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Efficient Novel Energy Spectrum Trading Scheme

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Abstract : *The Mobile Network in Green communications has received much attention recently. The power consumption of BSs is crucial to greening mobile networks because the base stations (BSs) account for more than 50% of the energy consumption of the networks. In this paper, we propose the Power consumption minimization (PCM) scheme which enables the macro BSs to offload their mobile traffic to ISP's wireless access points by leveraging cognitive radio techniques. Since the internet service providers wireless access points are usually closer to the mobile users, the energy and spectral efficiency of mobile networks are enhanced. However, in the HPCM scheme, achieving optimal mobile traffic offloading in terms of minimizing the energy consumption of the macro Base Stations is NP-hard. We thus propose a heuristic algorithm to approximate the optimal solution with low computation complicated. We have proved that the energy savings achieved by the proposed heuristic algorithm is at least 50% of that achieved by the brute-force search. Simulation results demonstrate the performance and viability of the proposed PCM scheme and the heuristic algorithm.*

Keywords - *Green communications, HPCM scheme, NP-hard, Power consumption minimization.*

I. Introduction

Power consumption of the Information and Communication Technologies (ICT) sector has become a key issue in the last few years, due to rising energy costs [1], [2] and serious environmental impacts on greenhouse gas emissions [3]. Pollution and energy savings are keywords that are becoming more and more of interest to people and governments, and the research community as well is more sensitive towards these topics in the last years. An important part of the ICT consumption, the energy consumption of wireless access networks is rapidly increasing [4] and in some countries it accounts for more than 55% of the whole communication sector [5]. Such increase also accounts to a non-negligible part of the operational expenditures (OPEX) of network equipment owners. Moreover, growth of data rates in wireless networks by a factor of roughly ten every five years and an increase in the number of users, result in a doubling of the energy consumption of wireless network infrastructure every 4–5 years [6]. With rising energy prices, base stations (BSs) as the most significant energy consumer in the wide area wireless access networks contribute up to 50% of the total OPEX, especially if operators have many diesel fueled off-grid BS sites[7]. In addition, the number of enterprise deployments and overall number of individual access points (APs) in small and medium size wireless local area networks (WLANs) increases exponentially every year [8]. Although average BS energy consumption is much higher in comparison to those of APs, vast numbers of WLAN network devices installed worldwide contribute to enlargement of the energy consumption in wireless access networks. Therefore, development of a new generation of wireless access networks characterized with significantly higher energy efficiency is a necessity. In order to offload mobile traffic, mobile network operators usually deploy small cell base stations (BSs), e.g., pico-BSs, femto-BSs and WiFi hot spots, in the area where the mobile traffic intensity is high. Such mobile network deployments, referred as to heterogeneous mobile networks, can efficiently offload mobile traffic from macro BSs, thus reducing the energy consumption of mobile networks [4]. However, deploying small cell BSs requires backhaul networks which connect the small cell BSs and the mobile core networks. The energy consumption of the backhaul networks may neutralize the increased energy efficiency. Thus, the lack of cost-effective backhaul connections for small cell BSs often impairs their performance in terms of offloading mobile traffic and enhancing the energy efficiency of mobile networks. With strong revenue growth in wireless data markets, internet service providers (ISPs) such as Comcast and Optimum are densely deploying WiFi hot spots to provide WiFi connectivity to their customers in urban and suburban areas [5].

Therefore, it is desirable to utilize the hotspots deployed by ISPs to offload mobile data traffic. However, since carrying mobile traffic introduces additional operation cost to ISPs' networks, without proper incentives, the ISPs are not willing to open their networks to mobile network subscribers.

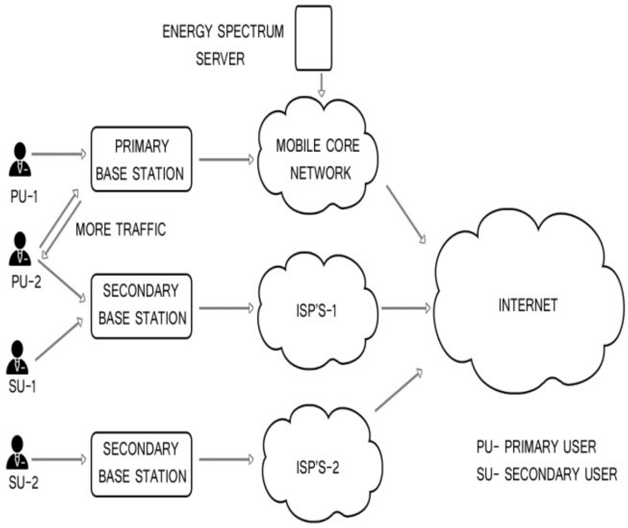


Figure 1: Architecture of EST Scheme

In this paper, a novel mobile traffic offloading scheme by leveraging cognitive radio techniques referred to as energy spectrum trading (EST). The EST scheme exploits the merits of both mobile networks and ISPs' networks. One of the advantages of the mobile networks is that the networks are operating on licensed spectrum, which is not accessed by unlicensed users. Therefore, by proper spectrum management, mobile networks are able to provide their subscribers a variety of services with different QoS levels. However, as compared with the hotspots deployed by ISPs, the BSs of mobile networks are usually sparsely deployed. Such deployments are not efficient in terms of the energy and spectral utilization. One of the merits of ISPs' hotspots is that they are densely deployed, and are able to provide high speed data rates to their subscribers. However, operating on unlicensed spectrum, the (QoS) of data services may not be guaranteed. The EST scheme enables mobile networks to offload data traffic to ISPs' networks to improve energy and spectral efficiency, and allows ISPs' hotspots access to the licensed spectrum to provide ISPs' data services with different QoS levels.

The proposed scheme is illustrated in Fig. 1, where the primary BS (PBS) is defined as the macro BS owned by the mobile network operator while the secondary BSs (SBSs) are referred to as the hotspots owned by ISPs. We assume both the PBS and SBSs are able to dynamically access the spectrum by leveraging cognitive radio techniques. There are two types of users: primary users (PUs) and secondary users (SUs). PUs are subscribers of the mobile networks while SUs are subscribers of ISPs. Different SUs may subscribe to different ISPs. The energy spectrum trading server manages the spectrum sharing and mobile data offloading between the mobile networks and ISPs' networks. The PBS has the exclusive access to the licensed band. However, owing to the wireless channel fading between the PBS and PUs, providing high data rates to the PUs, especially to those located at the cell edge, is both bandwidth and power consuming. As compared with the PBS, the SBSs which are closer to the PUs may experience less wireless channel fading and have higher spectral and energy efficiency in providing data services to the PUs. In the EST scheme, the PBS shares a certain amount of licensed bandwidth with SBSs while SBSs provide data services to PUs within their coverage area using the allocated bandwidth.

Since SBSs are close to PUs, the SBSs can satisfy PUs' QoS requirements by utilizing only a portion of the allocated bandwidth. The residual bandwidth can be utilized to fulfill SUs' data rate requirements. For example, in Fig. 1, if PU 1 is associated with the PBS, the PBS should allocate 2 M Hz bandwidth to the PU to satisfy its minimum data rate requirement. If associated with the SBS, PU 1 may only require 1 M Hz to ensure its minimum data rate. If the PBS offloads PU 1 to the SBS and grants the SBS 2 M Hz bandwidth, then the SBS spends 1 M Hz bandwidth to serve PU 1, and the other 1M Hz bandwidth can be utilized to enhance QoS of its SUs. Therefore, the EST scheme enables the PBS to reduce its power consumption by offloading some of the PUs to SBSs, and allows the SBSs to enhance their QoSs to SUs by utilizing the licensed bandwidth. Since SBSs usually have a low transmit power, the power consumption and the spectrum usages of mobile networks in providing data services to PUs is reduced. Thus, the EST scheme enhances both the energy efficiency and the spectral efficiency of mobile networks. The EST between the PBS and SBSs can be either event driven or traffic driven. For the event driven EST, the PBS triggers an EST process when a cell edge user initiates data service requests.

For traffic driven EST, the PBS monitors its traffic intensity from cell edge users. When the traffic intensity is beyond a threshold, an EST process is triggered. In this paper, assuming the PBS experiences heavy traffic load from the cell edge users, we design algorithms to optimize the EST between the PBS and SBSs to minimize the PBS's energy consumption when an EST process is triggered. However, minimizing the energy consumption of the PBS in the EST scheme is not trivial. On the one hand, in order to minimize the power consumption, the PBS has to maximize the number of users offloading to SBSs. Meanwhile, since the total amount of licensed spectrum is limited, the PBS aims to minimize the amount of bandwidth allocated to SBSs because the less bandwidth allocated to SBSs, the more bandwidth is reserved for the PUs associated with the PBS, and therefore the PBS consumes less power. On the other hand, the PBS has to give the SBS sufficient incentives in term of the amount of licensed spectrum to incentivize SBSs to provide data services to the PUs. Therefore, solving the power consumption minimization (PCM) problem is to find user-BS associations and bandwidth allocations to minimize the power consumption of the PBSs while satisfying PUs' minimum data rates and SBS's bandwidth requirements. In fact, the PCM problem is an NP-hard problem. Therefore, we propose a heuristic algorithm to approximate the optimal solution achieved by the brute-force search. The heuristic algorithm first finds the PUs whose user-BS associations are not determined, and then iteratively associates the PU, whose power-bandwidth ratio is the largest, with SBSs. If the power consumption of the PBS is reduced, the PU is associated with SBSs; otherwise, the PU is associated with the PBS. As compared with the brute-force search, the heuristic algorithm achieves at least 50% power consumption savings when the PBS experiences heavy traffic load from cell edge users.

II. Related Works

In this section, we briefly overview the related research on mobile traffic offloading and the solutions for user-BS associations in heterogeneous mobile networks. Mobile Traffic Offloading Based on the network access mode, the mobile traffic offloading schemes can be classified into infrastructure based traffic offloading and ad-hoc based traffic offloading. The infrastructure based traffic offloading is most related to our work. Therefore, we provide a brief overview of the infrastructure based traffic offloading. In the infrastructure based mobile traffic offloading, mobile traffic can be offloaded to small cell base stations (BSs), e.g., pico-BSs, femto-BSs and WiFi hot spots [6]. On the other hand, in order to reduce CO2 footprints, mobile traffic can be offloaded to the BSs powered by green energy such as sustainable biofuels, solar and wind energy [7]–[10]. In this way, the green energy utilization is maximized, and thus the consumption of the on grid energy is minimized. User-BS Associations in Heterogeneous Mobile Networks Heterogeneous network is a promising network architecture which may significantly enhance the spectral and energy efficiency of mobile networks. Three mixed integer programming formulations are presented in Das et al. [11] for the optimization problem of broadcasting a message from a source device to all the other devices with minimum energy. The problem is called MPB (Minimum Power Broadcast) and is shown NP-hard in [12]. Heuristic approaches have to be used to find sub-optimal solutions for hard problems of large size. Wieselthier et al. [13] described a constructive algorithm called BIP (Broadcast Incremental Power). The authors Guoliang Xing, et al, [14] proposed new algorithm based on minimum Steiner tree (ISTH). In this, they explained the nodes and transmission power at ideal and sleep nodes. And discussed the comparison of energy in MPCP (Minimum Power Configuration Protocol) and min-power routing. A new algorithm named as Dijkstra"s algorithm proposed by Abdellah Idrissi et al, for energy management in mobile ad hoc network is designed to rectify this problem [15].

III. Energy Consumption Algorithm

The PBS's power consumption consists of two parts: the static power consumption and the dynamic power consumption. The static power consumption is the power consumption of a BS without any traffic load. The dynamic power consumption refers to the additional power consumption caused by traffic load on the BS. The PBS's static power consumption algorithm.

```
Begin
DO FOR j in J, k in K
Capacity_(j,k) = 1;
Covered_new_TPs_(j,k) = 0;
DO FOR i in P_(j,k)
IF Capacity_(j,k)-Demand_(i)/Rate[k][r] > 0
IF i is not yet covered in S
Covered_new_TPs_(j,k)=Covered_new_TPs_ (j,k)+1;
Capacity_(j,k)=Capacity_(j,k)-Demand_(i)/Rate[k][r];
FI
IF i is already covered in S by the same j
Capacity_(j,k)=Capacity_(j,k)-Demand_(i)/Rate[k][r];
FI
IF i already covered in S by different j
IF powerRX_i_(j,k) > powerRX_i_(j,k in S)
Capacity_(j,k)=Capacity_(j,k)-Demand_(i)/Rate[k][r];
FI
FI
FI
OD
OD
SELECT(j,k)that has max(C*Covered_new_TPs_(j,k));
RETURN (j,k);
END
```

In the EST scheme, the PBS aims to minimize its power consumption by offloading data traffic to SBSs. Therefore, the power consumption minimization (PCM).

IV. A Heuristic Power Consumption

In this section, we propose a heuristic power consumption minimization (HPCM) algorithm to approximate the optimal solution of the PCM problem with low computational complexity, and prove that the maximum power savings achieved by the HPCM algorithm is at least 50% of that achieved by the brute force search.

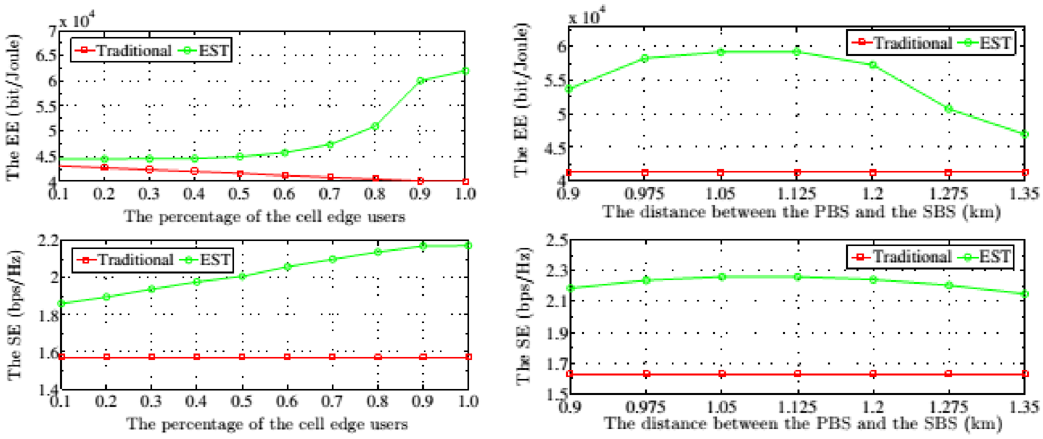
Assign all PUs in u;
Calculate $\varphi_{k,i}$ and w_i^{min}, k = arg $\min_{j \in S} \varphi_{j,m}$ $\forall i \in U$;
if $\sum_{i \in \cup} \phi k, i \leq W$ **then**
  C = p^{fix}, and all PUs are Associated with SBSs;
else
  (u^P , u^S , u^T) = User Filter Alg. ($\varphi_{k,i}$, w_i^{min});
  Calculate W^P and derive C, w_i^t , and p_i^t by solving the BA problem with $u^P = u^P \cup u^T$;
  if $\varphi_{k,i} \leq w_i^t$, $\forall i \in U^P$ **then**
    Assign the ith PU in u^S ;
  Find m = arg $\max_{i \in u^T}$ $\alpha p_i^t w_i^t$;

Calculate C^{max} by solving the BA problem with $u^P = u^P \cup u^T \setminus \{m\}$;
Assign $u^P_{max} = u^P \cup u^T \setminus \{m\}$;
while u^T is not empty **do**
  Calculate C, w_i^t, and p_i^t by solving the BA problem with $u^P = u^P \cup u^T$;
  Calculate pi, $\forall i \in U^T$;
  Find $m = \arg\max_{i \in u^T} pi$;
  if $\sum_{i \in u^P \cup u^T \setminus \{m\}} w_i^t + \sum_{i \in u^S \cup \{m\}} \varphi_{k,i} \leq W$
  then
    Calculate C^m by solving the BA problem with $u^P = u^P \cup u^T \setminus \{m\}$;
    if $C^m < C$ **then**
      Offload the mth PU to u^S;
      Assign $C = C^m$;
    else
      Assign the mth PU into u^P;
  else
    Set primary user m in u^P;
  Update $u^T = u^T \setminus \{m\}$;
if $C^{max} < C$ **then**
  Assign $u^P = u^P_{max}$, and $u^S = u \setminus u^P$

Derive w_i by solving the BA algorithm;
Return u^P, u^S and w_i, $\forall i \in U^P$.

V. SIMULATION RESULT

In this simulation scenario, we consider a radio cell with one PBS and one SBS in each sector, as shown in Fig. 2(a). The SBSs have the same operation parameters such as the transmit spectral-power density, the per-PU compensating bandwidth, and the distance between the SBS and the PBS.



We define the cell edge users as the users whose distances from the PBS are larger than 0.9 km. shows the EE and SE of the network versus the percentage of the cell edge users. In this simulation, the total number of mobile users in each sector follows the Poisson distribution with the mean equaling to 20. As the percentage of the cell edge users increases, the EE of the traditional scheme decreases because serving cell edge users usually requires more energy consumption. The EE of the EST scheme increases because more users are offloaded to the SBS. For the same reason, the SE of the EST scheme also increases.

V. Conclusion

In this paper, we have considered the problem of optimizing the energy consumption of Mobile Network by offloading and adjusting the on bandwidth assigned. We have proposed the communication models and corresponding heuristic algorithms that allow the network to offloading to secondary station which minimizes the energy consumption. The proposed heuristic algorithms can guarantee that 50% of energy consumption reduced.

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