Wireless Power Transfer: A Survey of Techniques, and Applications on Communication Networks †

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Abstract—Wireless power transfer (WPT) principles have been developed over a century since Tesla got a patent of apparatus for transmitting electrical energy. After the World War II, wireless power transmission at microwave frequencies have been focused and developed rapidly. The main goal of WPT is to transmit energy wirelessly from one place to another for charging purposes. WPT can be applied in many different application areas. New WPT technologies have been proposed not only for military purposes but also civil applications. The technologies satisfy either very long distances or short distances, such as satellite systems, unmanned aerial vehicles (UAV), vehicle networks, wireless sensor networks and especially communication networks. In this paper, we review basic concepts of WPT and recent applications. We focus on WPT for communication network applications. The new achievements and their practical uses are also mentioned and discussed. In addition, we point out new and challenging future research directions for Wireless-powered communication networks (WPCN).

Keywords—Wireless power transfer; electric charging; inductive coupling; resonant coupling; electromagnetic radiation.

I. INTRODUCTION

Nowadays, most wireless devices are powered via power cables or battery replacement, which limit the scalability, sustainability, and mobility of wireless devices. In fact, wire line charging or battery replacement may be infeasible or incur a high cost under some conditions. For examples, it is impossible to replace the battery of implanted medical devices in human bodies. Or, we do not want to replace batteries for wireless sensor networks deploying in hash conditions where people cannot access. Recent advance in RF-enabled wireless energy transfer technologies provide an attractive solution called wireless powered communication, where the wireless devices are powered by dedicated wireless power transmitters to provide continuous and stable microwave energy over the air. Wireless power transfer (WPT) has been exploited and developed for years in many applications [1, 2]. Satellite systems transmit power wirelessly from the geostationary orbit to the ground. WPT has become common usable charging methods for many different systems, such as unmanned aerial vehicles, wireless sensor networks, vehicle networks, especially communication networks. The most advantages of WPT are focusing on charging electrical devices wirelessly and energy harvesting in wireless communication networks. WPT is the approach that provides a solution for convenient alternative in charging conductively.

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† Short Letter

The WPT technology based on the magnetic resonance and near-field coupling of two-loop resonators was claimed Tesla a century ago [3]. As mentioned in the patent, WPT can be radiative or non-radiative depending on the energy transfer mechanisms. Radiative power can be emitted from an antenna and propagates through a medium (vacuum or air) over long distance (i.e., many times larger than the dimension of the antenna) in form of an electromagnetic wave. Non-radiative WPT relies on the near-field magnetic coupling of conductive loops and can be classified as short-range and mid-range applications. WPT technology is developing rapidly in recent years. The research field has been widely developed with various applications and corresponding technologies.

In this paper, we review common WPT applications and different techniques to exploit WPT uses in various fields, especially in communication networks. The main goal of WPT in communication networks is to harvest energy transmitting back and forth all the time. This narrows down the topics of WPT but explore more deeply into attractive applications in practical.

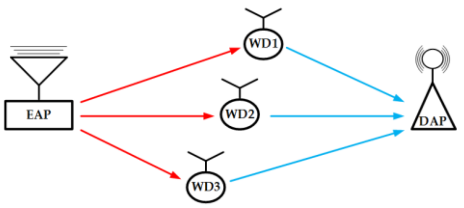
II. WIRELESS-POWERED COMMUNICATION NETWORKS (WPCN)

Wireless powered communication networking (WPCN) is a new networking paradigm where the battery of wireless communication devices can be remotely replenished by means of microwave wireless power transfer (WPT) technology. WPT opens up potential applications of a new type of network, namely wireless powered communication network (WPCN) [4], in which each user node is powered by wireless power from access points (AP).

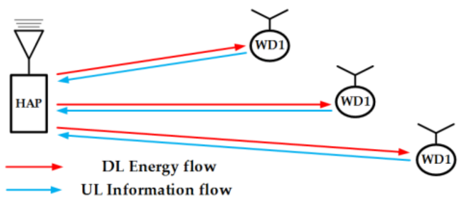
In WPCN, wireless devices (WD) harvest RF signal energy from the energy access point (EAP) and transmit information to the data access point (DAP) by using harvested energy. WPCN is able to classify to two categories namely Separated Access Points (SAP) and Hybrid Access Point (HAP) as shown in Fig. 1.

A. Separated EAP/DAP

In a typical wireless powered communication system, wireless device (WD) transmits information to DAP by using harvested energy from EAP. More details, downlink (DL) wireless charging and uplink (UL) information reception are conducted separately by an EAP and a DAP as depicted in Fig. 1 (a), respectively. The user is equipped by different physical entities for EAP and DAP, which have different antenna deployment and channel conditions. Separating of EAP and DAP lead to more flexibility in deployment of system and simple hardware implementation [5, 6, 7]. However, additional synchronization and coordination between two APs (EAP and DAP) is critical important.



(a) Separate Access Points (SAP) [7]



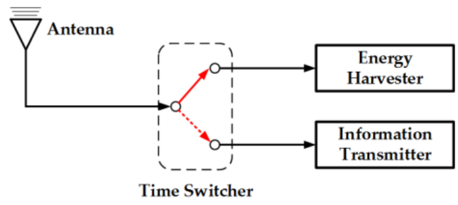
(b) Hybrid Access Point (HAP) [8]

Figure 1. Wireless-Powered Communication Networks Model.

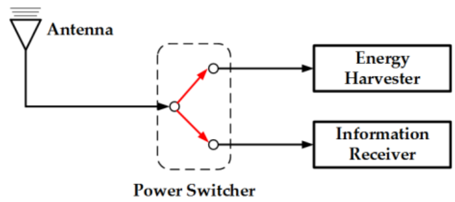
B. Hybrid Access Point (HAP)

In Hybrid Access Point (HAP) architecture [8], AP not only contributes in the data transmission, but also works as an energy resources (See Fig. 1 (b)). H-AP takes advantageous in information sharing and hardware reuse. The new receiver architecture is necessary for mobile devices able to harvest and gather energy from signals with a wide range of frequencies. Most of the recent designs based on switching methods such as time switching (TS), power splitting (PS), antenna switching (AS) and integrated receiver (IntRx) [9] as shown in Fig. 2.

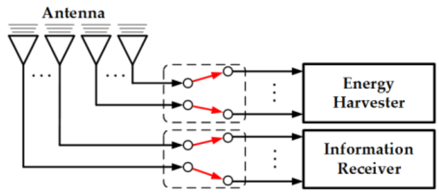
In Comparison of Rate-energy Trade-offs by using different methods, PS mode achieves higher information rate and harvested energy level as presented in Fig. 3. PS mode requires a power splitter, whereas TS mode requires a simple switch. Due to this, PS mode allows only in-band WET whereas TS mode can also support out-of-band WET. TS mode can accommodate both the sensitivity difference of energy, information receiver and channel, interference power dynamics to optimize its switching operation.



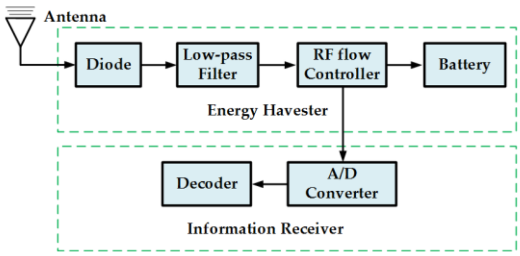
(a) Time Switching (TS) receiver



(b) Power Splitting (PS) receiver



(c) Antenna Switching (AS)



(d) Integrated Receiver (IntRx)

Figure 2. Receiver Operating Strategies.

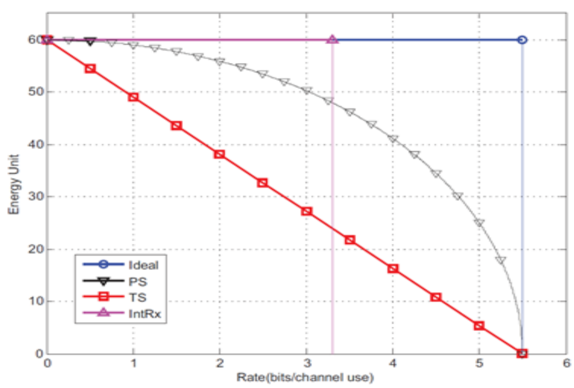


Figure 3. Comparison of Rate Energy Trade-offs of different methods.

Recently, the research efforts for WPCN, there are two major directions including exclusive wireless charging and simultaneous wireless information and power transfer.

III. Wireless-Powered Backscatter Communication Network

A. *Principles of Wireless-Powered Backscattering Communication*

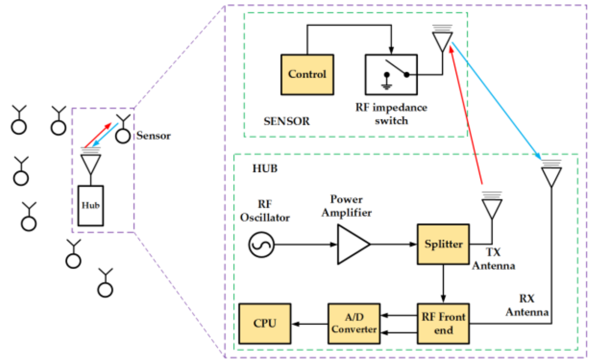
A network architecture that enable device-to-device (D2D) communication between passive nodes by combining backscatter communication and wireless power transfer is called wireless powered backscatter communication (WP-BackCom) network [10]. Basically, WP-BackCom is divided to three categories: monostatic backscatter (e.g. RFID tag), bistatic scatter (BS), and ambient backscatter (AB) [11]. In [12], bistatic scatter (BS) radio was proposed to maximize the range through non-classic bistatic architecture: the carrier emitter was detached from the reader. The range up to 130 meters with 20 milliwatts of carrier power were experimentally estimated. In additional, authors in [13] studied RF-powered bistatic scatter radio communication confirmed an increased long-range coverage and diminished SNR outage zone. In short distance, Ensworth et al [14] introduced Bluetooth 4.0 low energy (BLE) for smartphones and tablets.

Ambient backscatters used existing ambient RF such as TV base station, or Wi-fi router as only source of power and data transmission in near distance. In [15], the theoretical operation principle and hardware prototype was presented. However, the transmission distance is limited. Therefore, in [16, 17], the author proposed a hybrid backscatter communication for WPCN to enhance the transmission range.

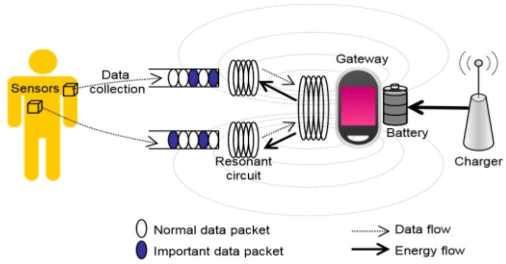
B. *Applications of Wireless-Power Backscatter Communication Network*

Several applications of WP-BackCom network are apparent and obvious. Firstly, WP-BackCom is an attractive technology for next generation of low-power sensor networks [18] especially in wireless backscatter sensor network (WBSN) such as Internet of Things (IoT) as shown in Fig. 4 (a). Secondly, making backscatter practical for ultra-low power on-body sensors by leveraging ration on existing wearable devices such as smart phones, tablets are new promising applications in health monitoring based on Wireless body area networks (WBANs) [19] (See Fig. 4 (b)).

In additional, Integrating WP-BackCome into RF-Powered Backscatter Cognitive Radio Networks (CRN) (Fig. 5) has been show promising approach for gathering energy and spectrum efficient communication [20]. The method is critical attractive for low-power to no power communication. Moreover, WP-BackCom is applied in self-sustainable Device-to-Device (D2D) communications [21, 22] for short range communication, with near-zero energy and renewable energy radios for IoT. In this case, human factors such as mobility and user patterns affect ambient energy sources.



(a) Wireless Backscatter Sensor Networks (WBSN)



(b) Backscatter-based Wireless Body Area Networks (WBAN)

Figure 4. Dedicated Backscatter Applications.

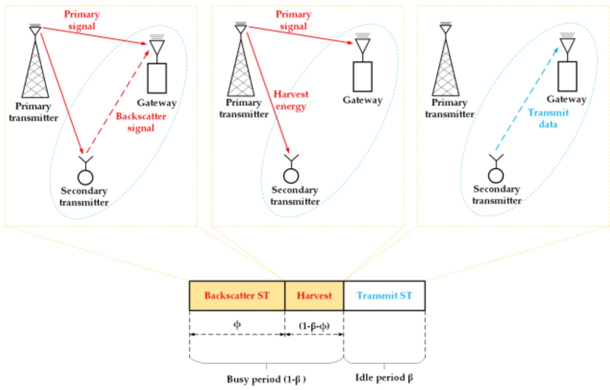
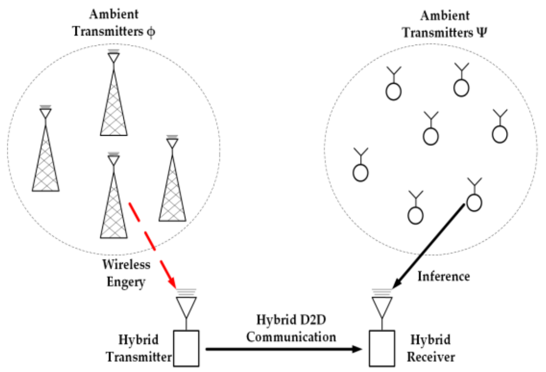
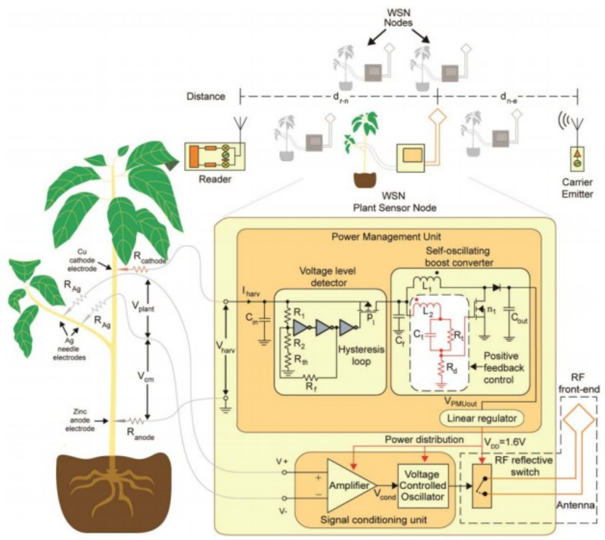


Figure 5. RF-Powered Backscatter Cognitive Radio Networks (CRN)

A hybrid D2D communication is depicted in Fig. 6 (a). A self-powered battery less electric potential (EP) wireless sensor was presented in [22]. This device harvests near-maximum energy from the plant itself and transmits the EP signal tens of meters away with a single switch, based on inherently low-cost and low-power bistatic scatter radio principles as in Fig. 6 (b).



(a) Illustration of hybrid D2D communications [17]



(b) Self-Powered & Backscattering Wireless Plant Sensor [22]

Figure 6. Wireless-Powered Backscattering Communication Applications.

IV. Conclusions and Future Work

Wireless Power Transfer (WPT) is a promising technology for today's applications especially in communication networks. In this paper, we have presented a comprehensive survey of wireless power transfer for communication networks. We first introduced the fundamental of Wireless-Powered Communication Networks (WPCN) with two basic models. Then, we have provided literature review of Wireless-Powered Backscatter Communication Networks regarding to state-of-the art achievements. Furthermore, various applications in many areas of WP-BackCome have been discussed which opens different research directions in the future.

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