Wireless Information and Power Transfer for Communication Recovery in Disaster Areas

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Abstract—When a disaster happens, the communication network is very likely to be damaged. Since communication is critical for coordinating the operations of disaster recovery, restoring the communication network is always the first priority. In many situations, however, the breakdown of the communication network results from the cutoff of the power network, and it is difficult to recover the power network in a short time. In this paper, we propose a wireless information and power transfer scheme such that the communication network can be recovered without firstly restoring the power network. Challenges of the proposed scheme are discussed.

I. INTRODUCTION

After a disaster, such as earthquake, typhoon/hurricane, and tsunami, happens, communication is usually disrupted in the disaster area. Restoring communications is always the first priority since, without communication, sending rescue personnel into the disaster area is dangerous and futile. Moreover, victims might be trapped in the collapsed building or covered by debris, and the easiest way to locate them or for them to connect to the outside world and call for help is through mobile communications. In many situations, the reason for the disconnection of communication network is due to the breakdown of power network, as shown in Fig. 1. Although many communication devices are still workable, the power source is cut off—the power plants could be damaged or the power grid that transports energy is destroyed. Even if the uninterruptible power supply (UPS) systems can provide backup power, they do not run long and could also be damaged. Although some small communication devices run on batteries, their power may run out quickly. Therefore, recovering the power supply is critical for disaster recovery. Unfortunately, restoring the power supply is not an easy task in the disaster area.

In this paper, we propose to deliver the power wirelessly to the disaster area to recover the communication network. We propose using the hybrid power transfer architecture with power relay. As shown in Fig. 1, aircrafts, such as airships, helicopters, and balloons, are used to transfer power wirelessly through inductive power transfer [1], [2] to large communication devices and through microwave power transfer [3] to small communication devices. Large communication devices then relay power to small communication devices through microwave power transfer. To minimize the human exposure to electromagnetic radiation and to maximize the power transfer efficiency, we propose using beam-steering and multi-direction powering. By feedbacking the location information and channel state information (CSI) from the devices to be powered to the power-providing devices, the power transmitters can steer the antenna pattern and beamform the power toward the power-receiving devices. In addition, power is transferred from multiple directions to reduce the hazard of electromagnetic radiation. The subsequent communication is setup by simultaneously considering the information and power transfer. In this way, the communication network can be quickly recovered without restoring the power network.

The rest of the paper is organized as follows. In Sec. II, we review the history and methods of wireless power transfer. In Sec. III, we elaborate on the proposed power transfer architecture for communication network recovery. Then in Sec. IV, we discuss the challenges of implementing the proposed scheme. Finally, conclusions are drawn in Sec. V.

II. WIRELESS POWER TRANSFER

In this section, we review the history and methods of wireless power transfer.

A. History of Wireless Power Transfer

The history of wireless power transfer can be traced back to the end of 1800, more than 100 years ago, starting with Nikola
Tesla’s dream of providing power wirelessly to everywhere in the world [4]. Although he did not succeed due to funding issues, several attempts on delivering power wirelessly had been made since then. The projects on space solar power (SSP) and unmanned aerial vehicles (UAVs), mainly funded by NASA and JPL, and later in Japan, became the major force behind the progression of wireless power transfer [3]. In recent years, wireless power transfer has significant progress [5] and finally finds commercial applications, such as completely wireless TV, cell phone and laptop charging, and RFID. The wireless charging standard Qi has been developed by the Wireless Power Consortium, and a few companies, such as WiTricity [6], have introduced their own products. Other than the aforementioned applications, wireless power transfer also arouses interests in scenarios involving isolated sensor nodes [7], implant devices [8], and online electric vehicles [9].

B. Methods of Wireless Power Transfer

There are two main categories of wireless power transfer methods: electromagnetic induction and electromagnetic radiation [10]. Electromagnetic induction methods, such as (resonant) inductive coupling and capacitive coupling, are non-radiative, near-field power transfer methods [1], [2], [5], [11], [12]. On the contrary, electromagnetic radiation methods, including microwave power transfer [3], [4] and laser, are radiative, far-field power transfer methods.

III. PROPOSED POWER TRANSFER ARCHITECTURE FOR COMMUNICATION RECOVERY

In this section, we describe the proposed hybrid power transfer scheme and the concept of power relay. We then elaborate on the method of maximizing the power transfer efficiency and minimizing the human exposure to radiation.

A. Hybrid Power Transfer and Power Relay

Electromagnetic inductive methods generally provide higher power transfer efficiency, but the power transfer equipments, e.g., coils, may be too large for small communication devices. On the other hand, the electromagnetic radiative methods, e.g., microwave power transfer, only require small receiver size. Therefore, for larger communication devices, such as base stations and access points, non-radiative electromagnetic induction methods are preferred, while the electromagnetic radiation-based power transfer methods are preferred for small communication devices.

Our proposed hybrid power transfer scheme is described as the following. When a disaster happens, airships, helicopters, or balloons with wireless power transfer equipments are dispatched to the disaster area. Those power-delivering aircrafts then transfer power to large communication devices using inductive coupling methods and deliver power to small communication devices through microwave power transfer. After harvesting enough power, these larger communication devices can then transfer power wirelessly to small communication devices using microwave power transfer. This is called power relay.

B. Power Transfer Efficiency Maximization and Radiation Exposure Minimization

To quickly transfer enough amount of power to the communication devices in order to restore the communication network, we need to (a) maximize the power transfer efficiency and (b) transmit at a large power. The latter causes a problem when electromagnetic radiative methods are used, that is, this causes a problem of human exposure to electromagnetic radiation. In order to circumvent this problem and to deliver power efficiently, we propose the following scheme.

At the beginning, the communication devices receive small amount of power which is used to feedback their GPS locations and CSI. (Note that if GPS signals cannot be received due to, e.g., covered by debris, then the location of a communication device can be estimated by the strength of the feedback signal.) After obtaining the location information, the
mainlobes of the power transmitting antennas of the power-providing devices are steered toward the location of the power-receiving devices. The CSI is used to maximize the power transfer efficiency and to beamform the electromagnetic radiation. To further reduce the human exposure to electromagnetic radiation, the power is delivered from multiple directions and concentrates on the location of the power-receiving device such that the total power acquired at the power-receiving device is large but the power strength along the path of each electromagnetic wave propagation is small. Therefore, the human exposure to electromagnetic radiation is minimized. See Fig. 3 and Fig. 4 for the system illustration.

C. Simultaneous Information and Power Transfer

After the initial power transfer, the communication link and then the communication network can be setup. In order to maintain the communication, simultaneous information and power transfer must be performed. The communication links between the power-delivering aircrafts and the large communication devices can be setup either using normal radio-frequency (RF) communication or by mutual induction, with the latter being similar to the near-field communication (NFC) [13]. On the other hand, the communication links between the power-delivering aircrafts and the small communication devices and those between the large communication devices and the small communication devices are more likely to use RF communication. When the same communication medium is used, the data rate must be maximized under the constraint of sufficient power transfer. Therefore, the receiver architecture of a device with simultaneous information and power transfer capability must be carefully designed. Fig. 5 shows an example of such receiver architecture for using radio frequency as the medium [14], [15]. The receiver has three functional blocks: energy harvester, information decoder, and channel estimator. When the time-switching architecture [16] is adopted, the receiver first operates at the energy harvesting mode to acquire energy. The acquired energy is used for channel estimation and then the CSI feedback. The CSI obtained at the transmitter is used for maximizing data and power transfer efficiencies. To maximize the data rate while maintaining enough power level to perform decoding and feedback, the optimal ratio for the time spent at the power transfer and the information transfer must be derived. This issue is currently under extensive studies [14], [15], [17].

IV. CHALLENGES OF THE PROPOSED SCHEME

There are several challenges of implementing the proposed system, including the availability of power-delivering aircrafts, the design of robust and efficient inductive power transfer systems, and the optimization of simultaneous information and power transfer protocols and schemes.

A. Power-delivering Aircrafts

The first challenge is the availability of the aircrafts that can carry power transfer equipments to the disaster area. The aircrafts not only need to be able to carry heavy power transfer equipments but also can stably stay at a location when performing power transfer. The reason that the aircrafts have to float stably is because the coils for inductive power transfer must be accurately aligned in order to maximize the power transfer efficiency [18], [19]. Slight misalignment will easily cause the power transfer efficiency to drop.

One possible solution is to use airships such as the Lockheed Martin P-791 aerostatic/aerodynamic hybrid airship [20]. The P-791 airship combines the advantage of the high speed of aerodynamic crafts and the lifting capacity of aerostatic crafts, and is suitable for carrying heavy power transfer equipments to the disaster area. However, it is unclear whether the stability performance can meet the requirements of accurate alignment for inductive power transfer.

B. Long Range, Multiple Receiver Inductive Power Transfer in Dynamic Environments

The current inductive power transfer techniques using resonant inductive coupling, can only be effective for a few meters [5]. This transmission range is definitely not sufficient for the proposed system to succeed. Although the power is able to reach the distance from several hundred meters to kilometers with microwave power transfer, the transmission efficiency is generally low. Consequently, long range inductive power transfer techniques are called for.

The proposed system is expected to operate in dynamic environments. In particular, the power transfer efficiency is a factor of the distance between the transmitter coil and the receiver coil [21]. Also, as mentioned earlier, the misalignment between the transmitter coil and the receiver coil significantly degrades the power transfer efficiency. Therefore, an inductive power transfer system that can be used in dynamic environments, such as the one discussed in [22], is essential. How to design a system that takes into account the misalignment effect and can self-adapt when the environment changes needs
further exploration. Additionally, an inductive power transfer system that can charge multiple receivers simultaneously is highly desired and needs further development [23].

Other than the human exposure to electromagnetic radiation, the effect of human exposure to magnetic fields must also be investigated [24]. Although our proposed scheme with transmitters from multiple directions can solve part of the problem, more effective approaches are welcome.

C. Efficient Simultaneous Information and Power Transfer

Simultaneous information and power transfer is an emerging research area [25], [26]. For the systems implementing microwave power transfer, other than the time-switching architecture mentioned earlier, the power-splitting architecture is also a possible approach. Although some preliminary results have been revealed, novel receiver architectures for simultaneous information and power transfer are required and more research efforts must be conducted in order to make the proposed scheme efficient. For the systems with mutual induction applied, there has been progress on NFC in recently years [13], [27], but we have not seen many researches on simultaneous information and power transfer with inductive coupling, except [25], [28]. Therefore, it would be exciting to see more advanced system design in the future.

V. CONCLUSIONS

The interruption of the communication network due to the breakdown of power network impedes the disaster recovery. Therefore, recovering the communication network is the first priority after the disaster happens. In this paper, we have proposed using wireless power transfer to recover the communication network without needing to restore the power network. A hybrid inductive power transfer and microwave power transfer architecture with power relay has been introduced. In order to maximize the power transmission efficiency and minimize the human exposure to electromagnetic radiation, we have proposed a scheme in which electromagnetic waves are beamformed and radiated from multiple directions. Challenges to implement the proposed system, including the availability of power-delivering aircrafts, the design of robust inductive power transfer systems, and the optimization of simultaneous information and power transfer protocols and schemes, have also been discussed in this paper.

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