INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume3, Issue3)
Available online at www.ijariit.com

Improve Energy Efficiency in Cognitive Radio Ad Hoc Networks by Selecting Secondary User

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Abstract: Wireless networks combining the advantages of both mobile ad-hoc networks and infrastructure wireless networks have been receiving increased attention due to their ultra-high performance. Users have capability to sense available spectrum in Cognitive Radio Networks (CRNs).Users can opportunistically access to the spectrum. Paper proposed for energy consumption for CRNs, Which is higher in traditional Cognitive Radio Ad Hoc Network (CRAHNs). Users mainly depend on spectrum access so the requirement of network architecture is user spectral. In the proposed network architecture, only parts of user's are equipped with Cognitive Radio (CR) module. Additionally user management done, a minimum number of users are selected to sense available spectrum, which aims at reducing the energy consumption further. The minimum number of user's selection problem is formulated as a optimal routing algorithm problem under the constraints of energy efficiency and the real-time available spectrum information. Hence, a distributed optimal routing algorithm is proposed to calculate the optimal solution. The optimal routing algorithm in the proposed network architecture outperforms and traditional Cognitive Radio Ad Hoc Networks in energy efficiency.

Keywords: Wireless Networks, Routing Algorithm, Load Balancing, Congestion Control, Energy Efficiency.

I. INTRODUCTION

The licensing of the wireless spectrum is currently undertaken on a long-term basis over vast geographical regions. In order to address the critical problem of spectrum scarcity, the Federal Communications Commission (FCC) has recently approved the use of unlicensed devices in licensed bands. Consequently, dynamic spectrum access (DSA) techniques are proposed to solve these current spectrum inefficiency problems. This new area of research foresees the development of cognitive radio (CR) networks to further improve spectrum efficiency. The basic idea of CR networks is that the unlicensed devices (also called cognitive radio users or secondary users) need to vacate the band once the licensed device (also known as a primary user) is detected. CR networks, however, impose unique challenges due to the high fluctuation in the available spectrum as well as the diverse quality of service (QoS) requirements [1].

CR Technology is the promising solution to the problem of the limited spectrum and the inefficiency of the spectrum usage. CR technology makes it possible for users to access the spectrum. In this paper, we mainly focus on CRAHNs. The existing architectures of CRAHNs consider that all SUs are equipped with CR module. The spectrum causes adverse effects on the performance of conventional communication protocols besides, all SUs need to sense available spectrum [2]. There is the installation of CR module will bring the extra cost to SUs. In addition, energy will be consumed when SUs sense available spectrum. Hence, the energy cost for cognitive functionality is undesirable for the battery powered devices of SUs [3].

CCH Cognitive Capacity Harvesting architecture is shown in Fig. 1. CCH consists of four categories of entities: Secondary Service Provider (SSP), Base Stations (BSs), Relay Stations (RSs) and SUs. BSs and RSs have cognitive function, they can use the spectrum to communicate with each other. Secondary user (SUs) do not have cognitive function, they cannot use spectrum [4].Cognitive radio (CR) technology has been proposed as an enabling solution to alleviate the spectrum underutilization problem. With the capability of sensing the frequency bands in a time and location-varying spectrum environment and adjusting the operating parameters based on the sensing outcome, CR technology allows an unlicensed user (or, secondary user (SU)) to exploit those frequency bands unused by licensed users (or, primary users) in an opportunistic manner[5].

SUs communicate via unlicensed bands with BSs and RSs. In above architecture, BSs and RSs collect the available spectrum information and the service requirements coming from SUs. Then transmit them to SSP via the common control channel. SSP is a centralized service provider. SSP collects available spectrum information and then allocates optimal available spectrum to BSs and RSs. At the same time, SSP leads SUs to access their nearby router (BSs or RSs). CCH aims at saving the energy of SUs and reducing the complexity of SUs [6].

There is some extra need for CCH i.e. unnecessary infrastructures (e.g., SSP, BSs, and RSs). In this paper, we propose for reducing energy consumption as well as production cost. There is some optimal selection of SUs from the selected CRN which having the property of sensing among the Cognitive Radio Users CRUs named as a Sensible Secondary User (SSUs) network. Given network architecture shows the property of a good balance between performance and energy efficiency [4],[5].

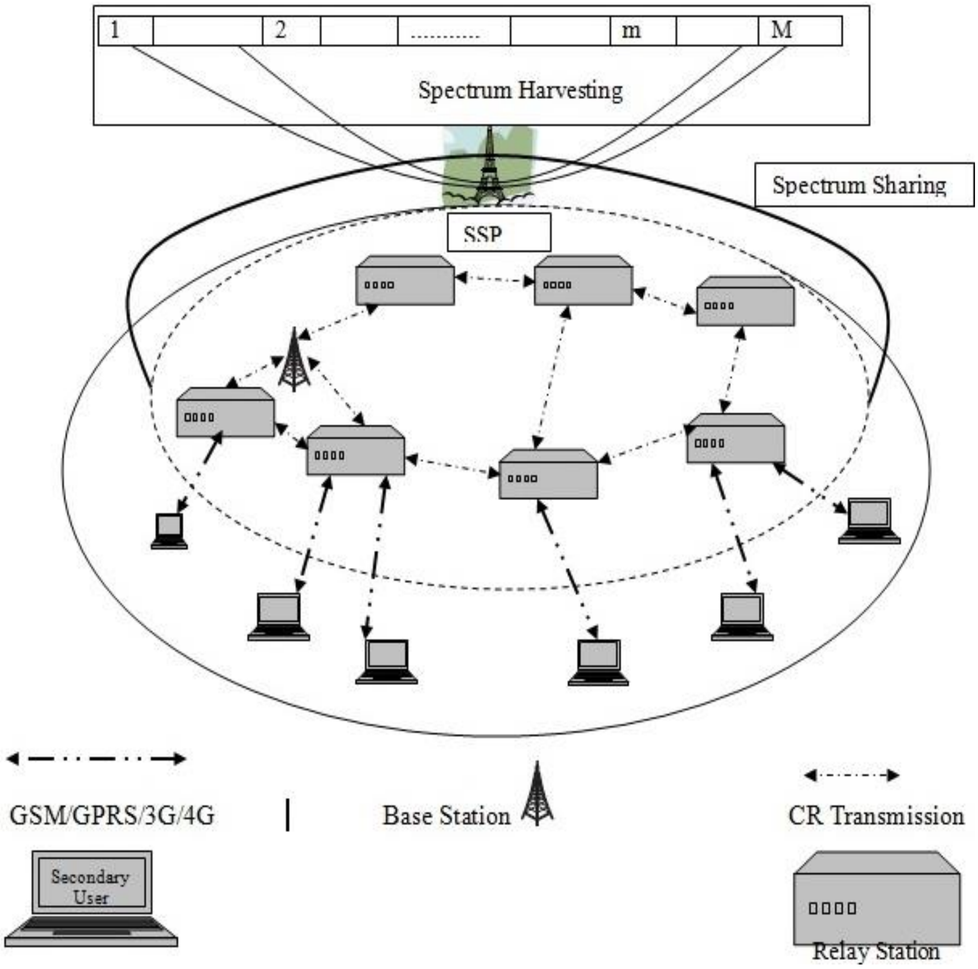

Fig 1. CCH Architecture

In this paper, we study how to select a minimum number of SUs among all CRUs. The main contributions of our paper are summarized as follows:

1. A novel network architecture is proposed for CRAHNs.
2. We study the problem of how to select a minimum number of SUs among CRUs to sense available spectrum using mathematically formulated optimal routing algorithm. Energy efficiency and cost of installation minimized.
3. However, the minimum number of SUs selection problem is an NP-hard problem. Hence, a distributed optimal routing is proposed for selecting the minimum number of SUs. The rest of this paper is organized as follows [21].

In section II, we describe the network model and the problem definition of the minimum number of SUs selection problem in detail. In section III, The problem of the minimum number of SUs selection problem is solved. In section IV, a distributed optimal routing is proposed to select SUs. The proposed network model is shown in section V. In section VI, we conclude our paper.

II. NETWORK MODEL AND PROBLEM DEFINITION

A. Network Model

In this section, we introduce the network model used in our analysis of SUs selection in CRN. SUs can either install CR module or not. Cognitive radio network allows the secondary users to use the channel whenever the channels do not occupy by the primary users.CR module classified into three statuses. First, the status of CR module can be classified into opened status and closed status. Then the opened status can be further classified into two statuses which are opened sense status and closed sense status. SUs in opened since status can sense available licensed spectrum information and adjust their parameters to access available spectrum. Table 1 defined different kind of SUs [4],[8].

SUs in closed status only use unlicensed spectrum. SUs in CRAHNs consist of CRUs and NCRUs. CRUs consist of OCRUs and CCRUs. OCRUs consist of SSUs and NSUs. We show the relationship between different kinds of SUs in Fig. 2.

TABLE I
DEFINITIONS OF DIFFERENT KINDS OF SUS

Term	Definitions
Cognitive Radio Users (CRUs)	SUs who are equipped with CR module
Non-Cognitive Radio Users (NCRUs)	SUs who are not equipped with CR module
Opened Cognitive Radio Users (OCRUs)	CRUs whose CR module are opened
Closed Cognitive Radio Users (CCRUs)	CRUs whose CR module are closed
Sensible Secondary Users (SSUs)	OCRUs who are selected to sense available licensed Spectrum
Non-Sensible Secondary Users (NSUs)	OCRUs who are not selected to sense available licensed Spectrum

We assume that there are |N| OCRUs at time t in CRAHNs. |N| OCRUs form set N. Only OCRUs can use idle spectrum in the proposed network architecture. OCRUs must accurately know the information of the available licensed spectrum. CRUs will cost much energy for sensing available spectrum.

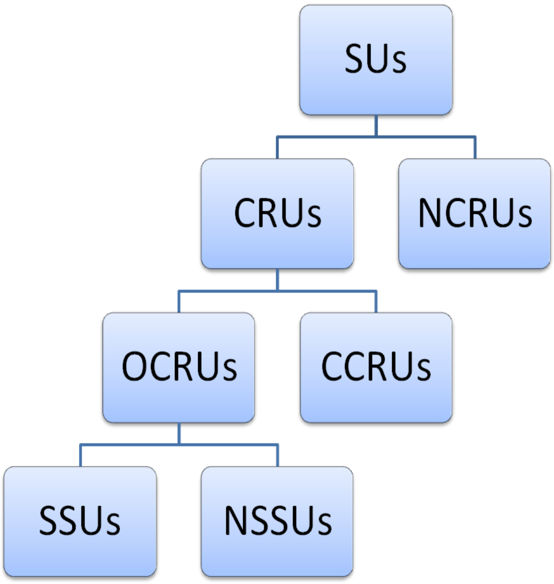

Fig 2. The relationship between different kinds of SUs

Hence, we aim at selecting |n| OCRUs among |N| OCRUs to sense available spectrum, and n c N. n is the set which consists of all SUs in the proposed network architecture. |N| is the total number of OCRUs. |n| is the total number of SUs, |n| c |N|. We must guarantee that |n| SUs could accurately and instantaneously sense the available spectrum information for |N| OCRUs. We study how to select the fewest SUs among |N| OCRUs.

We user to denote communication radius of OCRUs. Form users communication radius is rm. The coverage area of communication radius of SU m is the neighboring area of SU m. Any OCRU in the neighbouring area of OCRU m can use the available licensed spectrum information sensed by OCRU m directly [4], [9].

B. Problem Definition

Mainly the focus of network model on the minimum number of SUs selection that is how to select the fewest SUs among |N| OCRUs. The fewest SUs must guarantee that all OCRUs can clearly and exactly know their available spectrum information. Energy efficiency and the real-time spectrum sensing information are considered.

III. SELECTION OF SUS

A. Communication Radius

As shown in Fig.3 Selection of the minimum number of SSUs, we first describe how to calculate the communication radius [10] of OCRUs. According to, we can know that the relationship between the received power of the receiver and the transmission power of the transmitter, $Pr = \gamma d^{-\alpha} Pt$ (1) where Pr is the received power of the receiver, Pt is the transmission power of the transmitter, γ is the antenna related constant, d is the distance between transmitter and receiver, and α denotes the path loss factor. We assume that only when the received power is no less than Pk, the communication between transmitter and receiver will successes. Pk is a threshold of received power. We assume that the largest power of the OCRUs is P. For guaranteeing that two OCRUs can communicate with each other successfully, the following formula should be satisfied [4],[15].

$$Pk \leq \gamma d^{-\alpha} P$$

$$r = \left(\frac{\gamma P}{Pk}\right)1/\alpha$$

B. Selection of Minimum Number of SSUs

Selection of the minimum number of SSUs by using communication radius r. Inference of sensible region shown in Fig.3. The sensible region located around the primary user and the secondary users. The SUs in the sensible region can be traced by the communication bandwidth. Through witch optimal communication routing path can traced [14].

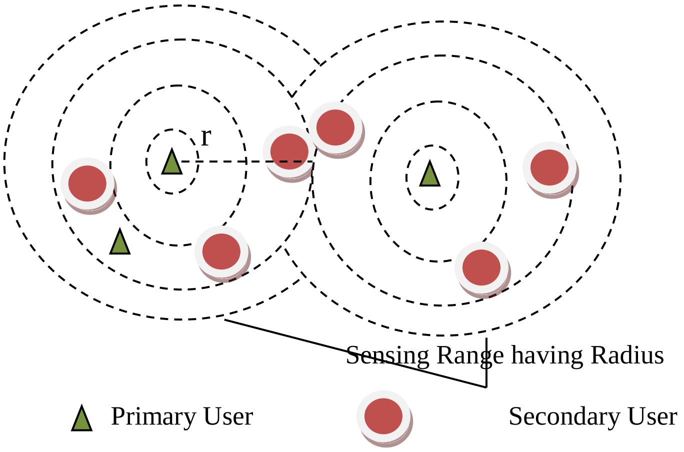

Fig. 3 Selection of minimum number of SSUs

1) Objective Function

The objective of the SSUs selection is to select the fewest SSUs under the constraints of condition 1 and condition 2. Hence, our objective function [4],[13] is

$$\min_{n \subset N} |n|$$

2) Condition 1

We assume that each spectrum sensing time of SSUs is Ts. The maximum transmission time for SSUs to transmit their sensing information to NSSUs is Tt.NSSUs can get their available licensed spectrum information from SSUs exactly only when there exists at least one same SSU within its neighboring area during Ts + Tt. We use δsi(t) to describe the communication relationship between SSU i and NSSU s. If dsi $\leq$ r during [t+i ; t+i + Ts + Tt],δsi(t) = 1. Otherwise, δsi(t) = 0. t+i denotes the start time for SSU i to sense available licensed spectrum information [4]. dsi denotes the distance between SSU i and NSSU s. δsi(t) = 1 denotes that SSU i can communicates with NSSU s during [t+i ; t+i + Ts + Tt]. δsi(t) is defined as

δsi(t) = 1; if dsi $\leq$ r during [t+i ; t+i + Ts + Tt]
0; otherwise

3) Condition 2

According to the definition of capacity, we can get the capacity Cij between SSU i and NSSU j is

$$Cij = Wijlog2\left(\left(1 + \frac{\gamma dij^{-\alpha} Pij}{N0}\right)\right)$$

Where Wij denotes the communication bandwidth between SSU i and NSSU j. Pij is the transmit power of SSU i when it sends data to NSSU j. N0 is the noise power [4]

IV. OPTIMAL ROUTING ALGORITHM

The non-linear programming problem that we found is a set cover problem. The set cover problem is an NP-hard problem. Hence, we propose a distributed optimal routing to get a near-optimal solution [21]. We describe the optimal routing as follows.

1. OCRU i calculates how many OCRUs in its neighbouring area.
2. If there are f OCRUs in the neighbouring area of OCRU i, the communication number of OCRU i is f [4],[12].
3. Using radius communicate with nearest SUs from the shortest path.
4. If some OCRUs have the same communication range, we will select the OCRU i that has the smallest Ti to participate in sorting.
5. Then delete other OCRUs that have the same communication number with OCRU i.
6. We begin the validate process which starts at the first OCRU i. We validate whether OCRU i can satisfy shortest path distance is equal or less than forming a radius of communication.
7. OCRUs in the neighbouring area of OCRU i can get their available spectrum information from OCRU i. If OCRU i does not satisfy shortest path distance is equal or less than forming a radius of communication the next OCRU with the shortest path will be validated [11].
8. If all OCRUs radius are validated with forming a path, and none of the OCRUs satisfies the shortest path, OCRU i will sense available spectrum by itself.

V. PROPOSED NETWORK MODEL

A. Optimal Path Selection

The flow of network model is shown in Fig.4 It shows that traversing from the source node to destination node while transferring packets. In cognitive radio transmission the selection method for path finding done with shortest path finding, from which we find the nearby SSU's. Frame structure consists of sensing and data transmission slots. Optimum route problem under an end-to-end error rate constraint and carries a comparative study of the power optimal graphs obtained with those a per hop error rate constraint [7].

Routing protocols are required to route data packets from source to destination. Routing protocols are basically categorized into table driven and on-demand routing protocols. In table driven routing protocols, up-to-date routing information is maintained by each node in the network. When a node requires a route to a destination, it initiates a route discovery process within the network [18].When a packet is sent along the shortest path, it will be forwarded in the same way as the traditional IP networks.

For achieving the maximum normalized throughput of the SU and control the interference level to the legal PUs, the optimal frame length of the SU is found via simulation [17]. The design of the sensing length to maximize the achievable throughput of a single channel cognitive radio network, under the constraint of the probability of detection. To provide better service for SUs, it is advisable to aggregate the perceived spectrum opportunities obtained through simultaneous sensing over multiple channels.

As soon as this overlay node gets the packet, it removes the outer IP header and forwards the packet to the final destination (or possibly to another overlay node). By this methodology, one can utilize as many alternative paths as needed. Note that using this architecture, we can still employ the simple shortest path routing inside the network. This allows us to use the existing traditional routers without any modification [19].

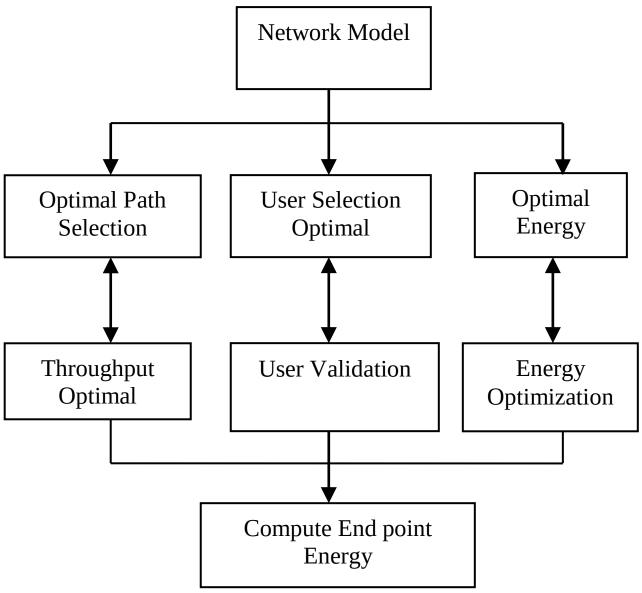

Fig 4. Optimal routing networking model

B. Selection of minimum number of SSUs

Nodes are located at all the source-destination nodes as well as at some core nodes. While traversing from source to destination the selection of user pattern done through categorisation of the user according to their sensible property i.e. when a nearby secondary user selection is done through optimal routing. While selection optimum number of user each node will trace by near neighboured and with self for user validation. By which no same SSUs can be detected while validation if same distance SSUs can detect, the selection method can choose one of them and delete another selected SSUs. So that the error rate in selection method can be minimised. Validation process checks all the selected SSUs [16].

While validation of SSUs the data packets attached with the user which communicate with throughput optimal unit and with energy optimisation unit for computing end point energy.

C. Energy optimization

Energy optimization calls for a cross-layer optimization across all the protocol layers and networking functions, such as transmission and spectrum handoff in our case. The energy consumed in the secondary network consists of consumption for i) data transmission, ii) spectrum sensing, iii) the communication protocol, including information exchange for cooperative spectrum sensing and for organizing the secondary transmissions [20].

Additionally, the circuit power consumed by the transmitter and the receiver, and the power consumed for tuning to the channel to be sensed can give a substantial part of the energy consumption. The optimal energy unit chooses the node having SSUs property and assign the categorization unit to them by which energy calculation done on each node. Optimal energy unit transfer this data to energy optimisation unit by which energy unit checks the default unit of energy according to transmission unit, while checking it shows some cache property assign with each node and also with transmission relays by clearing the cache assign with this unit the optimisation unit verify the endpoint energy also the transmission speed for data packets transferring can be minimised.

VI. SIMULATION AND RESULT

In this section, we construct a simulator to evaluate the performance of the proposed optimal routing algorithm in proposed network architecture. We consider a CRAHN that covers a square area. The Size of the area 100 X 100, the number of SUs is not change during the simulation. PUs and SUs are deployed in a random way. We compare the performance result of the proposed optimal routing algorithm with random selection algorithm in the proposed network architecture and Heuristic algorithm. Random selection is that we randomly select an SSU among OCRU each time until all OCRUs in CRAHN Satisfy the condition 1 and condition 2. We simulate the relationship between communication radius of SUs and relationship between average energy and time.

Tolerable delay t_δ varies from 0 to 50 ms. the communication radius of SUs is set to 15 m. The number of SUs in traditional CRAHNs. The reason is that all SUs sense available spectrum in traditional CRAHNs [4]. The number of SSUs Selected by proposed Optimal routing Algorithm in proposed architecture is no more than a heuristic algorithm and random selection algorithm whatever the t_δ is. The less number of SSUs in CRAHNs, the less energy consumption of SUs for sensing available licensed spectrum [4]. Hence, SUs can reduce their energy consumption in our novel network architecture by using optimal routing algorithm.

Figure 5 shows the number of SSUs under the different communication radius of SUs by using optimal routing algorithm in proposed architecture and heuristic algorithm and random selection algorithm in proposed. t_δ is set to 25 ms. The communication radius of SUs varies from 10 to 20 m. From figure 5 it can be observed that the number of SSUs decreases with increase in communication radius of SUs by using Optimal routing algorithm and heuristic algorithm and random selection algorithm in proposed architecture. The reason is that the larger communication radius of SUs is, the more OCRUs in one SSU's communication radius. Hence more OCRUs can get there available licensed spectrum information from one SSU. Proposed architecture is no more than that selected by the heuristic algorithm in proposed architecture random selection algorithm. Hence, SUs can reduce their energy consumption in our novel network architecture by using optimal routing algorithm.

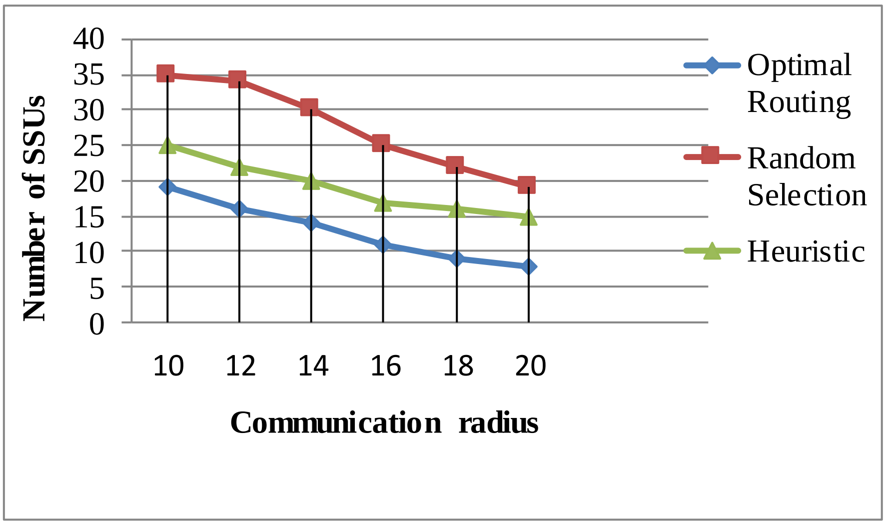

Fig 5. The relationship between the number of SSUs and the communication radius of SU

CONCLUSION

In this paper, CRAHNs network architecture is proposed. In the proposed network architecture, only parts of SUs have installed CR modules. Besides, a minimum number of SSUs among OCRUs are selected to sense available spectrum information. The minimum number of SUs selection problem is mathematically formulated as a non-linear programming problem. Because of the non-linear programming problem that we founded is an NP-hard problem, a distributed optimal routing is proposed. Results show that the proposed optimal routing in the proposed network architecture works much better in energy efficiency.

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