Report

"Backscatter Communications"

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❖ Introduction

the IoT has seen technological innovations in a wide range of applications such as smart city, smart home, autonomous robots, vehicles, and unmanned aerial vehicles. The IoT is expected to comprise tens of billions of sensors in the near future. Keeping the massive number of energy-constrained IoT sensors alive poses a key design challenge for IoT. This is especially challenging given a large number of the sensors may be hidden (e.g., in the walls or appliances) or deployed in remote or hazardous environments (e.g., in radioactive areas or pressurized pipes), making battery recharging or replacement difficult if not impossible. Thus, it is highly desirable to power IoT nodes by ambient energy harvesting or wireless power transfer. One particular promising solution in this regard is backscatter communications which allows an IoT node to transmit data by reflecting and modulating an incident RF wave.

In the past two decades, point-to-point BackCom has been widely deployed in the application of radio-frequency identification (RFID) for a passive RFID tag to report an ID to an enquiring Reader over the near field (typically several centimeters). In its early stage, IoT comprised of primarily RFID devices for logistics and inventory management. However, IoT is expected to connect tens of billions of devices and accomplish much more sophisticated and versatile tasks with city-wide or even global-scale influences. This demands the communication capabilities and ranges (tens of meters) between IoT nodes to be way beyond the primitive RFID operations supporting bursty and low-rate (several-bytes pre-written ID sequence) uni-directional transmission over several meters. This can be achieved via a full-fledged BackCom theory leveraging the advanced communication technologies such as small-cell networks, full-duplexingFootnote1, multi-antenna communications, massive access, and wireless PT, as well as advancements in electronics such as miniature radios and low-power electronics. Therefore, the developing IoT applications present many promising research opportunities, resulting in a recent surge in research interests in BackCom.

❖ Towards Battery-Less Communications

What if wireless communications can work without any battery? We would not need any active power source. This proposal will allow us to avoid the trouble of charging, replacement, and recycling. Small devices in cellular communications will have everlasting energy. Battery-less communications also enable devices to be connected round the clock without any battery failure problems. The positive traits of battery-less communications include the following:

Communication between devices can have a longer life.

Useful protocols of wireless communications could be long-lasting.

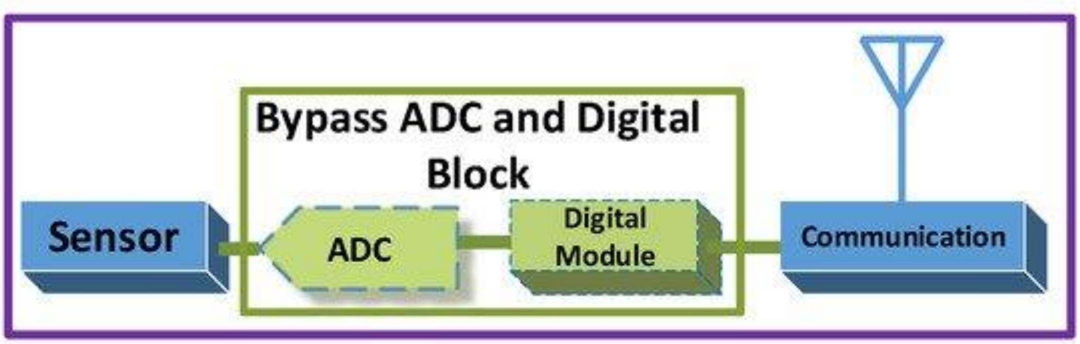
Devices will operate without power interruption.

These traits would revolutionize the current concept of wireless communications. Moreover, these characteristics would enable battery-less D2D communications in disaster scenarios. Furthermore, we would achieve the goal of IoT to connect everything with emerging wireless networks more practically and without power interruption. Mobile phones would neither require a battery nor long-duration power charging for their operation.

Previously it seemed unrealistic, but a recent research from the University of Washington introduced a prototype of a battery-free cellphone that made battery-free communication more practicable. Figure shows the block diagram of battery-free cellphone, which bypasses the power-thirsty components in battery-free cellphone design. The working principle of this phone depends on the reflection of radio waves, similar to methods used in radio frequency identification (RFID) systems. Usually, RFID is made up of two parts:

(i) transponder.

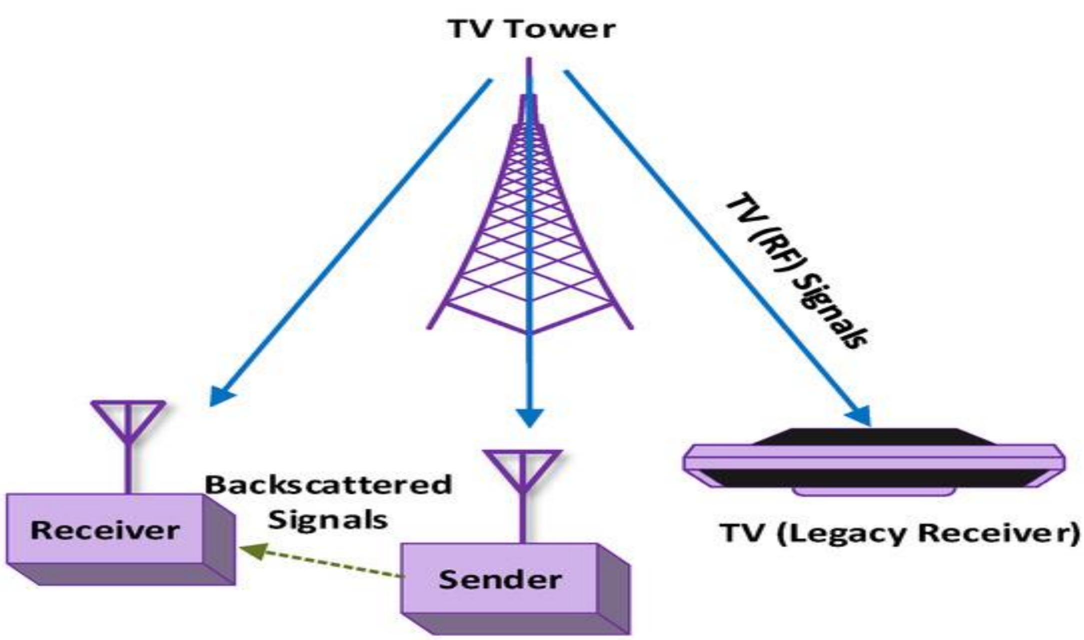
(ii) reader.



The transponder is placed in the product to be scanned, also known as a “tag”. The reader is used for sending the RF signals and then extracting the data from reflected waves. Traditional RFID readers can work on either active tags, those having their power source, or on passive tags, which do not possess their energy supply. In passive tag communications, neither any oscillator nor any active component is needed to generate the carrier waves for the transmission of data. However, the tag only reflects incident carrier signals by varying the antenna impedance, after modulating its information to those incident signals. This type of communication is referred to as backscatter communications (BackCom), which heralds battery-free communications. Recently, a multi-band development board is designed to support the battery-less autonomous semi-passive RFID transponder. This design allows the devices to harvest energy from various electromagnetic fields (UMTS, LTE, and WIFI). The harvested energy can further be utilized by using an ultra-efficient power conditioner and storage block in a number of battery-free applications.

❖ Ambient BackCom: A Solution to Limited Battery-Life

Conventional RFID systems utilize a dedicated radio source and reader. Unlike the traditional RFID system, ambient BackCom (Amb-BackCom) does not need a dedicated RF signal source, such as an oscillator or signal generator with the reader. However, Amb-BackCom explores the advantage of RF signals available in the vicinity (e.g., TV, Wi-Fi, cellular signals, etc.), thus revolutionizing wireless communications. Figure delineates the communication between passive tags by using backscattered TV signals. Currently, researchers are showing great interest in making future communications based on the reflection of ambient RF signals to combat the limited battery life problem in wireless communications.



❖ BackCom Architecture

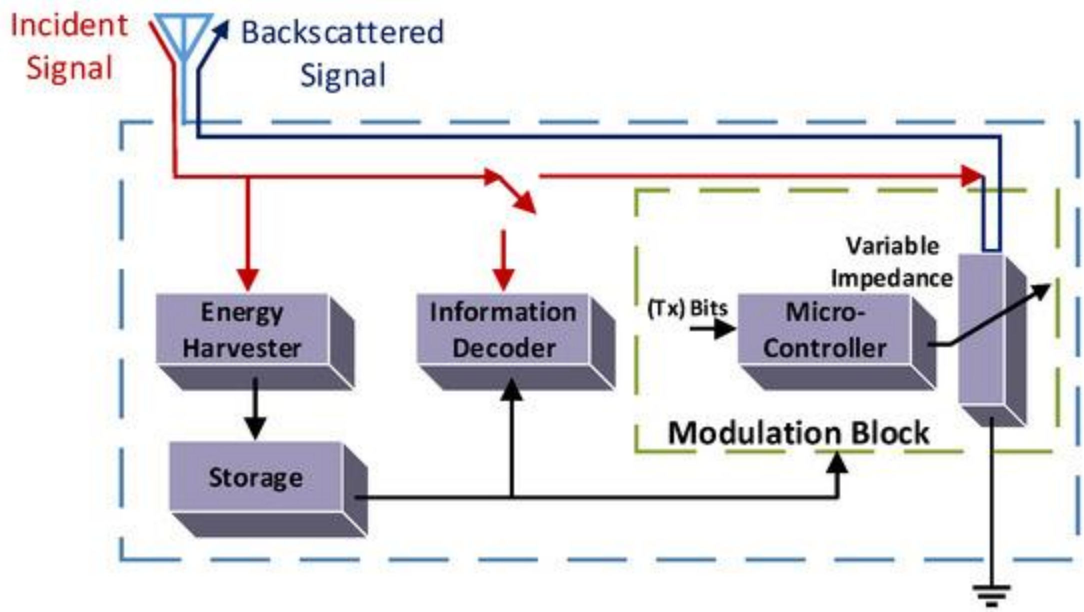


Figure
delineates the architecture of the BackCom tag and shows a passive tag receiving carrier signals, transmitted by the RF source. The energy harvester block of the tag can harvest energy from carrier signals. The accumulated energy can be collected in the capacitors or energy storing components in the storage block. The stored energy can supply consistent power to send information to the decoder unit and the modulation box. Subsequently, the micro-controller in the modulation box can modulate the unique information of the tag on the carrier signals via the backscattering operation. The signal backscattering is caused by changing the impedance intentionally, as shown by the variable impedance block in Figure. Similarly, an architecture of the 802.15.4 receiver is presented in. It consumes 361 μW and is compatible with battery-free applications.

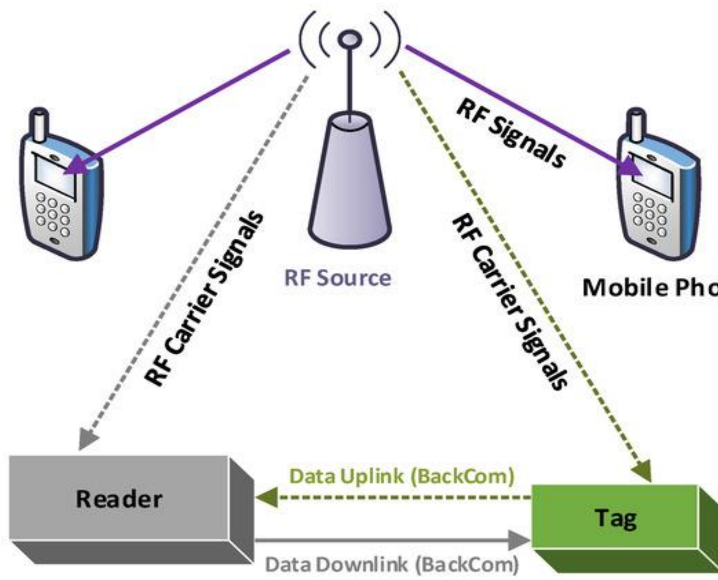
❖ Different Types of BackCom

- Ambient BackCom

This type of BackCom uses ambient (surrounding) RF signals, such as television (TV), cell phone, and WIFI signals as the carrier, to power up the passive tags, respectively.

A passive tag can communicate with another passive tag by reflecting incident ambient signals after modulating its information. Figure depicts ambient configurations.

- Passive tags receive RF signals from the surrounding RF sources.
- Tags harvest power from ambient signals to modulate their information, using the OOK scheme.
- Tags transmit binary bits due to change in the impedance. The “0” bit is transmitted when the antenna has high impedance and when major parts of the signals are reflected. On the other hand, for binary “1” the antenna impedance would be low, and the signals are considered least reflected.

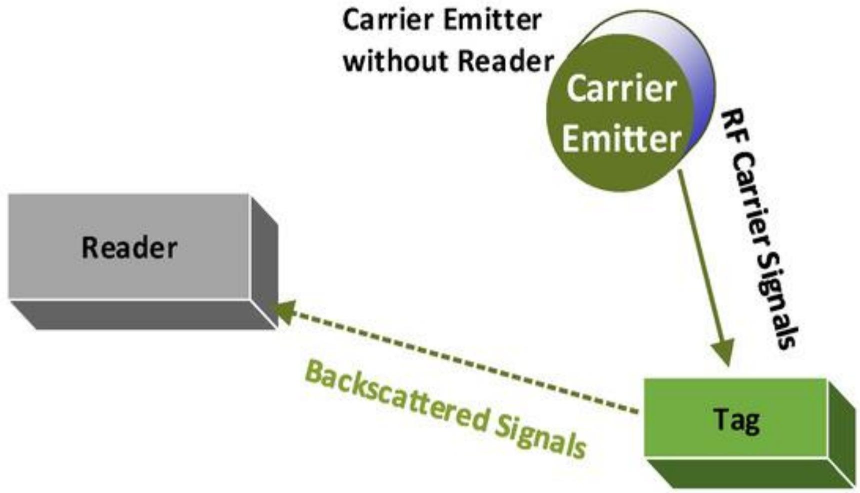


- Since the TV or other nearby signals already have information on them, to avoid data overlapping between original and modulated signals, the passive tags transmit their data by reflecting the signals at a smaller bit rate than the surrounding radio waves rate. Afterwards, the receiver can differentiate among both signals by taking their mean value.

This type of BackCom revived the use of RFID technology by utilizing nearby signals of different technologies. Different types of communication channels such as the basic backscatter channel and the dyadic backscatter channel for Amb-BackCom have been explored with multiple antenna designs. Furthermore, the idea of Amb-BackCom was utilized for the communication between two passive tags to calculate the associated bit error rate (BER). Unfortunately, the ambient signals have low signal power compared to dedicated source, and backscattering operation weakens these signals even more. In order to provide sufficient power to tags.

- Bistatic Scatter

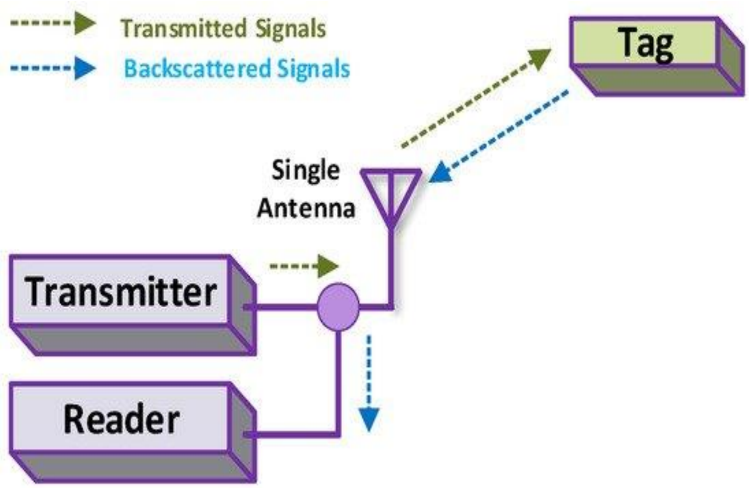
The bistatic scatter (BiS) configuration for BackCom. Figure illustrates BiS BackCom, showing an RF receiver that is separated from the carrier emitter. BiS configuration increases the communication range by bringing the carrier emitter closer to the tag. The carrier emitter has an oscillator and power amplifier to generate and transmit the carrier signals. It is different from the traditional reader, such that it does not possess its own receiver. The signals



generated from the adjacent carrier emitter in the BiS scenario reduce the round trip path loss by decreasing the distance between the tag and the power source (carrier emitter). In this way, the reflected signals have a higher signal-to-noise ratio (SNR) at the receiver end when compared to Amb-BackCom. Furthermore, this type of bistatic setup for communications shows better BER performance in the receiver than its counterpart. Similarly, for an extended range, a full signal model for BiS radio is derived to demonstrate the experimental ranges of order 100 m. However, it is not possible to consider a nearby signal generator in every scenario. Considering the size limitations of passive devices.

- Monostatic BackCom

The configuration of BackCom needs two separate antennas, one each for transmitter and receiver. On the other hand, some applications such as hand-held readers cannot afford two antennas, due to the additional size, complexity, and expense. Alternatively, a single antenna can be used for both transmission and reception. Such configuration is referred to as Monostatic BackCom (Mon-BackCom). Figure shows the transmission and reception process using the single common antenna in the reader. However, the data rate of this type of BackCom is low due to the one-way information transfer.



Exploiting two different types of BackCom.

❖ BackCom Applications

- Smart Homes/Cities using BackCom

the concept of smart home that enables each object in the smart home having a backscatter tag to communicate through Wi-Fi signals. Smart home consists of a considerable number of BackCom passive tags deployed at multiple locations. These tags can seek power from ambient sources such as Wi-Fi access points, TV towers. The applications of passive tags are smoke detection, gas leakage check, movement monitoring, surveillance, and indoor positioning. Smart cities utilize ubiquitous BackCom passive tags in buildings, streets, bridges, and parking spaces. The tags could help to improve the quality of life by monitoring air pollution, traffic monitoring, and parking availability. Furthermore, due to the availability of ambient signals in each home, it is now possible to remotely access household items utilizing BackCom. It is expected that BackCom enable smart cities and homes, making life easier and more comfortable.

- BackCom for Bio-Medical Applications

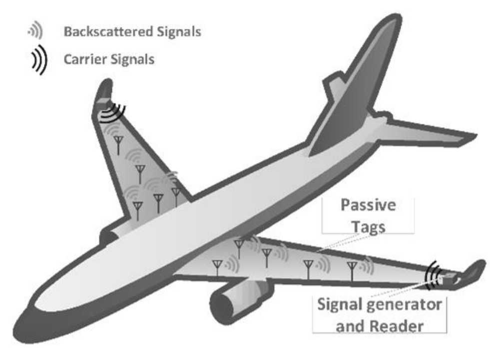
Tiny passive BackCom tags, with ultra-low power consumption, are widely used in the field of medical science. BackCom tags enable medical devices to communicate without power constraint, with the help of available ambient

WIFI signals. Moreover, Amb-BackCom tags allow medical practitioners to diagnose patients remotely. which can sense a patient's conditions remotely and transmit data using Wi-Fi signals using BackCom. A Wi-Fi-based gesture recognition for humans uses BackCom to recognize emotions with the reflected Wi-Fi signals.

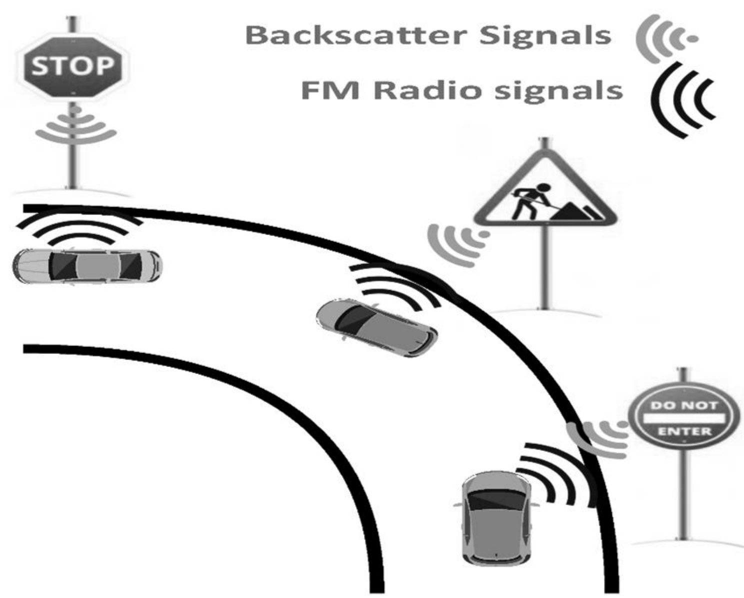
- BackCom in Textile/Clothes

Made the connectivity of regular clothes by transforming them into frequency modulation radio wave stations. This prototype is fabricated on the chest of the cotton T-shirt by making an antenna of a conductive thread. This T-shirt can transmit information to nearby smart devices using BackCom. Project Jacquard proposes BackCom for interactive digital textiles. Project Jacquard suggests that interactive clothing materials be made more economical, while utilizing existing textile weaving equipment and technology. Similarly, a battery-free platform is suggested for wearable devices. This platform works on harvested energy generated from feet movement, in addition to Amb-BackCom.

- Vehicle Monitoring by BackCom



National Aeronautics and Space Administration (NASA) aims to use passive WSN for a vehicle health monitoring system (VHMS) that can ensure the safety of crew and vehicles. Figure illustrates the concept of the VHMS. BackCom has many applications in aerospace vehicles to obtain benefits from ubiquitous passive sensor nodes. highlighted the need for a passive sensor node communication network in aerospace vehicles. In local traffic management, smart signboards use backscatter tags to communicate with FM radio receivers in cars. Figure shows the concept of vehicle safety using BackCom. This type of communication can be used to reduce the number of accidents.



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