degrade when they start transmitting after 14400 nmsec (4 normalised hours). Initially the APs using the GA method select different channels that may interfere with other cells. These other cells in turn select other channels and this causes a chain reaction, introducing further interference in to the centre cell. Consequently a poor SNR performance is evident for a short duration of 6480 nmsec (or 109.9 ms in a 25 Mbps link) as shown in Fig. 10. Eventually the APs are able to select channels that cause the network to converge to a new stable state at 20880 nmsec or 5.8 normalised hours.

IV. CONCLUSION

Three DCA methods namely the CS, the LI and the proposed GA are simulated and their respective received temporal SNR responses and packet throughputs are compared. The GA method converges to a SNR in excess of 20 dB while the CS and LI methods do not converge. Even so the LI method has a better SNR performance than the CS method. The GA method has the highest packet throughput followed by the CS method with the LI method having the lowest packet throughput. The GA method is shown to be able to converge from the worst-case interference scenario at simulation start up and is also capable of adapting to interference and reconverging to a new stable state.

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REFERENCES

[1] Matthew Cheng and Li Fung Chang, "Wireless Dynamic Channel Assignment Performance Under Packet Data Traffic," *IEEE Journal on Selected Areas in Communications*, pp. 1257-1269, vol. 17, no. 7, July 1999.

[2] Yoshihiko Akaiwa and Hidehiro Andoh, "Channel Segregation – A Self-Organized Dynamic Channel Allocation Method: Application to TDMA/FDMA Microcellular System," *IEEE Journal on Selected Areas in Communications*, pp. 949-954, vol. 11, no. 6, August 1993.

[3] Justin C.-I. Chuang and Nelson R. Sollenberger, "Spectrum Resource Allocation for Wireless Packet Access with Application to Advanced Cellular Internet Service," *IEEE Journal on Selected Areas in Communications*, pp. 820-829, vol. 16, no. 6, August 1998.

[4] Shin Horng Wong and Ian Wassell, "Performance Evaluation of a Packet Reservation Multiple Access (PRMA) Scheme for Broadband Fixed Wireless Access," *Proc. In the London Communications Symposium 2001*, pp. 172-182, London, September 2001.

[5] Melanie Mitchell, *An Introduction to Genetic Algorithms*. London: The MIT Press, 1999.

[6] P. Larranaga, C. M. H. Kuijpers, R. H. Murga, I. Inza and S. Dizdarevic, "Genetic Algorithms for the Travelling Salesman Problem: A Review of Representations and Operators," *Artificial Intelligence Review*, 13(2), pp. 129-170, April 1999.

[7] Walter Willinger, Murad S. Taqqu, Robert Sherman and Daniel V. Wilson, "Self-Similarity Through High-Variability: Statistical Analysis of Ethernet LAN Traffic at the Source Level," *IEEE/ACM Transactions on Networking*, pp. 71-86, vol. 5, no. 1, February 1997.

[8] D. Crosby, "Propagation Modelling for Directional Fixed Wireless Access System," *Ph.D. dissertation, University of Cambridge*, 17 November 1999.