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Power-efficient and Latency-aware Offloading in Energy-harvested Cloud-enabled Small cell Network

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Abstract

This paper has proposed an energy-harvested small cell network that is composed of large cells containing cloud-enabled small cell base stations inside to provide the users communication and computation services simultaneously. An application offloading strategy has been proposed based on small cell zooming. This is observed that the proposed network reduces the power consumption of small cells by approximately 14% and the proposed offloading method reduces the power consumption of the user device by 23-54% approximately during offloading an application.

1 Introduction

The objective of future generation mobile network is to provide high bandwidth and low latency services to the users. To address the challenges, small cells have become the principle elements of fifth generation (5G) mobile network [1]. The small cells refer to the picocells and femtocells, which are deployed inside the large cells like macrocells and microcells [2, 3]. However, to offer the users communication and computation services simultaneously Small Cell cloud enhanced eNodeB (SCceNB) [4, 5, 6] and femtolet [7, 8] come into the scenario. These small cell base stations have in build storage and computation ability so that the users registered under them can make and receive voice call as well as can offload their data and applications inside these devices. However, the radiation due to dense small cell allocation and rapid growth in multimedia traffic are increasing the CO_2 emission and polluting the air. To overcome this problem, an energy-efficient small cell network design has become important. Energy harvesting has become a promising solution for designing energy-efficient small cell network [9, 10, 11]. In energy harvesting the renewable energy resources such as solar, wind are used as a source of power supply. Moreover, the base stations transmit energy which can charge the batteries of other devices. Here energy harvesting occurs from radio-frequency environment. Though a small cell consumes very less amount of power, large number of small cell allocation increases the power consumption of the network. To address the issue, there are two major objectives of this work:

- To reduce the power consumption of the small cells in the network to provide a green small cell network.
- For energy-efficient offloading cloudlets [12, 13], fog devices [14], edge devices [8] are used. However, in cellular network indoor base stations providing data and computation offloading are available to reduce the latency as well as energy consumption. But if these devices have not enough power level to execute a requested code, then remote cloud has to be accessed. The objective is to propose a strategy that will provide power and latency aware offloading if the small cell has not enough power to execute computation.

To address the objectives, the contributions of the paper are:

- An energy-efficient small cell network has been proposed, where cloud-enabled small cell base stations (C-SB) are used inside the large cells for simultaneous computation and communication service provisioning. Femtolets and SCceNBs are used as C-SBs in the network. These C-SBs are powered using renewable energy resources. However, they can charge up using transmission energy from the adjacent C-SBs as they are located densely.
- A small cell zooming based offloading strategy has been proposed to save the latency and power consumption of the user device during offloading.

Rest of this paper is organized as: Section 2 discusses the proposed strategy, Section 3 studies the performance of the proposed strategy and Section 4 concludes the paper.

2 Energy-harvested C-SB based Network

In the network we have considered macrocell and microcell base stations and inside their coverage C-SBs are allocated. The solar and wind resources are used to charge the C-SBs.

Let the energy of a fully powered C-SB i is E_{pi} and the number of its adjacent C-SBs is n. Now a C-SB can have at most six adjacent C-SBs, i.e. $n \leq 6$. Let the energy received by the C-SB i from an adjacent C-SB j is E_{ij}. If the current energy of a C-SB is E_{ci} and $E_{ci} < E_{pi}$, then the C-SB i charges up with E_{ij}. The total energy received by the C-SB i from all its adjacent n C-SBs is $\sum_{j=1}^{n} E_{ij}$. In the proposed network each C-SB is able to expand its coverage up to $2*r$, where r is the radius of its current coverage area. The mobile users registered under a C-SB offload their data and applications inside the C-SB. We propose an application offloading method based on cell zooming in Algorithm 1. In cell zooming, the adjacent cellular base stations expand coverage areas to capture the customers of an inner congested cell [15]. If a C-SB has very low energy to provide its user communication and computation services but the power source is not available during that time, the C-SB sends message to the adjacent C-SBs. The adjacent C-SBs then expanding coverage capture the users. If a C-SB i has few users which are located at boundary region, it sends message to adjacent C-SBs. The under loaded adjacent C-SBs respond. The users from the C-SB i are handed over to the adjacent C-SBs and the C-SB i switches to idle mode.

Algorithm 1: Small cell zooming based application offloading

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Input  : Current energy level of a C-SB i (E_ci), Energy level
         required to offload application a (E_a)
Output: Result after executing the application
when a mobile device has to offload an application a, it sends
  message to C-SB i under which it is registered;
if E_a > E_ci then
    C-SB i sends message to its adjacent C-SBs;
    if no adjacent C-SB responds then
        a is offloaded to cloud;
    else
        adjacent C-SB with currentenergy > E_a and at nearest
          distance from the requesting device is selected;
        selected C-SB zooms coverage and the user is handed over
          to it;
        selected C-SB executes a and sends result to the device;
    end
else
    C-SB i executes a and sends result to the device;
end
```

2.1 Power consumption of C-SBs in proposed network

If the power consumption of an active C-SB is denoted by P_{ac} and there are N C-SBs in the network, the power consumption of the C-SBs will be given as, $P_{totc} = \sum_N P_{ac}$. As in our network, a C-SB switches to idle mode if its users are handed over to the adjacent C-SBs, among N C-SBs, some will be in idle mode. Let in idle mode the power consumption of a C-SB is P_{ic}. A device consumes lower power in idle mode than its active mode, i.e. $P_{ic} < P_{ac}$. If there are N_1 C-SBs in idle mode, the power consumption of the C-SBs is given as,

$$P_{totcp} = \sum_{N_1} P_{ic} + \sum_{N-N_1} P_{ac} \quad (1)$$

As $N_1 < N$ and $P_{ic} < P_{ac}$, then $P_{totcp} < P_{totc}$. Thus using the proposed network the power consumption is reduced.

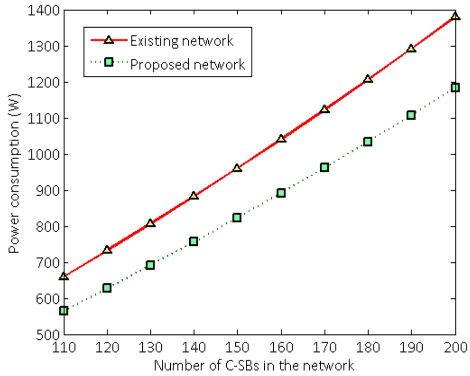

Figure 1. Power consumption of the C-SBs in the network

2.2 Power consumption of user device during offloading

If a device offloads an application a to a C-SB, the latency (L_a) depends on the time period for propagation (T_p), communication (T_c) and execution of the application (T_e), hence given as,

$$L_a = f(T_p, T_c, T_e) \quad (2)$$

The power consumption of the user device during this period is given as,

$$P_a = f(P_{iu}, P_{au}, L_a) \quad (3)$$

where P_{iu} and P_{au} denotes the power consumption of the user device in idle and active modes respectively. In SCceNB or femtolet based existing systems [4, 7], if the small cell is unable to execute the application, remote cloud is used for offloading. However, in our system the adjacent C-SB offloads the application by expanding the coverage. As a result, the time period in propagation and communication are lower, which saves total latency and power consumption of the user device.

3 Results and Discussions

In this section, theoretical and experimental analysis are performed to depict performance of the proposed method.

3.1 Theoretical analysis

For theoretical analysis, MATLAB2015 has been used. In this case, the power consumption of the C-SBs are determined using equation (1) and presented in Fig.1. The number of C-SBs in the network is assumed 110-200. The power consumption is measured in Watt (W). Fig.1 shows

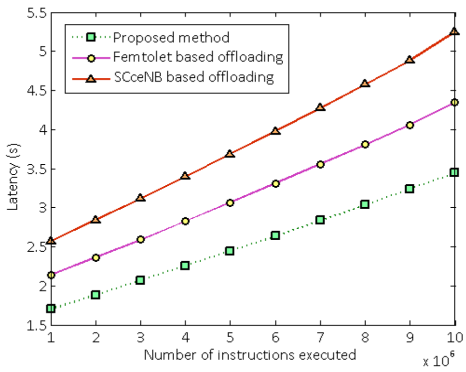

Figure 2. Latency in computation offloading

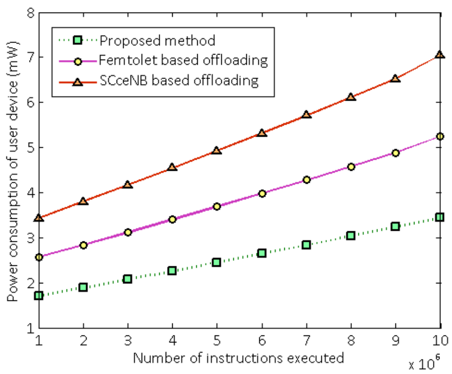

Figure 3. Power consumption of the user device during computation offloading

that the power consumption of the C-SBs in the proposed network is $\sim$ 14% less than the conventional cloud-enabled small cell network [7]. The latency in offloading computation is determined using equation (2) and presented in Fig.2. The number of instructions in the computation is assumed $1x10^6$-$10x10^6$. The latency is measured in second (s). Fig.2 shows that using the proposed offloading method the latency can be reduced by $\sim$ 31% and $\sim$ 17% respectively than using SCceNB based offloading [4] and femtolet based offloading [7] respectively. The power consumption of the user device while offloading computation is determined using equation (3) and presented in Fig.3. The number of instructions in the computation is assumed $1x10^6$-$10x10^6$. Fig.3 shows that using the proposed method the power consumption of the user device can be reduced by $\sim$ 50% and $\sim$ 33% respectively than using SCceNB based offloading [4] and femtolet based offloading [7] respectively. In [4] C-SB (SCceNB) with limited processing power has been used. Hence, the remote cloud has to be accessed for executing high-end computation. In [7] though the C-SB (femtolet) is able to perform high-end processing, if the energy level of the C-SB is low, then the offloading to remote cloud is required. But in our method energy harvesting is used and if the C-SB has lower energy level, adjacent C-SB expands coverage to offload the code. As a result, the probability of offloading computation to remote cloud is very less. Consequently the offloading latency and the power consumption

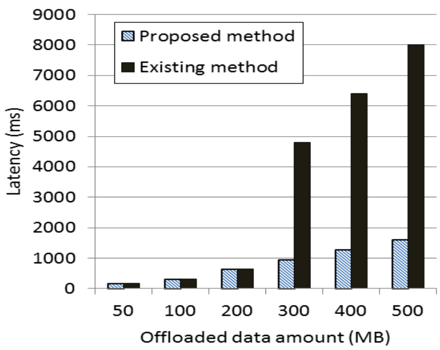

Figure 4. Latency in data offloading

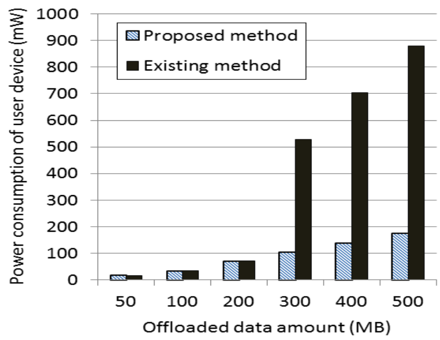

Figure 5. Power consumption of the user device during data offloading

of the user device during offloading are reduced.

3.2 Experimental analysis

For experimental evaluation five codes of different applications have been considered. A mobile phone with 2 GB RAM registers under a C-SB with 4 GB RAM. The mobile device requests for offloading the five codes to the C-SB. As per the current energy level of the C-SB, it can consume at most 1.5 mW for executing a code. If the existing method [7] is used, only the first code (linear search) is offloaded to the C-SB, whereas other four codes are offloaded to the remote cloud because the current energy level of the C-SB falls below the required energy level to execute these codes. But in the proposed approach the adjacent C-SB expands coverage and executes these four codes. As a result, the latency and power consumption of the user device during offloading are reduced. From TABLE 1, it is observed that offloading the code of merge sort using proposed approach reduces latency and power consumption of the user device by $\sim$ 44.92% and $\sim$ 54.28% than offloading using existing method. TABLE 1 shows that offloading the code of 4-Queens puzzle using the proposed approach latency and power consumption of the user device are reduced by $\sim$ 31.1% and $\sim$ 40.19% than offloading using existing method. TABLE 1 shows that offloading the code of image conversion from bmp to PGM file using the proposed approach the latency and power consumption of the user device are reduced by $\sim$ 14.23% and $\sim$ 23.36% than offloading using existing method. Thus the experi-

Table 1. Experimental results

Code	Latency in proposed scheme	Latency in existing scheme [7]	Power consumption in proposed scheme	Power consumption in existing scheme [7]	Latency reduction in proposed scheme	Power reduction in proposed scheme
Linear search	18.6 ms	18.6 ms	1.11 mW	1.11 mW	Nil	Nil
Merge sort	33.6 ms	61 ms	1.936 mW	4.235 mW	44.92%	54.28%
4-Queens puzzle	60.6 ms	88 ms	3.421 mW	5.72 mW	31.1%	40.19%
Converting a bmp image to PGM file	507.8 ms	592 ms	28.325 mW	36.96 mW	14.23%	23.36%

mental results demonstrate that the proposed method reduces the offloading latency by 14-44% approximately and power consumption of the user device during offloading by 23-54% approximately than the existing scheme. In Fig.4 the communication latency while offloading data using proposed and existing approaches [7] with respect to the size of the data are presented. The data transmission rate is 1 Mbps approximately. In the proposed scheme the C-SB under which the mobile device is registered if has lower power, then adjacent C-SB expands coverage and the mobile device is handed over to it. The mobile device then offloads the data to that C-SB. In the existing approach [7] the remote cloud is used to offload the data if the C-SB under which the mobile device is registered has lower power to offload the data. In Fig.5 the power consumption of the user device while offloading data using proposed and existing approaches [7] with respect to the data size are presented. In Fig.4 and Fig.5 the latency and user device's power consumption while offloading 50-500 MB data using proposed and existing methods [7] are compared. For high amount of data offloading (> 200 MB), the C-SB's energy level falls. Hence, in the existing scheme [7], the remote cloud stores the data. In the proposed method, the adjacent C-SB expands coverage and the mobile device offloads the data to it. This is observed that up to 80% reduction in latency and power consumption in offloading is achieved using the proposed approach. From the theoretical and experimental analysis, it is observed that the proposed method reduces power consumption of the small cells, offloading latency and power consumption of the user device.

4 Conclusion

In this paper we have proposed an energy-harvested small cell network which reduces the power consumption of the small cell base stations and the user devices. In the proposed network, the small cell base stations provide communication and computation services. They can expand coverage and execute applications of the user devices. When a small cell has very low energy level to afford computation service to its users, its adjacent small cells expand coverage and provide service to its users. This is observed that the proposed network reduces approximately 14% power consumption. This is also observed that the proposed method reduces approximately 23-54% power consumption of the user device during application offloading.

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