Energy Efficient Community Coding and Capacitive Sensing for Space Energy Internet

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Abstract

We present energy-efficient community coding and capacitive sensing for space energy Internet, where efficient coding techniques for information transmission as well as human operation protection in space with capacitive sensing are of great significance. Community coding is an emerging field of social computation and coding theory, which provides a method of aggregating resources from a community such as a group of space energy storage nodes to maximize the sum of their utilities by allowing the community members to coordinate their contributions of resources. Community coding for space energy Internet can be classified into two categories: *(a)* coding based on collective knowledge or information over aggregated community sources to maximize the efficiency such as the diagnosis of faults in space energy Internet system based on system status information at each node in the network; *(b)* coding based on collective contributory resources over aggregated community sources to minimize the possibility of the disruption of services such as the supply of energy based on the new paradigm of space energy Internet. We also touch on some human operation protection issues for space energy Internet with a set of experiments with capacitive sensing, which could be used as a means for community coding coordination for space energy Internet operations.

Keywords: Space Energy Internet**,** Community Coding, Network Coding, Source Coding, Capacitive Sensing

1. Introduction

With the ever-growing popularity of the Internet, the expansion of wireless local and personal area networks, the ubiquity of mobile devices (smartphones, tablets, etc.), nowadays people are living in an increasingly networked world. In general, a community consists of three pillars, which are connectivity, communication and coordination (WeChat, Twitter, Yammer, Facebook, Google+, etc.). Underpinned by a wide range of emerging technologies that facilitate better connectivity, better communication and better coordination among people, the notion of community has taken on new meanings. In a sense, a community can be regarded as a group of connected things (either actively or passively connected), composed of hardware, software and/or people and formed by common interests through activities. For example, space energy Internet can be viewed as a community of connected energy storage nodes in the space to efficiently and adaptively satisfy energy request demand.

In this paper, we present energy-efficient community coding for space energy Internet by applying advanced mathematical models and optimization tools to better understand the engineering design tradeoffs in the new paradigm of community coding for space energy Internet. The ultimate objective is to harness and unleash the power of a community of space energy storage nodes to better perform some tasks that one individual node is not able to accomplish efficiently and effectively. The basic principle is to treat space energy Internet not just as an energy system but also a human system. We also explore efficient means for some human operation protection issues for space energy Internet with a set of experiments with capacitive sensing, which could be used as a means for community coding coordination for space energy Internet operations.

To tackle some of the challenges in space energy Internet, we introduce energy-efficient community coding, where information systems meet social networks. Community coding is an emerging field of social computation and coding theory, which provides a method of aggregating resources from a community such as a space energy Internet to maximize the sum of their utilities by allowing the community members to coordinate their contributions of resources.

1.1 Community Coding

Formally, we introduce the notion of community coding as follows.

Let R_i stand for the available resources at node i in a community of N members. We define C_i as the committed resources from node i for a given joint event of the community. Let U_i denote the utilities for node i, resulted from the given event. Let U_F stand for the utility floor limit for members of the community.

The goal is to maximize the sum of the utilities among all the community members, subject to some given constraints.

$$\max_{C_i} \quad \sum_{i=1}^{N} U_i \qquad (1)$$

Subject to

$$C_i \le R_i \qquad \text{for } 1 \le i \le N \qquad (2)$$

$$U_i \ge U_F \qquad \text{for } 1 \le i \le N \qquad (3)$$

$$\frac{U_i}{U_j} \propto \frac{C_i}{C_j} \qquad \text{for } 1 \le i, j \le N \qquad (4)$$

$$U_i = f(C_1, C_2, ..., C_i, ..., C_N) \qquad \text{for } 1 \le i \le N \qquad (5)$$

Notably, the utility for each community member is not only determined by its committed resources but also by those contributed from other community members. Constraint (3) indicates the floor limit of the community member's utility, similar like the concept of minimum wage in our society. Constraint (4) denotes the proportional fairness issue in that the more resources one contributes, the more utilities that community member will be awarded.

Community coding can be classified into two categories: *(a)* coding based on collective knowledge over aggregated community sources to maximize the efficiency such as the diagnosis of faults in space energy Internet system based on system status information at each node in the network; *(b)* coding based on collective contributory resources over aggregated community sources to minimize the possibility of the disruption of services such as the supply of energy based on the new paradigm of space energy Internet.

1.2 Community Coding versus Network Coding

Network coding, which refers to coding at the nodes in a network [14], is a field of information theory and coding theory, which provides a method of attaining maximum information flow in a network.

The core notion of network coding is to allow mixing of data from multiple sources at intermediate network nodes to increase the entropy of the transmitted information. A receiver sees these data packets and deduces from them the messages that were originally intended for that data sink. Routing, which only routes information without mixing of the data at intermediate network nodes, can be regarded as a special case of network coding.

On the other hand, community coding is a field of social computation and coding theory, which provides a method of aggregating resources from a community to maximize the sum of their utilities by allowing the community members to coordinate their contributions of resources based upon some predefined rules such as the proportional fairness rule and the minimum utility rule.

In the following, we present some application scenarios of energy-efficient community coding for space energy Internet.

2. Energy-Efficient Community Coding

In this section, we present energy-efficient community coding for space energy Internet. In this case, each space energy storage node is regarded as a community member and the utility for each community member is the delivery of the information with the least total required resources among those energy storage nodes of the given network. The proposed energy-efficient community coding approach takes into account the information of the network topology of the space energy Internet during the source coding process and tends to maximize the sum of the utilities of all community members as a whole. We derive the optimal bounds for the minimization of the total required energy for space energy Internet. Implementation issues are also discussed.

Traditional source coding schemes solely assume the role of data compression, e.g., the process of encoding information using fewer bits than an un-encoded representation. The proposed energy-efficient community coding approach takes into account the information of the network topology of the space energy Internet and tends to maximize the sum of the utilities of all community members as a whole.

2.1 Related Work

Other researchers also address the source coding, power efficiency issues in wireless networks. The classic algorithm on source coding by Ziv and Lempel is described in [16]. The Huffman coding approach for deterministic sources is given in [8]. In [6], Goyal presented techniques for one single information source with several chunks of data, e.g., "descriptions", so that the source can be approximated from any subset of the chunks. The broadcast channel with degraded message set problem was described in multi-user information theory [3]. Bergmans present a similar broadcast channel scenario in [2]. Energy efficient issues for wireless ad hoc networks are described in [5] and [12]. Barr et al present an energy-aware lossless data compression approach in [1]. Scaglione and Serveto analyze the interdependence of routing and data compressing in wireless sensor networks in [13]. Zhao in [15] presents network source codes to take advantage of network topology for broadcast and multiple access systems. Li et al in [11] give an indept analysis on the capacity of wireless ad hoc networks and observe that the throughput for each node's applications is limited by the relaying load imposed by distant nodes in the network.

2.2 Problem Formulation

We consider the situation that a sender wants to simultaneously transmit n independent messages from n distinct sources to n different destinations for space energy Internet. Due to the popularity of multi-user and multi-task (process) operating system, the situation that a sender wants to send multiple messages simultaneously to different receivers could be commonplace in reality. Without loss of generality, we assume that the i^{th} source is destinated to the i^{th} receiver. We also assume that each message traverses different path with different path metrics, e.g., different number of hops, to its destination. The information from

n different sources is multiplexed by the source encoder and the encoded information is further processed by the channel encoder and the modulator. The signal is propagated through radio channel. Each receiver receives its intended messages through the process of demodulation, channel decoding and source decoding.

We also assume the model of memoryless sources in the sense that the symbols for each message are generated independently of each other. Let s_i ($1 \le i \le n$) stand for the number of independent symbols for the i^{th} source and $p_{i,j}$ ($1 \le i \le s_j$, $1 \le j \le n$) denote the probability of occurrence for the i^{th} symbol of the j^{th} source. Notably, for any source, say the i^{th} source, we have

$$\sum_{k=1}^{s_i} p_{k,i} = 1 \tag{6}$$

Without loss of generality, the minimization of the average codeword length is often used for the performance evaluation of a source encoder. From the network engineering perspective with a cross-layer design philosophy, we are most concerned with the total network throughput and the network lifetime. The total network throughput is determined by the total traffic load and the network lifetime largely depends on the energy consumption of each network node. Thus, the minimization of the average codeword length is not the only ultimate design object in our case. Rather, we consider the minimization of the total traffic load or the total required energy.

Let L_i ($1 \le i \le n$) stand for the possible number of symbols in the i^{th} message and normally L_i is a large number. Then we can have the normalized probabilities among symbols in all possible sources. Let $p'_{i,j}$ ($1 \le i \le s_j$, $1 \le j \le n$) denote the normalized probability of occurrence for the i^{th} symbol of the j^{th} source and we have

$$p'_{i,j} = \frac{p_{i,j} \times L_j}{\sum_{k=1}^{n}\sum_{m=1}^{s_k}(p_{m,k} \times L_k)} = \frac{p_{i,j} \times L_j}{\sum_{k=1}^{n} L_k} \tag{7}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{s_j} p'_{i,j} = 1 \tag{8}$$

Now let us recall the two basic principles on source coding, e.g., the prefix-free condition and the Kraft inequality. In order to guarantee instant decoding and to avoid confusion in the decoding process, the codeword of any symbol can not be the start part of the codeword of another symbol. The prefix-free condition guarantees unique decodability. It is known in this literature that any binary code satisfying the prefix-free condition, the codeword lengths $\{l_i\}$ must satisfy the Kraft inequality [4]. Let N stand for the total number of symbols and l_i denote the codeword length for the i^{th} symbol and the Kraft inequality constraint states that

$$\sum_{i=1}^{N} 2^{-l_i} \le 1 \tag{9}$$

Without considering the minimization of the traffic load or the total require energy, an extended Huffman coding approach based on the normalized probabilities among symbols in all the possible sources can be used to minimize the average codeword length. Let $l_{i,j}$ stand for the codeword length for the i^{th} symbol of the j^{th} source. Notably, the average codeword length in this case is downwards bounded by

$$\bar{l}_{\min} = -\sum_{j=1}^{n}\sum_{i=1}^{s_j}(p'_{i,j} \times l_{i,j}) \tag{10}$$

where $l_{i,j} = -\log_2 p'_{i,j}$ (11)

2.3. Minimizing Total Required Energy

Although the path loss model, e.g., the power attenuation is proportional to $1/d^{\alpha}$ where d stands for the distance between the transmitter and receiver antennas and the exponent α often takes a value between 2 and 4, depending on the communication media characteristics, is often used to quantify the energy consumption in wireless communication protocols, it has been reported in [12] that the path loss model often fails to capture the energy overheads of the hardware. Following a similar model used in [7], we consider the radio dissipates E_{tr} nJ/bit to run transmitter or receiver circuitry and E_{amp} $pJ/bit/m^2$ for the transmit amplifier to achieve an acceptable E_b/N_o. We define the total required energy to send the given n different messages from a given sender to n different destinations as the sum of the required energy at each node on the path from the sender to each destination node from the beginning of the transmission till all of the n messages are completely delivered to the intended destination nodes. Let $l_{i,j}$ stand for the codeword length for the i^{th} symbol of the j^{th} source and $d_{i,j}$ denote the distance of the i^{th} hop on the path that the j^{th} message traverses. Thus, we have the total required energy

$$E = \sum_{j=1}^{n}((2 \times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j \times \sum_{i=1}^{s_j}(l_{i,j} \times p'_{i,j})) \tag{12}$$

Under the Kraft inequality constraint (Formula (9)), we apply Lagrange multiplier method to minimize the total required energy (Eq. (12)) and we have

$$\min_{l_{i,j}} E = (\sum_{j=1}^{n}((2 \times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j \times \sum_{i=1}^{s_j}(l_{i,j} \times p'_{i,j})) + \lambda \times (\sum_{j=1}^{n}\sum_{i=1}^{s_j} 2^{-l_{i,j}} - 1) \tag{13}$$

Notably, in the above expression we consider L_j and h_j ($1 \le j \le n$) as constants. By performing the minimization process using Lagrange multiplier method, we have

$$\frac{\partial E}{\partial l_{i,j}} = (2 \times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j \times p'_{i,j} + \lambda \times 2^{-l_{i,j}} \times \ln 2 = 0$$

$$(1 \le j \ge n, 1 \le i \le s_j) \tag{14}$$

$$\frac{\partial E}{\partial \lambda} = \sum_{j=1}^{n}\sum_{i=1}^{s_j} 2^{-l_{i,j}} - 1 = 0 \tag{15}$$

From (6), (8), (14) and (15), we have

$$2^{-l_{i,j}} = -\frac{(2\times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j \times p_{i,j}^{'}}{\lambda \times \ln 2} \quad (16)$$

$$\lambda = -\frac{\sum_{j=1}^{n}((2\times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j \times \frac{L_j}{\sum_{k=1}^{n} L_k})}{\ln 2} = -\frac{\sum_{j=1}^{n}((2\times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times L_j^2)}{\ln 2 \times \sum_{k=1}^{n} L_k} \quad (17)$$

From (16) and (17), we obtain that the total required energy gets its minimum when the following choice holds

$$l_{i,j} = -\log_2 (L_j \times p_{i,j}^{'} \times \frac{(2\times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \times \sum_{k=1}^{n} L_k}{\sum_{k=1}^{n}(L_k^2 \times (2\times h_k \times E_{tr} + E_{amp} \times \sum_{m=1}^{h_k} d_{m,k}^{\alpha}))}) \quad (18)$$

From Equation (18) we can see that the symbol with a higher occurring frequency should get a shorter codeword and the message that traverses more hops over larger distances to its destination should get a shorter codeword. We can also see that the longer the message, e.g., more total number of symbols, the shorter the codewords for its symbols should be. Let us define

$$R_j = \frac{(2h_j E_{tr} + E_{amp} \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \sum_{k=1}^{n} L_k}{\sum_{k=1}^{n}(L_k^2 (2h_k E_{tr} + E_{amp} \sum_{k=1}^{h_k} d_{m,k}^{\alpha}))} \quad (19)$$

Thus from (12) and (18), the total required energy is downwards bounded by

$$E_{\min} = \sum_{j=1}^{n}((L_j (2h_j E_{tr} + E_{amp} \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \sum_{i=1}^{s_j} (p_{i,j}^{'} (-\log_2 (L_j p_{i,j}^{'} \times R_j))) \quad (20)$$

In reality the total number of symbols in a message, say L_j for the j^{th} message may not be known *a priori*. We can relax this constraint by assuming the lengths of all the messages are approximately equal. With this relaxation, the minimization of the total traffic load is only bounded with the number of hops that a message traverses and the probability that a symbol occurs.

Equation (7) can be rewritten as

$$p_{i,j}^{'} = \frac{p_{i,j}}{\sum_{j=1}^{n}\sum_{i=1}^{s_j} p_{i,j}} = \frac{p_{i,j}}{n} \quad (21)$$

Equation (18) can be rewritten as

$$l_{i,j} = -\log_2 (p_{i,j} \times \frac{2\times h_j \times E_{tr} + E_{amp} \times \sum_{k=1}^{h_j} d_{k,j}^{\alpha}}{\sum_{k=1}^{n}(2\times h_k \times E_{tr} + E_{amp} \times \sum_{m=1}^{h_k} d_{m,k}^{\alpha})}) \quad (22)$$

Equation (20) can be rewritten as

$$E_{\min} = C \sum_{j=1}^{n}((2h_j E_{tr} + E_{amp} \sum_{k=1}^{h_j} d_{k,j}^{\alpha}) \sum_{i=1}^{s_j}((-\log_2 (p_{i,j} \times R_j) \times \frac{p_{i,j}}{n}))) \quad (23)$$

where C is a constant, approximately representing the lengths of the messages.

3. Capacitive Sensing

In this section, we explore capacitive sensing that can be used for human operation protection for space energy Internet, which can also be used as a means for community coding coordination for space energy Internet operations.

Our goal is (a) to measure the velocity of the approaching object by examining the voltage changes over time, which could provide a guidance for the sensor's required response speed; （b） to examine the effective areas that capacitive sensors can detect; (c) examine the effects of different movements of the approaching object. A deep understanding of capacitive sensing will shed light on its effective use in the context of space energy Internet, in particular, for the safety issue of "no-touch" operations regarding energy storage and transmission for energy Internet in space.

In our experiments, we use PIC16F876's PWM to generate the pulse of 78 KHz as the input of the transmit electrode. We use OpAmp to amplify the pulse voltage from 5 Volts to 10 Volts and use OpAmp to connect the receive electrode as trans-conductance amplifier. We use PIC16F876's A/D and MAX233 to output digital results to PC and use Scope to measure the signals, where shunt mode is used.

Our first set of experiments involve with vertical hand's movement in and out in-between electrodes.

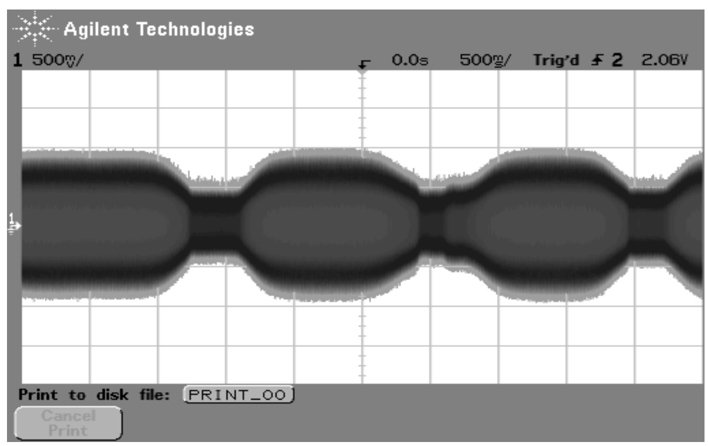

Figure 1: The output voltage in response to vertical hand's movement of in and out in-between electrodes.

As we can observe from Figure 1 that when hand moves in and out, the voltage drops and bounces to the original level.

A natural question arises as what happens if hand moves in and out in-between electrodes non-vertically. Our next set of experiments concerning the cases where hand moves in and out non-vertically in-between electrodes. From Figure 2, we can observe that if we move hand in and out non-vertically in between electrodes frequently, we can see that the voltage drop is not as faster as the case when the hand moves vertically.

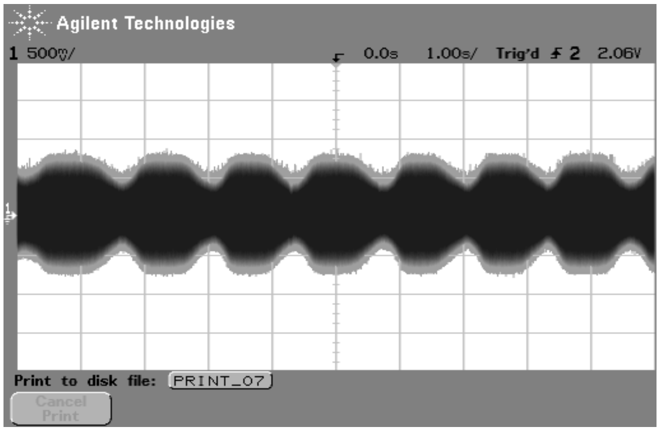

Figure 2: The output voltage in response to frequent non-vertical hand's movement of in and out in-between electrodes.

In our next set of experiments, we examine the dynamics of the output voltage when hand touches transit electrodes.

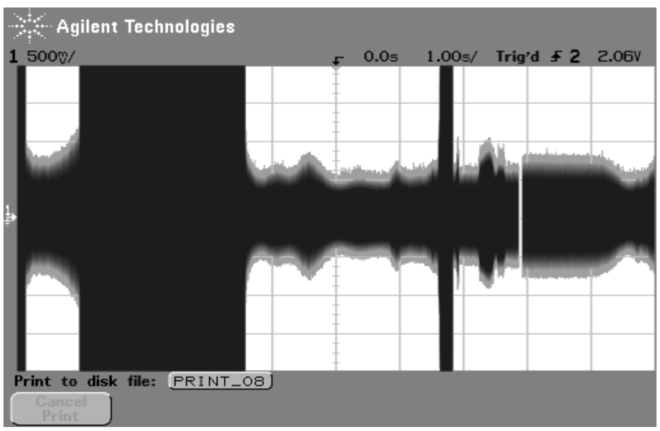

Figure 3: The output voltage in response to the case in which hand touches transit electrodes.

The above figure shows that when we touch the transmit electrode, we can see voltage spikes.

Finally, we examine the cases in which hand touches the receive electrodes frequently.

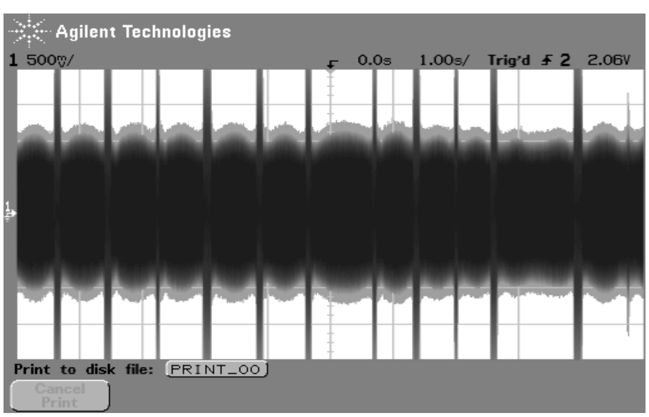

Figure 4: The output voltage in response to the case in which hand touches receive electrodes.

Figure 4 shows that compared with the case when hand touches the transmit electrode, we can see that when hand touches receive electrodes, the output voltage drops not that deep although we also see voltage spikes.

By performing extensive experiments regarding capacitive sensing for human operation protection in space energy Internet, we conclude that capacitive sensing is a simple way to achieve "no-touch" type protection. By measuring the voltage change over time, we can essentially map it to distance change over time, then we can get the derivative, which is the velocity of the object that is approaching. Capacitive sensing is only effective for movements in between the electrodes, thus in real implementation, the electrodes must be put at the ends of the protected object. The problem is that if the electrodes are far apart, the detected signal is tiny and it must be further amplified in order to get a measurable signal change. Capacitive sensing is only sensible to human's approaching, if a person uses another object such as a stick to approach it, it is very difficult to detect. When there are multiple pairs of electrodes, it seems that only the pair that has the smallest distance has the dominant impact.

4. Conclusion

In this paper, we present a new framework of energy-efficient community coding, where information systems meet social networks, which could be a group of space energy storage nodes in space energy network. Community coding is an emerging field of social computation and coding theory, which provides a method of aggregating resources from a community to maximize the sum of their utilities by allowing the community members to coordinate their contributions of resources. We examine energy-efficient community coding for space energy Internet through a concrete example of source coding. We also explore capacitive sensing for human operation protection in space energy Internet to study its inherent characteristics in a variety of circumstances. Capacitive sensing can also be used as a possible means for community coding coordination for space energy Internet operations.

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