Energy Efficiency and Channel Allocation in P2PWRAN

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***Abstract*—IEEE 802.22 is proposed for reusing the TV channels with cognitive radio technology to build Wireless Regional Area Networks (WRANs). The cellular topology of a WRAN makes the spectrum management easy. However, this topology reduces the network capacity significantly, because in one slot only one user can be allocated with a channel. Therefore, Peer-to-Peer WRAN (P2PWRAN) is proposed, in which direct CPE-(Consumer Premises Equipment)-to-CPE intra-cell communication is supported. While increasing the network capacity significantly, reducing the total energy consumption is a challenge.The energy efficiency of nodes in the standard for WRAN is difficult to improve, since the transmission distance of nodes to the BS is relatively static. P2PWRAN enables to achieve higher energy efficiency through better possibilities of channel allocation. Channel allocation influences energy consumption and network capacity significantly. Channel allocation also affects the upper layers, for example the routing protocol. Therefore, guaranteeing the network performance and fairness amongst CPEs, while achieving green networks, needs cross-layer design. In this paper, we define the channel allocation problem in P2PWRAN and we recognize it as a Multi-objective Quadratic Programming (MOQP) problem. An Energy-aware Channel Allocation (ECA) algorithm is proposed for exploiting the P2PWRAN paradigm to achieve the lower communication energy consumption and higher network energy efficiency and throughput than simple greedy policies. ECA jointly considers the network layer and Media Access Control (MAC) layer. By controlling the parameters in ECA, the fairness of channel allocation can also be guaranteed.**

***Index Terms*—IEEE 802.22, WRAN, P2PWRAN, cognitive radio, channel allocation, power control, green networks.**

I. INTRODUCTION

Cognitive radio technology is proposed to reuse the licensed bands by allocating them to Secondary Users (SUs) without causing any harmful interference to the Primary Users (PUs) [1], [2]. The IEEE 802.22 standard is the first standard for cognitive radio networks using TV white spaces [3], [4]. It is developed for Wireless Regional Area Networks (WRANs) with a cellular topology by reusing the available TV channels. The very large coverage range (up to 100 km) design in WRAN is a unique feature compared to other well-known standards such as the IEEE 802.11, 802.15 and 802.16. The Base Station (BS) in a WRAN cell manages the spectrum and the Consumer Premises Equipment (CPE) using a centralized approach. To communicate with the BS, each CPE is equipped with two antennas. One omni-directional antenna is used for spectrum sensing and geo-location, and another one is directional for communication with the BS.

This WRAN cellular topology provides a convenient way to manage channels and prevent harmful interference to PUs. However, network capacity is limited by this topology. Firstly, in every Orthogonal Frequency-Division Multiple Access (OFDMA) slot only one CPE can be allocated because of co-channel interference. Secondly, even though channel-bonding has been suggested in the standard for WRAN, only one operating channel is allowed and no-adjacent channels cannot operate at the same time [3]. Moreover, CPEs far away from the BS consume more energy to transmit the same amount of data than CPEs closer to the BS in standard WRAN. If a fixed transmission power is adopted, then the link availability depends on the CPE to BS distance.

Peer to Peer WRAN (P2PWRAN) [5] supports direct intra-cell communication between CPEs. It is a subtle modification to the standard such that channel allocation mechanisms in the BS and the P2P support on the medium access control (MAC) layer. P2PWRAN allows the network capacity to be increased significantly, due to usage of multiple channels and reuse of same channel multiple times. This is possible due to the geographical distance and physical phenomena on the signals. Therefore, multiple CPEs may be allocated with the same slots. Another issue in this scenario is the energy usage. Since nodes in a P2P network cooperate with each other, a single node or a subset of nodes should not be *energy stressed*. Thus we study the energy efficiency of a CPE, which is defined as the ratio between the data that has been transmitted for the CPE itself and the total energy consumption in transmission. Furthermore, the energy consumption should be reduced to build “greener” networks [6].

While P2PWRAN enables opportunities, the extent of their exploitation depends on the channel allocation mechanism. Channel allocation needs to take care of power and energy since it has consequences on upper layers, for example route selection should be based on channel allocation for lower network latency. Therefore, in order to achieve green networks, channel allocation on MAC layer should be jointly considered with routing protocols. Hence through this paper, we contribute the following:

- Formulate the channel allocation problem as an Multi-objective Quadratic Programming (MOQP) problem.
- Propose an Energy-aware Channel Allocation (ECA) algorithm jointly considering network and MAC layers.

- Work towards a framework of channel allocation, in which all fairness amongst CPEs, energy efficiency and network performance can be guaranteed.

The rest of the paper is organized as follows. In Sec. II, we address the background and related work. Sec. III defines the allocation problem in P2PWRAN and proposes ECA. The simulation details and results are discussed in Sec. IV. The paper is concluded in Sec. V, and the further work is described in this section too.

II. BACKGROUND AND RELATED WORK

A. Peer to Peer IEEE 802.22 Networks

P2PWRAN is based on WRAN with an additional feature to support direct intra-cell communication between CPEs [5]. Power control strategies are adopted in P2PWRAN, which makes it possible to allocated one slot to multiple CPEs simultaneously. The BS controls the channel allocation as in WRAN. The following advantages can be seen in P2PWRAN compared to the standard WRAN:

- By using power control mechanisms, one OFDMA slot can be reused multiple times without causing interference.
- Multiple operating channels can be adopted in P2PWRAN to extend the network capacity.
- The standard WRAN intra-cell message paths are “CPE to BS and then back to CPE”. However, in P2PWRAN the new message paths include “CPE to CPE” and “CPE-CPE-CPE”, which decreases the the packet delay.
- The frame structure of P2PWRAN is the same as the standard WRAN. This ensures easy implementation of P2PWRAN. Only decision related mechanisms require modification at the BS side to support direct allocation.

To achieve the above features, some new challenges are introduced in P2PWRAN. For example, multi-channel and channel reuse in P2PWRAN turn the channel allocation into a complex problem. The link quality of the intra-cell communication may lead to an outage because of the fading. Additionally, interference control becomes more critical because multiple CPEs are transmitting or receiving simultaneously. This article mainly discuss the energy issues jointly on network and MAC layer.

B. Related Work

Some work related to energy consumption can be found in the literature. In [7], a routing mechanism to balance the energy consumption among nodes is developed to maximize the network lifetime limited to single channel scenarios. However, the energy consumption is balanced without considering other aspects of network performance. A cooperative scheme is proposed in [8] for cellular-Bluetooth networks. Fairness in energy consumption is jointly considered with the minimizing of total energy consumption of Bluetooth nodes whenever long distance communication is needed. However, other network performance in channel allocation is not considered. The work of Devarajan et al. in [9] developed an energy-aware resource allocation paradigm for cellular networks with multiple relays. Minimizing the total energy consumption of the BS and relays is considered as the goal of the paradigm. Further, an algorithm to avoid starvation of users is proposed. The network throughput is not considered as an objective of the paradigm. This might lead to severe decrease in the network capacity. The behavior of energy consumption and efficiency in users is also not studied. Similar problems can be seen in [10] which mainly studies the selection of relays in a generic noise and interference scenarios.

Most of the related work in the literature is for sensor networks or cellular networks with single channel instead of multi-channel allocation. Although P2PWRAN is a network that is managed in a centralized cellular topology, it also has the peer to peer feature. Therefore, the algorithms and schemes in the literature cannot be directly used for the channel allocation in P2PWRAN. Furthermore, energy issues are mostly discussed without considering the energy efficiency but restrict to energy consumption. By observing the gaps, we are motivated to propose an algorithm called ECA (Energy-aware channel allocation) that considers both energy efficiency, fairness, and network capacity by a cross-layer design.

III. CHANNEL ALLOCATION AND FAIRNESS IN P2PWRAN

In this section we formulate the channel allocation problem in P2PWRAN as a MOQP problem, then an algorithm is proposed to solve it.

A. Energy Efficiency

The fair spectrum sharing on MAC layer is discussed in [5], [11] as a multi-channel allocation problem in P2PWRAN. The objectives are to maximize the network utility and the fairness amongst CPEs, and it is a computationally hard problem. However, channel allocation also influences the energy consumption of CPEs significantly. Thus, we study channel allocation jointly with the energy efficiency and fairness within this paper. We define the transmission energy efficiency of CPE i in the time slot s as Eq. (1).

$$e_i(s) = \frac{D_i(s)}{TP_i(s)}, \tag{1}$$

where $P_i(s)$ is transmitting power of i, $D_i(s)$ is the transmitted data of CPE i for itself in T slots. Note that $P_i(s)$ can be either the power of transmitting the own data of i or the power of routing for other CPEs. On the contrast $D_i(s)$ excludes the routing data for other CPEs, and reflects the energy efficiency to its own performance. Furthermore, because transmitting consumes much higher energy than receiving, we only consider the transmi ssion energy efficiency in this step of our work.

According to Eq. (1), energy efficiency can be increased by reducing the transmission power if the same amount of data is considered. However in standard WRANs, CPEs only communicate with the BS directly and they are relatively immobile with constant distances to the BS. Therefore $e_i(s)$ is constant. If we consider the similar node throughput ($D_i(s)$),

$e_i(s)$ is decided by $P_i(s)$, which is mainly decided by the distance and environment between the transmitter (CPEs) and receiver (the BS). Hence, because of various distances, the energy efficiency of CPEs in standard WRAN is not fair and not able to be changed. However, in P2PWRAN, a CPE can communicate both with the BS and other CPEs at different distances, and route for other CPEs at the same time. In this case $P_i(s)$ is not constant anymore, which makes the balancing of $e_i(s)$ possible.

B. Problem Definition

We define a flow as a communication link between a transmitter and a receiver. We assume that the flow set, $\mathbb{F}$, includes all possible directional flows in the P2PWRAN and the element f_{ij} represents a flow from user i to j in the set of users U. Considering channel allocation at slot s, the allocation $\mathbb{A}(s)$ is a $|\mathbb{F}| \times |\mathbb{C}|$ matrix, and if the element $A_{(ij)k}(s) = 1$, then flow f_{ij} is allocated with channel k at time slot s, otherwise $A_{ijk}(s) = 0$. The interference map is $\mathbb{M}$, which is a $|\mathbb{F}| \times |\mathbb{F}| \times |\mathbb{C}|$ matrix. If the element $m_{(ij)(pq)k} = 1$ in $\mathbb{M}$, then flow f_{ij} and flow f_{pq} interfere with each other when they use the same channel k, otherwise $m_{(ij)(pq)k} = 0$. The interference map can be built before channel allocation due to radio propagation models [12] and the geo-locations of CPEs and the BS. We also define the channel utility as Eq. (2).

$$\mathbb{U}(\mathbb{A}(s)) = \sum_{i,j,k} A_{(ij)k}(s). \tag{2}$$

$\mathbb{U}(\mathbb{A}(s))$ is the total allocation times of channels, which also reflects the network capacity and throughput.

For fairness, we consider the long term fairness in spectrum sharing with Jain's index [13]. We define the fairness measurement $f_a(s)$ as Eq. (3).

$$f_a(s) = \begin{cases} 1 & \text{If } \mathbb{A}(s) = \mathbf{0}, \\ \dfrac{\left(\sum_i \sum_{j,k,s} A_{(i,j)k}(s)\right)^2}{|U| \sum_i (\sum_{j,k,s} A_{(ij)k}(s))^2} & \text{Otherwise.} \end{cases} \tag{3}$$

$\sum_{j,k,s} A_{(i,j)k}(s)$ is the total times user i has been allocated with channels in the past time slots. $f_a(s)$ measures the fairness in channel allocation and $0 < f_a(s) \leqslant 1$. When every user is allocated with the same number of slots, $f_a(s) = 1$.

Until slot s the energy efficiency of user i can be defined as $E_i(s)$ in Eq. (4) based on Eq. (1).

$$E_i(s) = \begin{cases} 0 & \text{If } \sum_s P_i(s) = 0, \\ \dfrac{\sum\limits_s D_i(s)}{\sum\limits_s TP_i(s)} & \text{Otherwise.} \end{cases} \tag{4}$$

Then we can formulate the channel allocation problem at slot s as the following MOQP problem:

$$\begin{cases} \max\left(\mathbb{U}(\mathbb{A}(s))\right), \\ \max\left(f_a(s)\right), \\ \max\left(\frac{\sum_i E_i(s)}{|U|}\right), \end{cases} \tag{5}$$

Subject to

$$\sum_{\forall k \in \mathbb{C}} A_{(ij)k}(s) \leqslant 1, \forall i, j; \tag{6}$$

$$\sum_{\forall i,j,p,q(i \neq j \neq p \neq q), \forall k \in \mathbb{C}} A_{(ij)k}(s) A_{(pq)k}(s) m_{(ij)(pq)k} = 0. \tag{7}$$

The goals (in Eq. (5)) of this problem are to maximize the network utility, fairness of channel sharing and the network average energy efficiency, and to minimize the total energy consumption at the same time. The goals of fairness and energy efficiency may have a trade-off with the network utility, because the optimal solution for fairness and energy efficiency may cause additional interference and achieve less network utility. Similarly, energy efficiency may not be maximized when every CPE has the fair accessing possibility. Therefore, it is unlikely to achieve the optimal values of the goals in each allocation. However, it is possible to guarantee all of the goals above certain level. Eq. (6) imposes the constraint that every flow can at most be allocated to a channel once in a slot. It also avoids the situation where two transmitters send messages to the same receiver in the same time slot. The constraint in Eq. (7) indicates that if two flows are allocated with the same channel, then they should not interfere with each other according to the interference map. We propose an energy-aware channel allocation (ECA) algorithm to solve it.

C. The Energy-aware Channel Allocation (ECA) Algorithm

In this section, we first discuss the greedy strategy and queuing strategies, then we propose the ECA algorithm based on them.

Greedy strategies [14] are widely used to solve computationally hard problems especially for vertex coloring problems. Vertices are queued according to their degrees; vertices with lower degree are assigned with colors first, because they have lesser chance of collision than others. For most of the cases greedy strategies can give acceptable results. Therefore, our queuing algorithm is based on greedy strategies to guarantee the network utility as shown in Algorithm 1.

Algorithm 1 The queuing algorithm.

```
for flow $f_{ij}$ in the request flow set $R$, do
  for flow $f_{pq}$ in $R$ and $i \neq j \neq p \neq q$, do
    // Search the interference map.
    if $m_{(ij)(pq)k}$ is equal to 1, then
      The collision degree $g_{ij} = g_{ij} + 1$.
    end if
  end for
end for
Queue the flows in $R$ as vector $\vec{R}'$ due to their collision degrees $g_{ij}$.
```

For the objectives of maximizing the fairness in channel allocation and energy efficiency, we add a condition as shown in Eq. (8) during the allocation of CPE i at current time slot s_1 to guarantee the long term fairness. For the long term fairness, we consider from the start of the network until current time slot s_1.

$$K_a \frac{|U| \sum_j \sum_{s=0}^{s_1-1} A_{(ij)k}(s)}{\sum_i \sum_j \sum_{s=0}^{s_1-1} A_{(ij)k}(s)} + K_e \frac{|U| E_i(s_1-1)}{\sum_i E_i(s_1-1)} \leqslant 1+\delta. \quad (8)$$

K_a and K_e are two factors that balance the channel allocation fairness and energy efficiency, and $K_a + K_e = 1$. δ is a factor to loosen the fairness constraints, and $0 \leqslant \delta \leqslant 1$. Note that when $K_a = 0$ and $K_e = 1$, an undesired case may happen during the allocation, which is no channel can be allocated at all. It is because the transmission power consumption depends on the distance of transmitting and receiving CPEs. If the previous transmission happened mostly within a short range, then the average energy efficiency might be very low. At the same time if all possible energy efficiency of the flows in request set R is higher than the former average energy efficiency, then the allocation is a deadlock and no channel can be allocated anymore. δ is introduced to decrease the possibility of the worst case.

Based on the greedy algorithm, the energy-aware channel allocation (ECA) algorithm is proposed as shown in Algorithm 2. $\overline{E(s)}$ is the average energy efficiency at slot s. CPEs send their requests to the BS of the cell and the BS makes the allocation decisions according to this algorithm. The intuition of the algorithm is to serve the lower degree requests first, since it attempts to minimize the interference chances and maximizes the network utility. If it does not interfere with the already allocated channels according to the interference map, then it is checked furthermore. If it is a BS request, then this request is allocated directly because the performance of the BS should be guaranteed. Otherwise, the constraint in Eq. 8 is evaluated. If Eq. 8 is satisfied and because of lower energy efficiency than average, then Algorithm 3 is employed to find a router (CPE) for this request, and this request becomes a request from the source to the router, and a request from the router to the destination. The router to destination request is added to the waiting list of next frame, but the sour to the router request is considered in the current frame. If it does not cause any interference, then it is allocated, otherwise it is added to the waiting list too. However, if Eq. 8 is satisfied and the reason is that this request is treated unfairly (has less than average allocation times), then it is allocated directly. All requests that are not able to allocated are moved to the waiting list for next frame allocation.

The routing protocol in Algorithm 3 shortens the communication distance of CPEs by routing messages in a multi-hop method, which increases energy efficiency and decreases energy consumption. An intra-cell multi-hop routing protocol is adopted in Algorithm 3, in order to increase the energy efficiency and network utility at the same time. The algorithm is used to find a router r for flow f_{ij}, such that $E_r(s-1) \geqslant \overline{E(s-1)}$ and r can provide the highest possible $E_i(s)$.

Algorithm 2 The energy-aware channel allocation (ECA) algorithm.

```
Add the elements in the waiting request set $R''$ into current request set $R$.
// Guarantee of network utility.
Queue the element in $R$ with Algorithm 1 as vector $\vec{R'}$.
for every flow request $f_{ij} \in \vec{R'}$ , do
  if there is still a channel $c$ that has never been allocated with any request, then
    Calculate the link budget and allocate $c$ to $f_{ij}$.
  else
    for every available channel $c_k \in \mathbb{C}$, do
      // Guarantee of no collision.
      if for every flow request $f_{pq}$ that is already allocated with $c_k$ in the current time slot, it is satisfied that $m_{(ij)(pq)k} == 0$, then
        // Guarantee of fairness and energy efficiency.
        if $i$ is the BS of the cell, then
          Allocate channel $c_k$ to $f_{ij}$.
          Calculate the link budget for $f_{ij}$ and allocate.
          // If $E_i(s-1)$ is low, then find a neighbour to route the package.
        else if Eq. (8) is satisfied and $E_i(s-1) < \overline{E(s-1)}$, then
          Find a router $r$ by Algorithm 3,
          //Check whether interference may happen.
          if for every flow request $f_{pq}$ that is already allocated with $c_k$ in the current time slot, it is satisfied that $m_{(ir)(pq)k} == 0$, then
            Allocate channel $c_k$ to $f_{ir}$.
            Calculate the link budget for $f_{ir}$ and allocate.
            Put $f_{rj}$ in the waiting request set $R''$.
          else
            Put $f_{ir}$ and $f_{rj}$ in the waiting request set $R''$.
          end if
          //If the allocation is not fair.
        else if Eq. (8) is satisfied and $i$ has lesser allocations than the average, then
          Allocate channel $c_k$ to $f_{ij}$.
          Calculate the link budget for $f_{ij}$ and allocate.
        else
          Move $f_{ij}$ into the waiting request set $R''$.
        end if
      else
        Move $f_{ij}$ into the waiting request set $R''$.
      end if
    end for
  end if
end for
```

TABLE I
PARAMETERS.

Parameters	Notations	Values
Number of nodes	N	100
Coverage radius	-	40 km
Received power	P_{Rx}	-90 dBm
Tx antenna gain	G_t	12 dBi
Rx antenna gain	G_r	12 dBi
Weibull model	k	3
Super Frame time	-	0.08 s
Frame time	-	0.01 s

Hence, $E_i(s)$ increases while $E_r(s)$ decreases. However since $E_r(s)$ has higher than average energy efficiency, the routing makes the energy efficiency balanced. The router to destination request is added to the waiting list of next frame, but the sour to the router request is considered in the current frame. If such a router cannot be found, then the BS acts the router for f_{ij}.

Algorithm 3 The energy efficiency routing protocol.

```
Set $TempE = E_i(s-1)$ and $r = 1$(the BS).
for every CPE $k$ except $i$ and $j$, do
    if $k$ is in the transmission range of both $i$ and $j$ and $E_k(s-1) \geqslant \overline{E(s-1)}$ and when $k$ is selected as the router, $E_i(s) \geqslant \overline{E(s)}$ and $TempE > E_i(s)$ , then
        Set $TempE = E_i(s)$ and $r = k$.
    end if
end for
Return $r$.
```

IV. SIMULATION AND RESULTS

A. Scenarios

IEEE 802.22 supports communication in a large area (regional area), which is applicable for P2PWRAN too. We consider an area with the radius of 40 km, in which there is one BS and one hundred CPEs are deployed. CPEs generate communication request to random destinations (the BS or CPEs), in which once the request of a CPE is allocated successfully this CPE will generate another request in next frame. The BS collects requested information and also is in charge of channel allocation, in which ECA is deployed. The simulations are carried out in Matlab. In the simulations, we adopt the link budget model in [15] and the most widely used log-distance path loss model [12]. Since wireless communication can also be influenced by small scale fading, we considered Weibull model [12] in the simulations to examine ECA. The values of other parameters can be seen in Table I.

B. Results

In our simulations, the greedy strategy and ECA with different values of K_a and K_e were adopted. We carried out the cases in ECA with $(K_a, K_e) = (1, 0)$ (the fair allocation), $(K_a, K_e) = (0.5, 0.5)$, $(K_a, K_e) = (0, 1)$ (the energy efficiency allocation) and the greedy strategy. The results of network throughput, energy consumption, energy efficiency and fairness in channel allocation is as shown in Fig. 1.

As we can see in Fig. 1(a), the greedy strategy can provide the highest network throughput, and ECA($(K_a, K_e) = (0, 1)$) follows it. The fair allocation and ECA ($((K_a, K_e) = (0.5, 0.5)$) achieve low network throughput since long distance communications are allocated in order to balance the channel sharing, and these communication normally have higher chance to interfere with other CPEs.

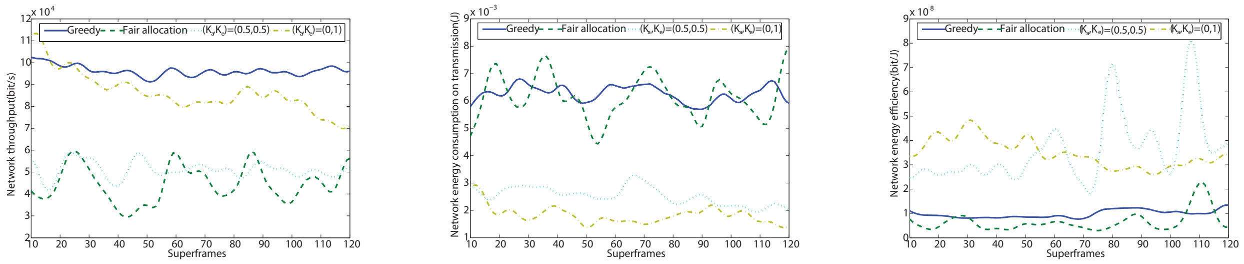
The average network energy consumption in every superframe is show in Fig. 1(b). The greedy strategy consumes the most energy because it transmits the most data as shown in Fig. 1(a). Long distance communication are allocated in the fair allocation, which increases the energy consumption in transmission. However, ECA ($(K_a, K_e) = (0, 1)$) consumes only about one third energy of the fair allocation and the greedy strategy, and with high throughput (as in Fig. 1(a)). It is because that the routing protocol in Algorithm 3 shortens communication ranges and results in less energy consumption. ECA($(K_a, K_e) = (0.5, 0.5)$) shows a trade-off between the energy efficiency and network throughput. Note that different path loss and link budget models may lead to different numerical results, but the trend of the energy consumption is expected to be similar.

Fig. 1(c) is the average energy efficiency. ECA performs much better than greedy and fair allocation since Algorithm 3 decreases the transmission distances. The greedy and fair allocation may allocate long distance transmissions, which decrease the average energy efficiency.

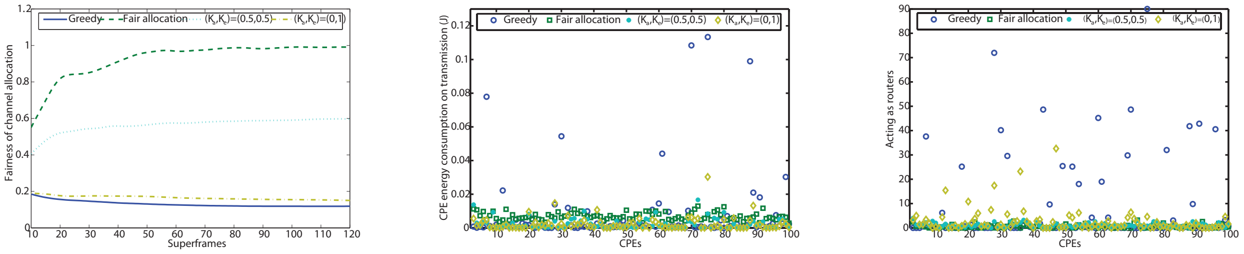
Fairness in channel sharing is shown in Fig. 1(d). The fair allocation is better than greedy strategy and ECA($(K_a, K_e) = (0, 1)$) when only *fairness* is considered. ECA($(K_a, K_e) = (0.5, 0.5)$) results in medium fairness because fair sharing strategies partially influences the allocation too. However, the greedy strategy and the case ($(K_a, K_e) = (0, 1)$) do not consider fairness amongst CPEs at all, and very poor fairness level can be seen.

CPE energy consumption in a frame is shown in Fig. 1(e). Some CPEs consume more energy compared to others if they are at the edge of the cell. However ECA and fair allocation lead to smoother energy consumption amongst CPEs since CPEs have equal chance to be allocated with a channel. ECA decreases the differences in energy consumption amongst CPEs by balancing the energy efficiency. Again, the results in Fig. 1(e) may be different if different link budget and path loss model are adopted, but the trend should stay similar.

CPEs acting as routers in hundred time slots is shown in Fig. 1(f). For the CPEs around the BS, they have more chance of being selected as routers as shown in Fig. 1(f), which causes unfair channel allocation. Some CPEs act as routers more than other CPEs in cases with ECA if they have more chance to obtain higher energy efficiency than other CPEs. However, their energy consumption is not particularly higher than other CPEs as shown in Fig. 1(e). Fair allocation mainly balances the allocation chance of CPEs, therefore CPEs have the similar chance of acting as routers.



(a) Network throughput. (b) Network energy consumption on transmission. (c) Average network energy efficiency.



(d) Fairness of channel allocation. (e) CPE energy consumption on transmission. (f) Number of times CPEs acting as routers.

Fig. 1. Performance of the ECA in a P2PWRAN with 100 nodes and a radius range of 40 km.

With the above results, we can draw the conclusion that ECA can provide very high throughput and energy efficiency while with low energy consumption. By setting different K_a and K_e, a trade-off between energy efficiency and fairness in channel allocation can be achieved.

V. CONCLUSION AND FUTURE WORK

Energy saving is an important step towards building green networks. Increasing the energy efficiency has also the same consequences and it is significantly influenced by channel allocation and routing protocols in wireless networks. Meanwhile other performance issues are also affected by channel allocation and routing protocols *viz*, fairness and throughput. Hence, we tried to achieve guaranteed performance while reducing energy consumption in P2PWRAN. In this paper, we formulate the channel allocation problem in P2PWRAN as a MOQP problem and propose an energy-aware channel allocation (ECA) algorithm. ECA jointly considers the channel allocation and routing protocols to accomplish increased energy efficiency and also acceptable fairness and throughput. The performance of the greedy strategy and ECA with different values of parameters ((K_a, K_e)) are compared too. The results show that ECA can achieve higher throughput and energy efficiency with low energy consumption. The parameters K_a and K_e lead to a trade-off between energy efficiency and fair channel sharing.

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