

# Optimization of broadcasting scheme for the CASoRT system

Shuo Hou, Xiaofeng Zhong, Shunliang Mei

State Key Laboratory on Microwave and Digital Communications

Tsinghua National Laboratory for Information Science and Technology

Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

Email: hous10@mails.tsinghua.edu.cn, {zhongxf, meisl}@tsinghua.edu.cn

**Abstract**—Content Aware Soft Real Time Media Broadcast (CASoRT) is a new solution for information service of cellular network. As the similar distribution of users interest, the data of same content may be accessed and retransmitted frequently in cellular network during certain period of time, which caused the dissipation of both energy and spectrum efficiency. With the development of Data Mining, the CASoRT system could discover the users common interests and broadcast such content to users who may be interested in. With those users accessing the content locally, the potential retransmission could be avoided and thus it could save energy from carriers view while providing the same real time experience to the users. In this paper, we propose a set of algorithm for the optimization of broadcasting scheme for the CASoRT system to achieve more energy efficiency.

## I. INTRODUCTION

With the fast development of wireless communication, the energy consumption has increased significantly and thus energy efficiency has become the challenge topic. As the similarity of the users behavior, the current cellular network consumes tremendous energy on transmitting repeated information. With the development of Data Mining technology, finding out the common interest from users behavior becomes possible. Avoiding such retransmission would reduce huge percentage of energy consumption. Caching content in local is well studied in the area of wired network[1], and caching in wireless network area has becoming a more and more popular in recent years. Sailhan and Issarny [2] propose protocols as well as cache management scheme to reduce energy consumption in Ad hoc network. Chand and Joshi [3] proposed the cooperative scheme on caching management in Ad hoc network. Goemans and Li [4] proposed the non-cooperative caching scheme in ad hoc network. Moreover, Xiang [5] introduce the cooperative caching scheme into cellular network. In the paper [6], it provides the innovative idea: Content Aware Soft Real Time Media Broadcast(CASoRT) system. CASoRT system broadcasting the information that is commonly interesting to users. Users could store such information in their own local cache, then users would access to such information in their local cache. Thus, spectrum resource would be saved by one broadcast because it meets users potential demand for

retransmitting the same content. However, that paper provides the preliminary idea with a little detail.

In this paper, we provide the optimized broadcasting scheme for CASoRT system. As the inconsistent distribution of users and their interest in position, simply broadcasting the content to all users in their respective coverage range would induce to lower efficiency: the efficiency of broadcasting is much lower than that of unicast transmission. Therefore, the balance between the broadcast coverage and its energy consumption should be considered. Thus, the CASoRT system should be able to adjust its broadcasting range according to the distribution of users location, arrival rate and interest.

The main contribution of the paper is: This paper provides the basic system model for the innovative idea of CASoRT system for research. Then, we propose the objective of optimization of CASoRT service. For the optimization of broadcasting radius scheme for Base Station (BS) is a combinatory optimization problem, which is NP-hard, we present the algorithm, which is polynomial time complex, inspired by game theory to achieves sub-optimal.

The reminder of this paper is organized as follows: In part II, we present the system and users interest model with the utility function for the whole system. In part III, we present the algorithm for the optimization of broadcasting radius for each BS. The simulation results are shown in part IV and the last part conclude the paper.

## II. SYSTEM MODEL AND PROBLEM FORMULATION

### A. System Model

We consider a cellular network with multiple BSs, where our focus is on downlink communication, i.e., from BS to Mobile Terminal (MT). We consider a two dimensional region  $\mathcal{A} \subset R^2$  served by a set of BS, denoted by  $\mathbf{B}$ , and let  $BS_i$  to index the  $i$ th-BS. Also, define a set of all users by  $\mathbf{U}$ . Let  $x$  denote the location of a specific MT.  $g(x, i)$  denote the channel gain from  $BS_i$  to MT at position  $x$ , which includes path loss attenuation, shadowing and other factors. However, the fast fading is not considered because the time scale for measuring is assumed to be much larger. Therefore, the expected signal strength received at position  $x$  from  $BS_i$  can be expressed as  $E_i(x) = P_i \cdot g(x, i)$  where  $P_i$  denotes the transmission

This work is supported by National S&T Major Project (2010ZX03005-003), and Chinese 973 Program (2012CB316006)

power of  $BS_i$ . Accordingly, SINR at location  $x$  for  $BS_i$  can be written as:

$$SINR(x, i) = \frac{E_i(x)}{\sum_{j \in \mathbf{B}, j \neq i} E_j(x) + \sigma^2} \quad (1)$$

where  $\sigma^2$  is the background Gaussian noise power from atmosphere. Following the Shannons formula, the channel capacity for user at position  $x$  from  $BS_i$  could be expressed as:

$$c(x) = \log_2(1 + SINR(x, i)) \quad (2)$$

The channel capacity at location  $x$  is not necessarily the function of distance from BS to MT, but a function of specific position, or to be more specifically, the SINR of such location. We assume that if  $SINR(x, i) > \eta$ , MT could receive the data correctly.

We assume that file transfer requests arrive following an inhomogeneous Poisson point process with arrival rate per unit area  $\lambda(x, t)$  and file size which are independently exponentially distributed with mean  $\frac{1}{\mu(x, t)}$  at location and time  $t$ . Thus, the traffic loads at position  $x$  is also a Poisson process with arrival rate:

$$\gamma(x, t) = \frac{\lambda(x, t)}{\mu(x, t)} \quad (3)$$

Then the system-load density of  $BS_i$  at position  $x$  is defined as:

$$\rho_i(x, t, \mathbf{B}) = \frac{\lambda(x, t)}{\mu(x, t)} \quad (4)$$

if the user at position  $x$  is served by  $BS_i$ , which could be explained as the average time to deliver traffic loads at location  $x$  from  $BS_i$ .

Further, we define  $r(x, i)$  as the camp scheme for user  $x$ . If user at location  $x$  is camped at  $BS_i$ , then  $r(x, i) = 1$ . If such user is not camped in  $BS_i$ , then  $r(x, i) = 0$ . Then, the system load of  $BS_i$  could be expressed as:

$$\rho_i = \int_{x \in \mathcal{A}} \rho_i(x, t, \mathbf{B}) \cdot r(x, i) \cdot q(x, t) dx \quad (5)$$

in which the  $q(x, t)$  means the possibility that location  $x$  has a user at time  $t$ .

The energy consumption of  $BS_i$  could be defined as[7]:

$$E_i = \rho_i \cdot P_i \quad (6)$$

since  $\rho_i$  could be interpret as average time  $BS_i$  to deliver its traffic loads to MT and  $P_i$  is the transmission power. The total energy consumption could be expressed as:

$$E = \sum_{i \in \mathbf{B}} P_i \cdot \rho_i \quad (7)$$

### B. Users interest model

We have a basic assumption here that the interest of users, that is the possibility for each user to access for the specific content, would not change significantly during certain period of time. Thus, we can use the statistic about the content to estimate the interest of such content in current and set the broadcasting scheme based on such estimation. Assuming that

the specific content with  $y$  bit would be accessed by user located at  $x$  with possibility  $p(x)$  during a period, with the nature of Poisson process, the arrival process would also be a Poisson process with arrival rate per unit area  $\lambda(x, t)(1-p(x))$  and same file size distribution, if the user received the broadcast and store such information in local cache and then access such content from storage. However, in order to broadcast such  $y$  bit information to all the users covered by such BS, the BS should guarantee that the user with poorest SINR within its broadcast radius could receive the information properly. That would consume system load:

$$\frac{y}{c(\tilde{x}_i, i)} \quad (8)$$

where the  $\tilde{x}_i$  is the user with least channel capacity in  $\mathcal{A}'_i$ , which means the broadcasting range covered by  $BS_i$ , and we may call such user as the broadcasting radius of  $BS_i$ . Thus the total system power consumption with such  $y$  bit information broadcasted would be:

$$E' = \int_{t=0}^T \int_{x \in \mathcal{A}'} \sum_{i \in \mathbf{B}} P_i \frac{\gamma(x, t)(1-p(x))}{c(x, i)} r(x, i) q(x, t) dx dt + \int_{t=0}^T \int_{x \in \mathcal{A} - \mathcal{A}'} \sum_{i \in \mathbf{B}} P_i \frac{\gamma(x, t)}{c(x, i)} r(x, i) q(x, t) dx dt + \sum_{i \in \mathbf{B}} P_i \frac{y}{c(\tilde{x}_i, i)} \quad (9)$$

where  $\mathcal{A}' = \mathcal{A}'_1 \cup \mathcal{A}'_2 \cup \dots \cup \mathcal{A}'_{|\mathbf{B}|}$ . Thus, the system power consumption decrease could be expressed as follow:

$$\phi(y) = E - E'(y) = \sum_{i \in \mathbf{B}} \left( \int_{t=0}^T \int_{x \in \mathcal{A}'} \frac{\gamma(x, t)p(x)}{c(x, i)} r(x, i) q(x, t) dx dt - \frac{y}{c(\tilde{x}_i, i)} \right) \quad (10)$$

Here, we use the time averaged users position in period  $T$  to estimate the system load, that is we believe that the distribution of users SINR is not change significantly during period  $T$  and  $\int_{x \in \mathcal{A}'} \frac{1}{c(x, i)} q(x, t) dt = \sum_{i \in \mathbf{U}'} \frac{1}{c(x, i)}$ , and thus change the continuous integral into discrete sum. Also, we assume the distribution of traffic load and users interest is irrelevant with users SINR. Then, after the exchange of the sequence of integration, we have  $\int_{t=0}^T \gamma(x, t) dt = I(x)$ . Thus, (10) could be written as:

$$\phi(y) = \sum_{i \in \mathbf{B}} P_i \left( \sum_{j \in \mathbf{U}'} \frac{I(x_j)p(x_j)}{c(x_j, i)} r(x_j, i) - \frac{y}{c(\tilde{x}_i, i)} \right) \quad (11)$$

### C. Problem formulation

In this paper, we consider the scheme of broadcast range optimization. Assuming that we have had the knowledge about the specific content with  $y$  bit that would be accessed with probability  $p(x, t)$ , we interest in the optimization of broadcasting range. The problem could be described as follows:

$$\max_{\tilde{x}} \sum_{i \in \mathbf{B}} P_i \left( \sum_{j \in \mathbf{U}'} \frac{I(x_j)p(x_j)}{c(x_j, i)} r(x_j, i) - \frac{y}{c(\tilde{x}_i, i)} \right) \quad (12)$$

However, the problem (12) is a combinatory optimization problem, which is NP-hard and takes  $O(|\mathbf{U}|^{|\mathbf{B}|})$  time to exhaustively find the optimal solution. So, we propose the following sub-optimal algorithms with less complexity inspired by game theory. The algorithms have two steps. In step one,

each BS greedily search for their own optimal broadcasting range. In second step, the BS adjust its own broadcasting range respect to other BSs broadcasting range strategy.

### III. OPTIMIZATION OF BASE STATION BROADCASTING RADIUS

As defined in 3G/4G cellular network, as every MT maintains the SINR not only its camped BS, but also neighboring BS it discovers. If the users could reports the all the SINR of BS which the user could successfully demodulate its signal to SGSN, the BS could acknowledge the all the users who can successfully demodulate its signal even if the user is not camped in such BS. The BS could help cover the border neighboring BS when BS could broadcast the content to those uncamped users at the border of neighboring cells. Thus it makes the neighboring BS need less energy to broadcasting the content while the network achieves the same broadcasting range. The network may get additional gain if there is rational cooperation scheme between BS. However, the problem of finding out the optimal broadcasting range for each BS is a combinatory optimization problem, which is NP hard. Also, the global optimal is not achieved even if every BS attains their respective local optimal. Thus, we introduced a two-step sub-optimal algorithm, which is inspired by game theory, to mitigate such complexity.

#### A. Base station greedily search for local optimal

In the greedy search step, each BS tries to find the optimal broadcasting radius greedily. We will first describe the structure of the optimal and then give the search algorithm.

*Lemma 1:* For users  $i$  and  $j$  located at  $x_i$  and  $x_j$  and  $BS_k$ , if  $SINR(x_i, k) < SINR(x_j, k)$  and user  $x_j$  is found by BS in optimal broadcasting range, then the user  $x_j$  is already found by  $BS_k$ .

*Proof:* If the user  $x_i$  is found by  $BS_k$ , then  $SINR(\tilde{x}_k, k) \leq SINR(x_i, k) \leq SINR(x_j, k)$ . As the channel capacity is monotonous increasing with SINR, so the user  $x_j$  could also receive the broadcast properly. Thus as  $x_j$  is not the broadcasting radius, and let  $X$  denote the users in broadcasting range, we get

$$\phi(X \cup \{x_j\}) - \phi(X) = \frac{I(x_j)p(x_j)}{c(x_j, k)} \geq 0$$

Since if the broadcasting radius  $\tilde{x}_i$  is set, the users in the broadcasting range of  $BS_i$  could be specifically determined, which is denoted by  $U_i$ . Therefore we do not differentiate the two concept in the following context.

*Corollary 1:* The broadcasting radius of  $BS_k$  is optimal if it has optimal broadcasting radius.

Thus, we can propose Algorithm 1 for BS to achieve its local optimal

*Theorem 1:* Algorithm 1 gets the local optimal broadcasting range with linear time.

*Proof:* For all the users that could demodulate the signal from  $BS_k$  are sorted in increasing order by their  $SINR$  to

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#### Algorithm 1 BSs greedy algorithm for local optimal

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- 1: INITIATE: sort the user available to  $BS_k$  in increasing order by SINR and concatenate  $\infty$  to the end of the sequence
  - 2: **for**  $j$  in the sequence **do**
  - 3:   **if**  $x_j$  is not camped in  $BS_k$  **then**
  - 4:     find  $x_j$ 's camped  $BS'_k$  and calculate
 
$$\alpha(x_j) = \frac{c(x_{j+1}, k) - c(x_j, k)}{c(x_j, k)(x_{j+1}, k)}y - \frac{P_{k'}}{P_k} \frac{I(x_j)p(x_j)}{c(x_j, k')}$$
  - 5:   **else**
  - 6:     calculate
 
$$\alpha(x_j) = \frac{c(x_{j+1}, k) - c(x_j, k)}{c(x_j, k)(x_{j+1}, k)}y - \frac{I(x_j)p(x_j)}{c(x_j, k)}$$
  - 7:   **end if**
  - 8:   **if**  $\alpha(x_j) \leq 0$  **then**
  - 9:     add  $x_j$  to temporal list and add  $\alpha(x_j)$  to temporal value.
  - 10:   **else**
  - 11:     **if**  $\alpha(x_j) + \text{temporal value} \leq 0$  **then**
  - 12:       add  $x_j$  to temporal list and  $\alpha(x_j)$  to temporal value.
  - 13:     **else**
  - 14:       clear out the temporary list and value.
  - 15:     **end if**
  - 16:   **end if**
  - 17: **end for**
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$BS_k$ . If user  $x_{j+1}$  is the current broadcasting radius, replacing  $x_{j+1}$  with  $x_j$  as the broadcasting radius would induce the change of network power consumption as follows: If user  $x_j$  is camped in  $BS_k$ , and this induces the change of reduction of power consumption of  $BS_k$  as:

$$\begin{aligned} & \sum_{i \in B} P_i \left( \sum_{l \in U' \cup \{x_{j+1}\}} \frac{I(x_l)p(x_l)}{c(x_l, i)} r(x_l, i) - \frac{y}{c(\tilde{x}_i, k)} \right) - \\ & \sum_{i \in B} P_i \left( \sum_{l \in U'} \frac{I(x_l)p(x_l)}{c(x_l, i)} r(x_l, i) - \frac{y}{c(\tilde{x}_i, k)} \right) \\ & = P_k \left( \frac{I(x_j)p(x_j)}{c(x_j, k)} - \frac{c(x_{j+1}, k) - c(x_j, k)}{c(x_j, k)c(x_{j+1}, k)} \right) \end{aligned}$$

And if user  $x_j$  is not camped in  $BS_k$ , but with  $BS_{k'}$ , the user would communicate with  $BS_{k'}$  after receive the broadcast from  $BS_k$ , and thus induce the change of reduction of power consumption of  $BS_k$  as:

$$\begin{aligned} & \sum_{i \in B} P_i \left( \sum_{l \in U' \cup \{x_{j+1}\}} \frac{I(x_l)p(x_l)}{c(x_l, i)} r(x_l, i) - \frac{y}{c(\tilde{x}_i, k)} \right) - \\ & \sum_{i \in B} P_i \left( \sum_{l \in U'} \frac{I(x_l)p(x_l)}{c(x_l, i)} r(x_l, i) - \frac{y}{c(\tilde{x}_i, k)} \right) \\ & = P_{k'} \frac{I(x_j)p(x_j)}{c(x_j, k')} - P_k \frac{c(x_{j+1}, k) - c(x_j, k)}{c(x_j, k)c(x_{j+1}, k)} \end{aligned}$$

If  $\alpha(x_j) \leq 0$ , replacing the broadcasting radius  $x_{j+1}$  with user  $x_j$  would get additional power saving. User  $j$  would replace  $x_{j+1}$  and be the new broadcasting radius if  $x_{j+1}$  becomes the broadcasting radius. If  $\alpha(x_j) > 0$ , the  $BS_k$  may also get power saving, if making  $x_j$  as temporal broadcasting radius could sequentially make the potential broadcasting

radius be in BSs broadcasting range and the total change of power consumption is towards power saving. Else, however, excluding such user, along with the potential broadcasting radius so far, from the broadcasting range of  $BS_k$  would avoid power dissipation. Finally, if the last user in the sequence could join the broadcast region, we can claim that all the potential broadcasting radius users could save power. So, we should examine that if the last user could lower the system power, which is equivalent check its  $\alpha$ -function with an fictitious user whose SINR is  $\infty$ .

The BS enumerate each users in its available range only once, and in each round, the BS only need to calculate the  $\alpha$ -function and decide whether the user should be in the broadcast range or not with simple rule. Thus the BS could finish the greedy search in  $O(|U|)$  time ■

The global optimal is not achieved after every BS applied algorithm 1. When the broadcasting range of two BS overlap with each other, they recount the power saving of users in the overlapped area in their local optimal range. However, the user would not provide more power saving if it receives more than one copy of the same content. Thus we introduce algorithm 2 inspired by game theory for the network to adjust the broadcasting range of each BS to achieve global optimal.

#### B. Achieving global optimization with Game Theory

First, we introduce the background of Game Theory. Suppose we have  $k$  agents and disjoint strategy set  $A_1, A_2, \dots, A_k$ , and let  $a_i \in A_i$  be the available strategy agent  $i$  may takes. And we define strategy set  $A \in A_1 \times A_2 \times \dots \times A_k$ ,  $A = \{a_1, a_2, \dots, a_k\}$  as the implemented strategy set by each player. A pure strategy is the strategy in which every agent uses only one of the available strategy. We define the local utility function for agent  $i$  as  $\alpha(a_i, a_{-i})$ , where  $a_{-i}$  means that the implemented strategy set of agents except for agent  $i$ . We call the strategy set  $A^*$  is Nash Equilibrium (NE) if for all agents,  $\alpha_i(a_i^*, a_{-i}^*) \geq \alpha_i(a_i, a_{-i}^*)$  for all available strategy. We call the Nash Equilibrium is a pure Nash Equilibrium if all the agents uses pure strategy.

We call function  $f: 2^V \rightarrow R$  as set function. We define the discrete derivation at  $X \subset V$  in set  $D$  as

$$f'_D(X) = f(X \cup D) - f(X) \quad (13)$$

A set function is submodular if

$$f'_D(A) \geq f'_D(B) \quad \text{if } A \subset B \text{ and } \forall D \subseteq V - B \quad (14)$$

If the game satisfies the following conditions: (I) The global utility function  $\gamma(A)$  is submodular. (II) The local utility  $\alpha(a_i, a_{-i})$  of an agent is at least the impact in global utility if such agent quit the game. We call such system as utility system game. If we define  $A \oplus \emptyset_i = \{a_1, a_2, \dots, \emptyset_i, \dots, a_k\}$ , the utility system game should, by definition, satisfy  $\alpha(A) \geq \gamma_{\alpha_i}(A \oplus \emptyset_i)$ . More specifically, if we have the equation, we call such game as basic utility system game. Moreover, we require that the sum of local utility is no larger than the global utility, that is  $\sum_i \alpha_i(a_i, a_{-i}) \leq \gamma(A)$ . In such circumstance, we call such game as valid utility system game

**Lemma 2:** If we define  $A_i = \{a_1, a_2, \dots, a_i, \emptyset_{i+1}, \dots, \emptyset_k\}$ , then for global utility function  $\gamma(A) = \sum_{i=1}^k \gamma'_{a_i}(A^{i-1})$

**Theorem 2:** The valid basic utility system has pure strategy Nash Equilibrium.

**Theorem 3:** For a valid utility system, then for any Nash Equilibrium  $A^*$  we have:

$$OPT \leq 2\gamma(a^*) - \sum_i \gamma'_{a_i^*}(a^* \cup \Omega - a_i^*)$$

where the  $OPT$  means the global optimal value and  $\Omega$  means the strategy induce to global optimal. The  $a^* \cup \Omega$  means the union of the set chosen by optimal strategy and the set chosen by NE strategy.

For the limitation of the length of this paper, please refer to [8] for the detail of proof for theorem 2 and theorem 3. The proof of theorem 2 not only proves the correctness of the theorem, but also provides us the way to reach the NE. For every agents sequentially maximizing their own local utility greedily with respect to other agents current action, and the NE would be finally reached.

We can re-formulate the optimization problem as a broadcasting radius optimization game  $\{\mathbf{B}, \tilde{x}_1 \times \tilde{x}_2 \times \dots \times \tilde{x}_{|B|}, \alpha(x_i, x_{-i})\}$ . Each BS is a player, and their respective strategy is its broadcasting radius, which could determine its broadcasting range. Since the BS could not obtain additional power saving on users set  $\bigcup_{j \neq i} U_j$ , who already joined in other BSs broadcast, when the BS still broadcast the same content to it. Thus, the rational local payoff for any BS is the power saving it achieve on user set  $U - \bigcup_{j \neq i} U_j$ , which is  $\alpha_i(\tilde{x}_i, \tilde{x}_{-i}) = \gamma(\tilde{x}) - \gamma(\tilde{x} \oplus \emptyset_i)$ . Every BS tries to maximize its local payoff. The global pay off is the problem objective in (12).

**Theorem 4:** The broadcasting radius optimization game is a valid basic utility game

**Proof:** First, we proof that the global utility function is submodular.

$$\begin{aligned} \gamma(U'_i, U_{-i}) - \gamma(U_i, U_{-i}) &= \sum_{l \in B} P_l \left( \sum_{j \in U'_i / (U_i \cup U_{-i})} \frac{I(x_j)p(x_j)}{c(x_j, l)} r(x_j, l) \right) - \frac{y}{c(\tilde{x}_i, i)} + \frac{y}{c(\tilde{x}_i, i)} \\ \gamma(U'_i, U'_{-i}) - \gamma(U_i, U'_{-i}) &= \sum_{l \in B} P_l \left( \sum_{j \in U'_i / (U_i \cup U'_{-i})} \frac{I(x_j)p(x_j)}{c(x_j, l)} r(x_j, l) \right) - \frac{y}{c(\tilde{x}_i, i)} + \frac{y}{c(\tilde{x}_i, i)} \end{aligned}$$

where  $U_{-i}$  means the broadcasting range exclude  $U_i$ . For  $U_{-i} \subset U'_{-i}$ , it is easy to proof that  $U_i / (U_i \cup U_{-i}) \subset U_i / (U_i \cup U'_{-i})$ . As  $\frac{I(x_j)p(x_j)}{c(x_j, l)} r(x_j, l) \geq 0$  we can get that the first equation is larger than the second one, and thus the global utility function is submodular.

Second, we will proof that the broadcasting system is a valid basic system. As the definition of the local utility,  $\alpha_i(\tilde{x}_i, \tilde{x}_{-i}) = \gamma(\tilde{x}) - \gamma(\tilde{x} \oplus \emptyset_i)$ . According to the submodularity of global utility,

$$\begin{aligned} \gamma'_{a_i}(\tilde{x}^{i-1}) &= \gamma(\tilde{x}_1, \tilde{x}_2, \dots, \tilde{x}_i, \emptyset_{i+1}, \dots, \emptyset_k) - \\ &\gamma(\tilde{x}_1, \tilde{x}_2, \dots, \emptyset_i, \emptyset_{i+1}, \dots, \emptyset_k) \geq \alpha_i(\tilde{x}_i, \tilde{x}_{-i}) = \\ &\gamma(\tilde{x}_1, \tilde{x}_2, \dots, \tilde{x}_k) - \gamma(\tilde{x}_1, \tilde{x}_2, \dots, \emptyset_i, \tilde{x}_{i+1}, \dots, \tilde{x}_k) \end{aligned}$$

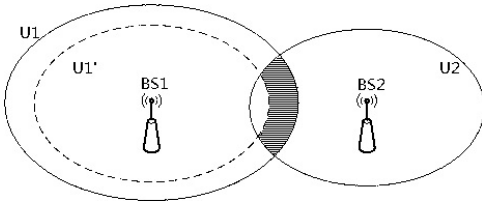


Fig. 1. Broadcasting range change in two base station condition

Therefore

$$\sum_i \alpha_i(\tilde{x}_i, \tilde{x}_{-i}) \leq \sum_i \gamma_{\alpha_i}(\tilde{x}^{i-1}) = \gamma(\tilde{x})$$

Therefore, we could propose the algorithm 2:

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**Algorithm 2** broadcasting radius optimization

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- 1: Set the broadcasting radius as  $\emptyset$  for all the BS
  - 2: **while**  $\alpha_l > \gamma_{threshold}$  **do**
  - 3: For every  $BS_i$ , use Algorithm 1 to find the optimal broadcasting radius  $\tilde{x}_i$  from the user set  $U - \bigcup_{j \neq i} U_j$
  - 4: calculate their own local utility gain  $\alpha_i = \gamma(\{\tilde{x}_1, \dots, \tilde{x}'_i, \dots, \tilde{x}_k\} - \{\tilde{x}_1, \dots, \tilde{x}_i, \dots, \tilde{x}_k\})$
  - 5: set  $l = \arg \max_i \alpha_i$  and update  $x_l$  with users whose SINR is larger than  $x'_i$  from the view of  $BS_i$ .
  - 6: **end while**
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*Theorem 5:* Algorithm 2 would converge to NE in at most  $2 \cdot |B|$  iterations and the time complexity of broadcasting range optimization is  $O(|B| \cdot |N|)$ .

*Proof:* As every iteration, the BS with maximum  $\alpha_i$  updates its broadcasting range,  $\alpha_i$  is non-increasing with iterations. Thus, if in any iteration, the broadcasting range of any BS stops changing, all of BS reach the NE point. We first consider the condition of two BS and then extend to the general condition. For BS1 and BS2, in the first two iterations,  $BS_1$  sets its broadcasting range  $U_1$  and  $BS_2$  sets its broadcasting range  $U_2$ , as is shown in fig 1. Then, in next two iterations,  $BS_1$  and  $BS_2$  adjust their respective broadcasting range. If the sequence of broadcasting range updating is from  $BS_1$  to  $BS_2$ , then  $BS_1$  should shrink its broadcasting range for  $U_2$  may overlap with  $U_1$  and the those overlapped range is not considered by  $BS_1$  in determining its broadcasting range. Then,  $BS_2$  would change its broadcasting range because  $BS_2$  get additional available range (the shadowed area). However, the shadowed range is within  $U_2$ . According to algorithm 1, the BS search for new broadcasting radius outside the current broadcasting range and thus the shadowed range do not contribute to the enlargement of current broadcasting range. Further more, according to algorithm 1, adding new users in current broadcasting range would not induce to reduction of broadcasting range. Thus, we conclude that BS2 would not change its broadcasting range in the fourth iteration.

We can conclude from the two BS situation that BS could only resize its broadcasting range by reducing or maintaining

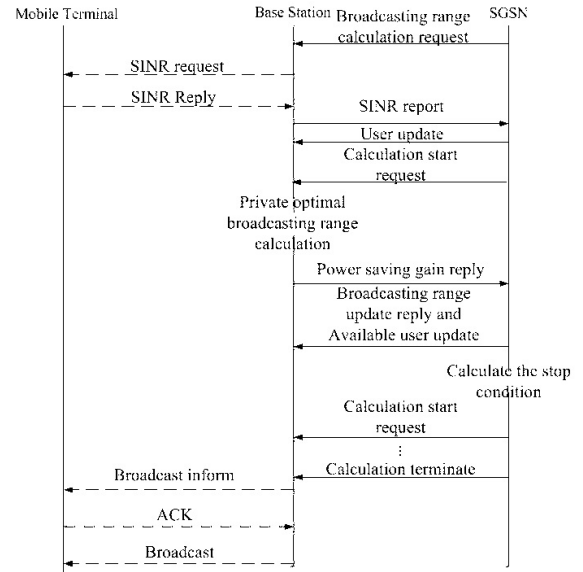


Fig. 2. The protocol to realize algorithm 2

its broadcasting range. For the network with  $|B|$ , after first  $|B|$  iterations, every BS should resize its broadcasting range according to other BSs broadcasting range. If within the  $2|B|$  iteration there is a BS whose broadcasting range stops change, we get the NE within  $2|B|$  iterations. Else, at the  $2|B|$  iteration, if the BS in operation of changing broadcasting range is  $BS_k$ , all the BS overlaps with  $BS_k$  in the last  $|B|$  iterations reduce their respective broadcasting range at the best response of  $U_k$ , and  $U_k$  would maintain its broadcasting range unchanged for the similar reason in the two BS situation. Thus the Algorithm is reached in at most  $2|B|$  iterations. For each iteration, the BS would search for the local optimal at the expense of  $O(|U|)$ , then the total time complexity is  $O(|B| \cdot |U|)$ .

The protocol graph for network to optimize its broadcasting range could be depicted in fig 2. In the SINR request and SINR Reply step, the BS request the users maintained SINRs: from its camped BS and its neighboring BS. Then, BS report the received SINR to SGSN and SGSN informs each BS about those users which is not camped in this BS but could demodulate its signal successfully. After that, each BS distributively calculate its local optimal broadcasting range and send the outcome to SGSN. SGSN is responsible for managing the iteration process, which include calculating the stopping criterion and sending user set update  $U - \bigcup_{j \neq i} U_j$  to BS. After the iteration stops, SGSN informs users about the broadcasting information, which includes broadcast receiving preparation information and from which BS the broadcasting comes from. Finally, the SGSN controls the BS to broadcasting the content in the calculated broadcasting range.

#### IV. SIMULATION

We consider a area of  $5 \times 5 km^2$  with 6 uniformly distributed BS with which are controlled by a single SGSN. There

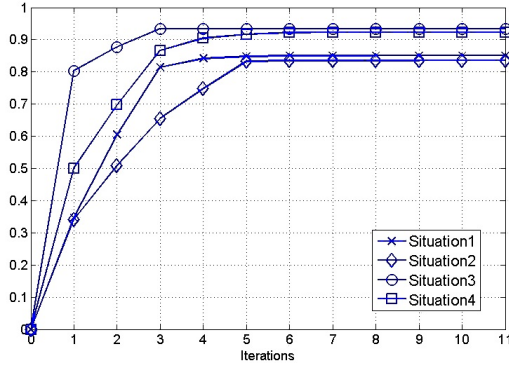


Fig. 3. The percentage of power saving of our Algorithm to exhaustive search. The X axis is iteration and Y axis is the percentage of power saving in each iteration normalized by the optimal value found by exhaustive search

are total 1000 active users in this region and the users are uniformly distributed in this area and have homogenous arrival bits at 100Mbit in a period. The content we may broadcast have 10Mbit bits. We use typical value of the transmission power for each BS, i.e., 40W, respectively. The route factor 2.5 for simulate the route damping. We assumes that the distribution of users interest could be formulated with Gaussian distribution, which is accord with the law of big numbers, or homogeneous within a region.

For the Gaussian distribution of interest, the access rate for the content is

$$p(x, y) = 0.4 \times \frac{1}{2.5 \times 2\pi e \times 2.5^2} e^{-\frac{(x-\bar{x})^2 + (y-\bar{y})^2}{2 \times 2.5^2}}$$

The center of the Gaussian distribution  $(\bar{x}, \bar{y})$  is randomly selected in the region. For the homogeneous distribution of interest with access rate as  $p(x, y) = 0.4$

In fig 3, we show the performance of our algorithm in the following situation. As the absolute number of power saving is changing with the specific location of users, the power consumption saving by our algorithm is normalized by the optimal outcome by exhaustive search to reveal its performance. We can see that the algorithm would converge quickly to the NE and it takes within 12 iteration to attain the NE for 6 BS, which is accorded with Theorem 6. The users access rate for the content situation 1 to 3 is Gaussian distributed with random center. The distribution of users interest in situation 4 is homogeneously distributed. We can see from fig4 that the algorithm would obtain very close outcome to the optimal result. In all of the situations, our algorithm could achieve above 80% the optimal result.

In fig 4, we show the power saving when users interest is uniformly distributed and the access rate for such content grows from 0 to 1 with different size of content. The position of BS is fixed, and the users are uniformly distributed with homogeneous interest of the content with three different conditions of size of content. From fig 3, it could be concluded that as the size of content grows, the power for broadcasting such content grows and thus makes the total performance of the CASoRT system decline. However, the performance do

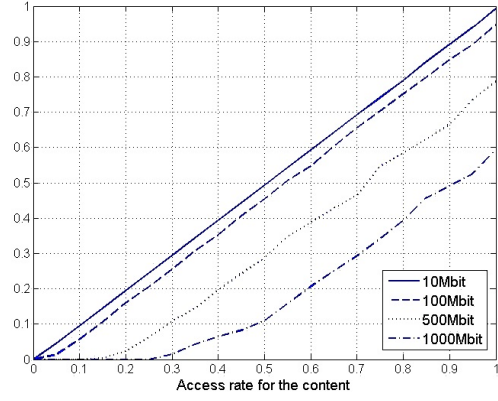


Fig. 4. The efficiency of our algorithm in different access rate of users interest. The X axis represents possibility each user access the content and the Y axis represents the percentage of the power saving to the total power consumption of the system

not degrade significantly with the increase of the size of the content. Also, the total power saving is almost hold a linear relationship with the access rate for the content.

## V. CONCLUSION

In this paper, we focused on the problem of designing the broadcasting scheme for CASoRT system in wireless cellular network. We proposed the scheme to achieve energy saving, considering the character of broadcasting, the distribution of users and their interests, and time complexity of the CASoRT system. Moreover, our algorithm could converge much more quickly and attain at least 80% power saving compared with the theoretical optimal scheme.

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