Improving Cell Broadcasting Scheme to Support Multi-Lingual Service in Wireless Networks

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***Abstract*—In this paper we propose a new problem named *energy-efficient multi-lingual cell broadcasting*(EEML-CB) to support multi-lingual service in cell broadcasting system. We prove that the problem is NP-hard and then propose ILP model as well as a greedy algorithm named *smart multi-lingual cell broadcasting* (SMCB). We evaluated our heuristic by simulations.**

***Index Terms*—Multi-lingual service, cell broadcast.**

I. INTRODUCTION

NOWADAYS, it is more convenient to receive information via short messages using mobile phones, e.g. stock prices, traffic information, weather reports, and emergency alerts. Such a service can be achieved by *Cell Broadcast Messaging System* (CBMS), a newly developed mobile technology defined by the ETSI's GSM committee as part of the GSM & 3G standard [1]. CBMS is also known as *Short Message Service-Cell Broadcast* (SMS-CB) [7]. It allows a text or binary message to be defined and distributed to all mobile terminals (*clients*) connected to a set of cells (*base stations*). Instead of point-to-point message delivery, CB messages are sent point-to-area. It has many attractive features: (1) using one-to-many technology, which is more efficient than basic SMS; (2) providing efficient real-time communication, which is more convenient than traditional wireless systems; (3) supporting emergency location based info services; and (4) saving memory space, since *Cell Broadcast* (CB) messages can be seen as stream content.

However, CBMS eliminates user characteristics, for example, language preference. This problem is even worse in multi-ethnic and tourist cities. For instance, Singapore has four official languages: Chinese, English, Malay, and Tamil. Furthermore, a majority of the population only understand one or two of these languages. The motivation of our paper is to find an efficient scheme for CB to meet different language requirements.

Few systems can support multi-lingual service. One is *Wireless Mesh Network* (WMN) [4], [6], [8], which provides multi-channel communication, where each channel corresponds to a specific language. Another is CBMS [1], [2]. These two mechanisms have the same strategy, which treats the same content in different languages as different packets, and broadcasts them repeatedly in a single cell (different channels) within BS's maximum transmission range. Compared with those approaches, our approach is more energy efficient.

The rest of this paper is organized as follows: Section II lists all the assumptions and describes our problem. In Section III we propose *integer linear programming* (ILP) and a greedy algorithm, in Section IV we illuminate the heuristics with numerical experiments, and finally Section V gives a conclusion.

II. PROBLEM STATEMENT

We consider a single hop cell broadcasting system with n *clients*, m *base stations* (BS), and k languages. Assume clients are static during a period of time. Each client accepts only a subset of the languages. Since the length of packets for the same content in different languages varies significantly, we assign a weight for every language to denote the average cost for CB. The weight is a ratio that indicates the relative amount of data required for a language in comparison to some base language (e.g, we set the weight of English to 1, and the weight of Chinese to 0.7, meaning the size of packets in Chinese is 0.7 times that of English, on average). The following lists all the symbols we use for our model.

1) $\mathbf{C} = \{c_i\}$: Client set, $1 \le i \le n$;
2) $\mathbf{BS} = \{bs_j\}$: BS set, $1 \le j \le m$;
3) $\mathbf{H} = \{h_i\}$: Index set, $1 \le i \le n$. Each h_i denotes the index of the BS communicating with c_i.
4) $\mathbf{D} = \{d_i^{h_i}\}$: Distance set. Each $d_i^{h_i}$ denotes the distance between c_i and bs_{h_i};
5) $\mathbf{L} = \{l_q\}$: Language set, $1 \le q \le k$;
6) $\mathbf{W} = \{w_q\}$: Language Weight Set, $1 \le q \le k$;
7) $\mathbf{CL} = \{cl_i^q\}$: Client Acceptable Language set, $1 \le i \le n$, $1 \le q \le k$. Each cl_i^q is a boolean parameter, where
$$cl_i^q = \begin{cases} 1 & \text{if } c_i \text{ accepts language } l_q; \\ 0 & \text{otherwise.} \end{cases}$$
8) $\mathbf{R} = \{r_j^q\}$: Broadcasting Radius set, $1 \le j \le m$, $1 \le q \le k$. Each r_j^q is the broadcasting radius for bs_j with l_q.
9) $\mathbf{E} = \{E_j^q\}$: Energy set, $1 \le j \le m$, $1 \le q \le k$. Each E_j^q represents energy consumption for bs_j to broadcast packets in language l_q with radius r_j^q.
10) $\mathbf{X} = \{x_i^q\}$: Acceptance set, $1 \le i \le n$, $1 \le q \le k$. Each x_i^q is a boolean variable where
$$x_i^q = \begin{cases} 1 & \text{if } c_i \text{ receives a packet in language } l_q; \\ 0 & \text{otherwise.} \end{cases}$$

Fig. 1 is an example of a CBMS for multi-lingual service. It contains 5 BS's, 8 languages, and several clients with their acceptable language sets.

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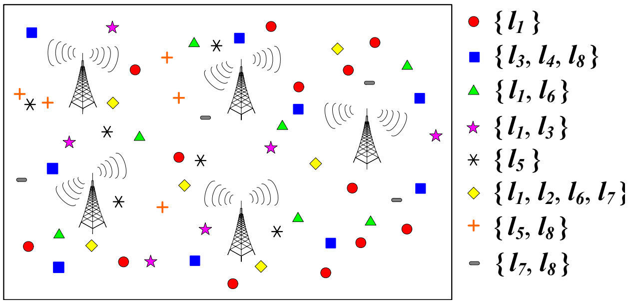

Fig. 1. An example of CBMS system.

The following are other assumptions we need in CBMS:

1) Assume all BS's use omnidirectional antennas with the same transmitting antenna gain G_t, and they use the same wavelength λ. Similarly, all the clients have the same G_r.
2) Our model is built under Euclidean free space with simplest form of the Friis transmission equation. Therefore, $d_i^{h_i} = |c_i - bs_{h_i}|$. If BS bs_{h_i} sends data to client c_i, we will have
$$P_r^i / P_t^{h_i} = G_t G_r \big(\lambda / 4\pi d_i^{h_i}\big)^2 \tag{1}$$
where P_r^i is the receiving power for c_i, $P_t^{h_i}$ is the transmitting power for bs_{h_i}. In order to guarantee that client c_i receives data correctly from bs_{h_i} in language l_q, we must assign enough energy. Let $E_{h_i,i}^q$ be the energy consumption for bs_{h_i} to c_i in l_q. Let P_{th} be the lowest power of client c_i to correctly receive 1 bit (threshold). Obviously,
$$P_r^i = G_t G_r \big(\lambda / 4\pi d_i^{h_i}\big)^2 P_t^{h_i} \geq P_{th}. \tag{2}$$
If a packet has length s, then the whole energy needed at bs_{h_i} to c_i is
$$E_{h_i,i}^q = P_t^{h_i} s \geq \frac{P_{th}}{G_t G_r} \big(\frac{4\pi d_i^{h_i}}{\lambda}\big)^2 s = A (d_i^{h_i})^2 s \tag{3}$$
3) Assume that each client will receive a packet from its nearest BS. To break a tie, we assume there is an ϵ distance difference for a client located at the middle of two BS's.
4) Assume each BS has the same maximum transmission radius r_{max}, and the union of all transmission ranges can cover the entire target area.

As we use a point-to-area broadcasting scheme, the total energy for a BS to transmit a packet in language l_q with length s to all its clients can be defined as follows:
$$E_j^q = \max_{c_t \in \mathbf{C_j^q}} A \cdot (d_t^{h_t})^2 s = A \cdot (r_j^q)^2 s \tag{4}$$
where $\mathbf{C_j^q}$ is bs_j's client set who accepts l_q.

Since clients may accept different languages, each BS should broadcast the same CB message by different languages several times. However, it is a waste of energy if a BS broadcasts data using the maximum transmission distance each time. As CBMS supports location based push service [3], a smarter way is to collect its client information for their preferred language sets, and broadcast messages in a certain language with the distance of its farthest client who prefers this language. Our goal is to find an efficient language and energy assignment for BS's such that every client will receive at least one copy of the packet with their acceptable languages, and minimize the total energy used for each BS. Therefore, we define our new problem as follows:

Definition 1 (EEML-CB)**.** *The Energy-efficient multi-lingual cell broadcasting (EEML-CB) problem can be described as*

Given: **C**, **BS**, **H**, **L**, **CL**, **W** R_{max} *and* A*. For each* bs_j*, assign an efficient strategy* S_j*, containing several couples as* $< l_q, r_q^j >$*, which means that* bs_j *should broadcast language* l_q *with distance* r_q^j*.*

Find: *a minimum energy consumption strategy* $\mathbf{S} = \{s_j\}, (0 \leq j \leq m)$ *for every BS, such that each client* c_i *can receive at least one copy of the required messages with its acceptable languages.*

Theorem 1. *EEML-CB is NP-hard.*

Proof: We prove the NP-hardness by a reduction from the *minimum weighted set cover problem* (MWSC). Formally, given a collection $\mathbf{C} = \{C_q\}_{q=1}^k$ of subsets of a finite set $S = \{s_i\}_{i=1}^n$ with weight $\mathbf{W} = \{w_q\}_{q=1}^k$, the MWSC problem is to find a minimum weight subset $\mathbf{C'} \subseteq \mathbf{C}$ such that $\forall s_i \in \mathbf{S}$, $\exists C_q \in \mathbf{C'}$ satisfying $s_i \in C_q$.

Now we construct an instance for EEML-CB. In this instance there are 1 BS, n clients $\{c_i\}_{i=1}^n$, and k languages $\{l_q\}_{q=i}^k$ with weight $\mathbf{W}$. All the n clients will be put on a circle with BS as the center. For each client c_i, if $s_i \in C_q$, then c_i accepts language l_q.

Notice that all clients have the same distance from the BS, thus we only need to care about the number of languages in which messages are broadcast. Then, given a solution $\{C_{a_1}, C_{a_2}, \cdots, C_{a_t}\}$ for MST we have a solution $\{l_{a_1}, l_{a_2}, \cdots, l_{a_t}\}$ for EEML-CB and vice versa, where $t \leq k, a_1, a_2, \cdots, a_t$ are positive integers. This reduction can be done within polynomial time. This finishes the proof. ■

Based on Theorem 1, heuristics are required to find a good feasible solution for EEML-CB.

III. ILP Model and Heuristic Approach

In this section, we will first exhibit the ILP model of the EEML-CB problem, and then provide a greedy algorithm, named *Smart Multi-Lingual Cell Broadcasting*(SMCB), to solve EEML-CB quickly.

First of all, we briefly give the ILP model as follows:

$$\begin{array}{lll}
\min & \sum_{j=1}^{m} \sum_{q=1}^{k} E_j^q & \\
s.t. & \sum_{q=1}^{k} x_i^q \geq 1 & \forall c_i; \\
 & x_i^q \leq cl_i^q & \forall c_i, l_q; \\
 & A \cdot (d_i^{h_i})^2 \cdot w_q \cdot x_i^q \leq E_{h_i}^q, & \forall c_i, l_q; \\
 & d_i^{h_i} \cdot x_i^q \leq r_{h_i}^q, & \forall c_i, l_q.
\end{array}$$

The objective of this ILP model is to minimize the total energy consumption for a BS. The first two constraints guarantee that each client receives at least one language from its accepted language set. The third constraint calculates the energy consumption for each language, while the last one guarantees that for each given language, the energy is large enough for the BS to cover all target clients.

The ILP is acceptable in small scale networks. However, when network size grows, the time consumption of ILP grows exponentially, bringing inefficiency and redundant waiting time for clients. Thus, we need to develop heuristics.

TABLE I
SIMULATION RESULT FOR EXAMPLE 1.

W_{max}	1	1	1	1	1	1	2	2	2
r_{max}	1	2	4	6	8	10	1	2	4
ILP	1.9	6.2	18.4	36.9	97.6	117.3	2.2	6.5	30.8
SMCB	3.0	9.9	20.2	54.3	128.5	199.4	3.3	10.0	37.2
TCBMS	3.3	13.2	38.6	70.8	190.8	356.1	4.0	14.7	88.8
W_{max}	2	2	2	4	4	4	4	4	4
r_{max}	6	8	10	1	2	4	6	8	10
ILP	64.3	105.1	219.8	2.7	10.9	62.6	86.7	236.9	398.9
SMCB	66.4	150.1	260.2	3.5	10.9	83.8	86.7	361.4	525.9
TCBMS	221.5	398.1	602.2	7.3	30.2	163.3	173.3	664.7	760.5

Now let us depict our greedy algorithm for EEML-CB. The main idea of this algorithm is to find the farthest client for a BS, broadcast with its least weight acceptable language l_q, then remove all clients accepting l_q. We repeat this greedy step until no client is left without getting a copy of the content. The formal description is as follows.

Algorithm 1 Smart Multi-Lingual Cell Broadcasting (SMCB)

Input: **C**, **BS**, **H**, **L**, **CL**, **W** r_{max} and A.
Output: S and E.

1: For each bs_j, select its client set $\mathbf{C_j}$.
2: Find the farthest client $c_t \in \mathbf{C_j}$ with it least weight language l_q. Assign $r_j^q = d_t^j$. Mark this client.
3: Mark clients whose acceptable language set includes l_q.
4: Repeat step 2-3 until no client left unmarked in $\mathbf{C_j}$.

Theorem 2. *SMCB outputs an assignment with minimal energy consumption, and has time complexity* $O(n^2)$.

Proof: First, we cannot reduce any r_j^q in S otherwise some client cannot receive its required packet, which means SMCB outputs a minimal solution. Second, finding each c_t needs $O(n)$ time, and marking other clients needs additional $O(n)$ time. Thus SMCB needs $O(n \cdot n)$ time complexity. ■

IV. SIMULATION

In this section, we present two examples to show that the ILP can solve EEML-CB in small-scale networks very well, while SMCB achieves good performance in both small and large scale networks. The ILP was solved by CPLEX 7.0 [5].

a) Example 1: In this example, we check the performance of the ILP model and show that SMCB can obtain results close to the ILP in small scale networks. This CBMS contains 1 base station, 100 clients, and 5 languages. The elements in distance vector **D** and the weight set **W** are uniformly distributed in the range from 0 to maximum transmission radius r_{max} and maximum weight w_{max}, respectively. We assume $A = 1$ when we calculate the energy consumption. We also randomly generate the **CL** set for each client c_i. Table I gives the results of the ILP and SMCB. In this table TCBMS denotes traditional CBMS broadcasting protocol. From this figure, we can find that as w_{max} increases, the CB consumes more energy to deliver longer packets to clients. r_{max} also affects the energy consumption because the longer r_{max} is, the more energy is needed to deliver the packet.

Finally, we find that our heuristic can achieve good feasible results which are close to the optimal solution, and can save around 50% energy compared with traditional CBMS. Besides, it shows the same trends as the ILP.

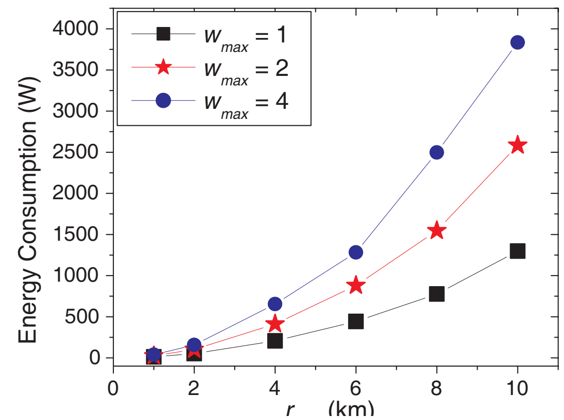

Fig. 2. Simulation Result for Example 2.

b) Example 2: This example checks the performance of SMCB for a large scale network that contains 5 base stations, 100000 clients, and 50 languages. Other parameters are the same as Example 1. We run SMCB 10000 times as distinct scenarios. Figure 2 illustrates the results that are obtained by SMCB. Similarly, if the weight of languages increases, energy consumption will be significantly increased. The same results are produced when the maximum distance increases. The energy consumption trend is similar to Example 1. Thus, the value of r_{max} and w_{max} will affect our result tremendously.

We also find that our heuristic saves more than 50% of the energy consumed by traditional CBMS. Due to the space limitation, we do not show data for traditional CBMS.

V. CONCLUSION

In this paper, we define a new problem for energy efficient assignment in CBMS named EEML-CB. We propose an ILP model to solve small-scale networks optimally, and a greedy approach to find good feasible solutions in large-scale networks. The simulations clearly indicate that the increase of transmission range and weight of languages will significantly affect the energy consumption for BS's. These results also prove that our heuristic SMCB can solve EEML-CB properly.

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