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Zero Energy IoT Devices for RF Energy Harvesting in 6G (Terahertz) Communication

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Abstract

In harvesting RF energy from the ambient source, Radio Frequency (RF) plays an important role for zero energy IoT devices. Current research focused on 4G/5G technologies, however, after the concept of Artificial Intelligence (AI), Virtual and Augmented Reality (VAR), Three-Dimensional (3D) media, Internet of Everything (IoE), multi-way virtual meeting with holographic projection, brain communication interface, remote surgery and digitalize the whole word, 6G has got a great attention of the researchers because of latency, reliability and data rate requirements of 4G/5G systems. Several technologies companies such as Ericson and MIT started to work on 6G zero energy devices. Energy harvesting is an open research challenge in 6G technology due to latency, reliability and data rate requirements in 4G/5G technology. In this paper, we have conducted a real-world experiment on Power cast energy harvesting zero energy devices and examined the behaviour of sensed data in different scenarios, such as indoor/outdoor, distance (feet/ meters), and directions. In addition, an overview of different electricity generated methods is presented to better understand the energy and energy harvesting techniques. Furthermore, we have obtained results for these scenarios and show that this technology has a promising future in 6G.

Keywords: Artificial Intelligence (AI) • Virtual and Augmented Reality (VAR) • Internet of Everything (IoE) • Power cast energy • Nippon Telegraph and Telephone (NTT)

Introduction

After the concept of Artificial Intelligence (AI), Virtual and Augmented Reality (VAR), Three-dimensional (3D) media, Internet of Everything (IoE), multi-way virtual meeting with holographic projection, brain communication interface, remote surgery and digitalize the whole word, 6G has got a great attention of the researchers because of latency, reliability and data rate requirements of 5G systems. Now the 4G/5G technologies importance is so much more than traditional cellular networks but 6G will continues benefits from it [1]. The tremendous growth of IoT based devices in the world, the demand of 6G zero energy IoT devices has reach to its peak to digitalize the world. The 6G technology inherits the capabilities of 4G/5G technology to introduce new technology and 4G/5G technology inherited 2G/3G capabilities to introduce the 4G/5G era's technologies. In simple words, every generation of wireless technology used previous technology benefits to enhance the new technology capabilities. For example, 1G technology (Nippon Telegraph and Telephone (NTT) in Tokyo in 1979) used large-sized portable phones and analog voices for communication with 2.4 Kbps speed. 2G technologies used a digital voice and messaging system with a speed of 1 Mbps. 3G technology has changed the game and enhanced the mobile network and data use to a new level. Also in the 3G technology era, video conferencing (skype) and social media platforms start their activities due to the high capability of data transfer rate up to 2 Mbps. In 4G technologies the data rate has raised to 1 GB speed and increased video to HD quality with mobile broadband, Long Term Evolution (LTE), and LTE advanced technology that users experience today. This era boosts the profit of the mobile phone industry and reached trillion-dollar companies [2]. But the technology companies started a race and introduce several cell phones in the market which cause a burden on 4G and degrades the performance of the network. To tackle this problem, the researchers and technology companies move to 5G and this is the starting point for Industry 4.0, the Internet of Things (IoT) [3]. The foundation for 5G is five brand-new technologies, including millimeter wave (mmWave), Massive Multiple-Input Multiple-Output (MIMO), small cell, beam forming, and full-duplex [4]. IoT is based on hundreds to thousands of tiny smart devices and research says that there are more than 30 billion IoT devices (sensors, actuators, wireless devices, smart meters, lighting systems, etc.) all over the world 2020 used in different domains [5]. The 6G technology can

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increase the capabilities of 5G in terms of low latency and high data rate in these small size devices (Figure 1).

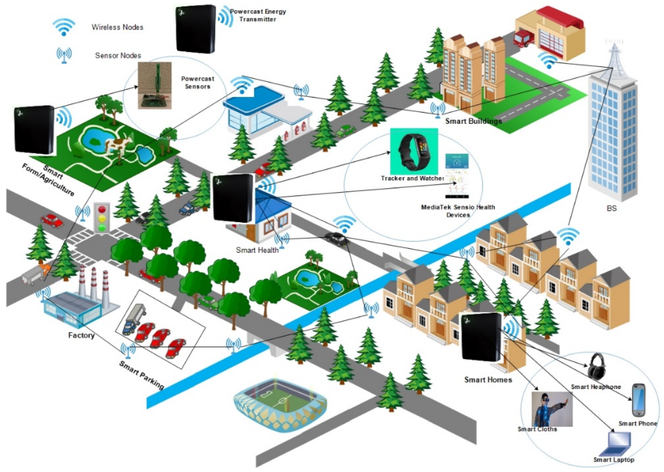


Figure 1. The 6G technology can increase the capabilities of 5G in terms of low latency and high data rate in these small size devices.

One of the main drawbacks of these small devices is the loss of the working environment after the outage of electricity. Everything shuts down after an electricity outage. Scientists solve this problem by introducing energy storage devices. There are two types of energy storage devices, *i.e.,* super capacitors and rechargeable batteries [6]. Super capacitors are environment friendly and have a longer lifetime, higher recharge cycle, broader range of voltage and current and higher performance in low temperatures over batteries. However, the performance of super capacitors can degrade by energy leakage. The leakage problem occurs due to weather, charge duration, and energy storage [7]. Rechargeable batteries are inexpensive and have a low self-discharge rate and high energy per unit weight. Batteries can suffer from internal chemical activities [8]. The author of presents a comparison of some types of batteries such as alkaline, Nickel-Metal Hydride (NiMH), Lithium-Ion (Li-Ion), and Lithium Iron Disulfide ($LiFeS_2$) batteries. The authors also compare super capacitors and rechargeable batteries. Batteries have several problems in common such as current leakage, breakdown due to weather conditions, and battery timing, which may hinder the sensor network operation. One effective way to solve these problems is the energy neutral system, which adopts Energy Harvesting (EH) technologies from the environment such as solar, Radio Frequency (RF), vibration, vehicles, and life things (human beings, plants, animal's etc). We categorize various EH techniques. Sensor nodes are using batteries for living. When the battery becomes dead, the operation of the sensor node halts. Then we should replace the battery with a new one or charge the battery. However, both are not easy if the sensor nodes are located in inaccessible places. RF technique is a reasonable candidate for charging the existing battery. We can convert RF energy to DC power through a special antenna, called a rectenna [9]. The rectenna consists of an antenna capturing the electromagnetic waves as AC and a rectifying circuit performing the AC to DC conversion. A lot of research has been conducted to use the RF for energy harvesting in 4G/5G, however, energy harvesting is an open research challenge in 6G technology [10].

Literature Review

IoT based WSN is a collection of sensor nodes and other devices to monitor a given area for some specific purpose. Each sensor node has the capability of sensing the environment and sending the data to the BS or sink. Each sensor node has a power source (battery), wireless transceiver, processing unit, and memory. Battery time is one of the main research topics for researchers because battery replacement is a challenging task. To cope with the challenges, researchers have introduced energy harvesting from different sources such as RF, solar, sound, etc to recharge the battery of a sensor node. Following the line, the researchers have proposed energy harvesting aware protocols. According to Siddharth S, the main goal of IoT based EH-WSN protocols is not to focus on energy but use the variable energy to support QoS requirements. In this paper, we present some EH-WSN protocols that use RF-EH for IoT based WSNs. EH-WSN is not a limited area for research. From the extensive literature review, we divide the RF-EH for WSNs into the following categories:

- Wireless Power Communication Networking (WPCN).
- Simultaneous Wireless Information and Power Transfer (SWIPT).
- Polling based.
- Wireless Power Communication Networking (WPCN).

WPCN is an RF-EH based communication networking that the uplink and downlink concept for Wireless Energy Transmission (WET) and Wireless Information Transmission (WIT). The basic idea of WPCN is as follows: Each node harvests the energy from RF and transmits this energy wirelessly to other nodes by using the downlink. Other nodes use this harvested energy to transmit the data to the destination over the uplink. Presented an efficient data collection algorithm for WPCN based WSNs. In the algorithm, WPCN nodes harvest their energy from RF and store it in capacitors or rechargeable batteries. The downlink is used for WET and the uplink is used for WIT at the same time. The authors assume a one-hop star topology, in which the sink node is surrounded by sensor nodes and the sensor nodes harvest their energy from the sink node. The sink node collects the sensed data from the nodes by using the uplink and sends wireless energy to one hope node by using the downlink. The authors investigate the throughput of the node during collecting the sense data to the sink per unit time. MAC is a layer 2 protocol for communication between nodes to access a transmission line. A lot of research has been made to develop MAC protocols for EH-WSNs presented the Slotted ALOHA (SALOHA) based protocol and claim that this is the first work to apply the SALOHA in EH-WSNs for WPCN. SALOHA has time slots; each node waits for a time slot and sends the data during the time slot. Otherwise, it waits for the beginning of the next time slot. We can describe EH-SALOHA as follows: Eeach node harvests the energy from the RF energy harvester, and when a slot is accessed then it transmits the data [11]. The authors proposed the harvest until access technique, where nodes harvest energy continuously until a slot is accessed and then send the packet. The same authors proposed another scheme of the harvest or access technique.

Simultaneous Wireless Information and Power Transfer (SWIPT)

The first paper in this area was as claimed. SWIPT uses a single transmission line for information as well as for energy harvesting. In SWIPT, Information Decoding (ID) and EH are performed on each node. We review and discuss some papers related to SWIPT. Presented an energy aware routing algorithm for RF based EH-WSN, which is based on the SWIPT technique. SWIPT uses a relay node to transmit data and power to nodes at the same time. The relay node decodes and forwards the data between nodes. Some researchers adopt the amplify and forward technique instead of the decode and forward [12]. The authors introduced the energy and information allocation problem, and then they presented an energy aware SWIPT routing algorithm called ESWIPTR. The protocol is improved to a distributed synchronous proactive version and an asynchronous proactive table-driven version, respectively. The basic routing algorithm is based on an energy equation called Ecost. ESWIPTR finds the minimum energy cost path for routing through a routing function (Figure 2). The author also presents a distributed version of ESWIPTR by using distributed Bellman-Ford protocol.

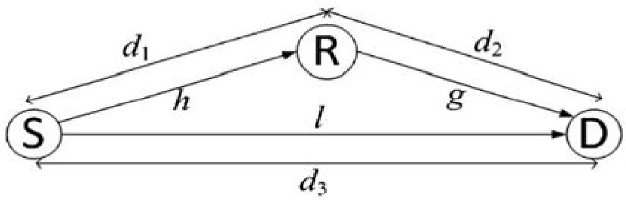


Figure 2. SWIPT based relay architecture.

The author considered a WSN with sensor nodes and each sensor equipped with a single antenna. The data flow between the source and destination nodes. Two transmission modes are used between any two (i,j) nodes, Information Transmission (IT) and Simultaneous Wireless Information and Power Transfer (SWIPT). The IT is used when the battery of the sensor is full and SWIPT is used when the battery energy is less than the minimum energy requirements. The author addressed three problems in this work, routing, information, and energy allocation. In Decode and Forward (DF) protocols, the receiver node first decodes the information and forwards it to the next node. Therefore successful decoding is essential for DF protocols. The author presented a decode as follows:

$$\Upsilon_{ij}^{SWIPT}=p_{ij}|h_{ij}|^2 P_{ij} /\sigma_{ij}^2-n_{ij}^2 \geq R_{min} \quad (1)$$

Where, P_{ij} is the sender node sending power, p_{ij} is the power splitting value, h_{ij} is the channel gain, σ_{ij} is power of signal, R_{min} is the required SNR requirement, and n_{ij} is the antenna noise.

The forward equation is as follow:

$$E_{ij}^{eh}= \epsilon (1-p_{ij}) (|h_{ij}|^2p_{ij}+\sigma_{ij}^2) \geq P_{cj} \quad (2)$$

Were, Pcj is the energy harvesting power requirement for forwarding the information to the next hop node.

$$P_{cj}=P_{ji}, \text{ if } r_{ji}=1 \quad (3)$$

P_{ji} is the powercast for forwarding to neighbor/next node and r_{ji} is the link state (active=1, not active=0). In routing, the main objective of the author was to find the minimum cost link.

The author presented two types of routing algorithms, *i.e.,* centralize and distributed. The routing algorithm is based on the concept that when a node has low energy, it selects the next node for routing. The presented routing algorithms, ESWIPTR, are based on equation [13]. Dijkstra based centralized routing algorithm was used in this work. The Dijkstra algorithm first checks the shortest path between the neighbor nodes and selects the node with the shortest or closest path to the destination. Just like the Dijkstra algorithm, the authors first examine the path with the minimum energy from the source to the destination node and allocate resources. The minimum energy can be calculated through the Ecost equation. The authors also presented the distributed version of the ESWIPTR algorithm by using distributed Bellman-Ford protocol. The algorithms are evaluated by convergence rate, the impact of the node density, minimum energy requirements for packet forwarding, and the impact of the barrier. The authors presented another paper for interference-aware routing. Interference occurs when one-directional link affects other directional links or uplink affects downlink in cellular networks [14]. Presented another SWIPT based RF-EH WSNs with amplify-and-forward relay nodes. Presented a selection cooperation protocol with feedback from destination to source node. Presented a cluster based SWIPT protocol.

Polling based: Presents a polling based MAC protocol for energy harvesting. The sink fires a packet to other nodes that contain a contention probability instead of ID. Nodes in the network decide through this packet whether to transmit their packet or not. The contention probability is based on the number of nodes, current energy harvesting rat, and packet collision. The contention probability is increase when other sensor nodes respond and decrease when a collision occurs. Polling-based MAC protocol for energy harvesting uses the charge and spends harvesting strategy in which it first accumulates enough energy and then goes into the receiving state to listen and receive the polling packet. The author used three parameters for the performance of the given protocol, throughput, fairness, and interarrival time [15]. Throughput was used to successfully receive the packet at the sink node. Fairness is used for a balanced degree of the network. Fairness and inter-arrival time equations are as follows:

$$F=(\sum^n_{i=1}R_i)^2/n\ (\sum^n_{i=1}Ri^2) \quad (4)$$

$$\Gamma=(\sum^n_{i=1} 1/R_i)/n \quad (5)$$

Both SWIPT and WPCN techniques use the RF-EH technique but the questions are which one is good?

Other RF based EH-WSN protocols: Presented a routing protocol for EH-WSN. In this work, he used Improved Energy Efficient Ant Based Routing Algorithm (IEEABR) for RF Energy harvesting and management of the harvested and available energy for wireless sensor networks. He first discusses the RF power density, storage of the harvested power, calculation of the received power, and management of the power in the EH-WSN protocol. IEEABR technique used for routing. The author of this paper used the Friis equation which is used for a situation where the distance between two nodes or antennas is known and this equation is discussed in detail. Presented an energy harvesting-aware routing protocol.

$$P_t/G_t=G_tG_r\lambda^2/(4\pi)^2d^2 \quad (6)$$

Where, P_t is the transmitted power, P_r is the received power, G_t is the transmitter gain power, Gr is the receiver antenna received power, d is the T-R-Separation distance in meters, and λ is the wavelength in meters. Gain power is based on the aperture of the antenna.

Power density equation is as follow:

$$P_D=P_t/(4\pi)R^2 \quad (7)$$

Where, P_D the power density and R the distance between the transmitter and the receiving antenna, P_t is the peak or average power. Energy storage equation is as follow:

$$T=C/I_N \quad (8)$$

Where, C is the theoretical capacity of the battery expressed in ampere-hours; I is the current drawn in Ampere (A); T is the time of discharge in seconds, and n is the Peukert number (Figure 3).

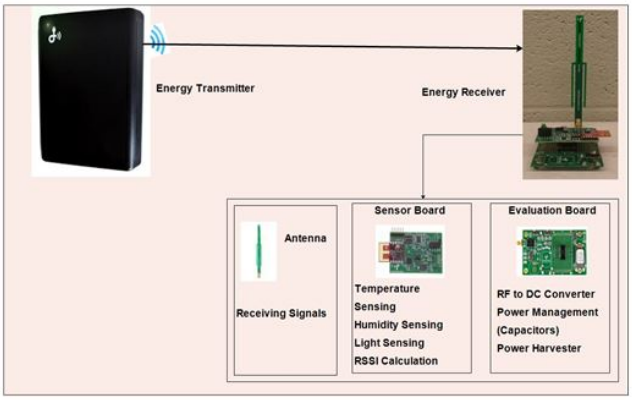


Figure 3. Didicate EH model.

The power management Algorithm's main idea is as follows: First of all, initialize the routing table and find the neighbor nodes, if a node is visited two times then halt otherwise select the next node according to the probabilistic equation. This process will continue until the destination node is reached. The author used NS-2 for simulation result [16]. Used AODV traditional routing algorithm for presenting EH based routing protocol EH-AODV. EHAODV uses the advantages of AODV with only changes in packet header by replacing hop count with Transmission Cost (TC). TC is used in route request (RREQ) and route replies (RREP) operations. TC is a predictable technique that can be predicted through the below equations [17]. Presented a MAC protocol. The basic idea is, first of all, a sensor node will harvest the energy through RF and then the sensor node will charge its battery. After charging the node will sense and gather the respected information. A backup time concept is used for packet collision avoidance and the sensor waits for a time. At last, the packet can be transmitted when there is no collision. Presented an RF-EH battery-free energy cooperation wireless network for reducing communication latency to improve network performance [18]. Presented a cluster-based protocol that harvests the energy from solar (Figure 4).

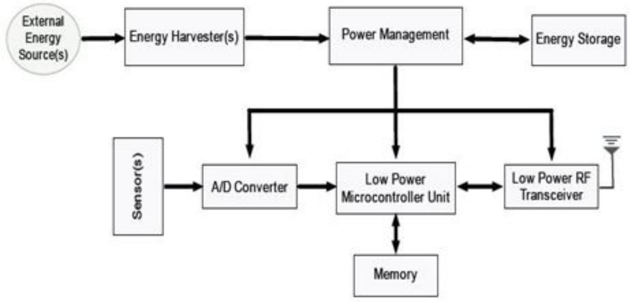


Figure 4. Ambient EH model.

Results and Discussion

4G/5G technologies face low latency problems due to the high volume of data, computation of this data, and network load. Thus 6G technology can overcome this problem because it supports Ultra-Reliable Low Latency Communication (URLLC). Several applications such as smart city, smart transportation, smart health, and smart railways can take benefits from 6G technology; however, 6G technology can boost smart agriculture all over the world. The author of presented good research on these applications except for smart agriculture. Here we are going to discuss only smart agriculture [19].

Smart agriculture

Research says that there will be more than two billion people expected to add to the population of the world so the food production should be increased up to 60 to 70 percent [20]. This product can only be achieved by applying advanced technology to the agriculture sector such as 6G. there is much research which abating the production of agriculture sectors such as diseases, plant health, needs (water, humidity, light, temperature, etc.), information, and smart agriculture management system. The 6G enabled sensors can play a vital role in this regard. Powercast technology company provides state of the art equipment and development kits which include sensors, antennas, evaluation boards, etc to cover a small area for humidity, temperature, and light sensing. We can use this kit for a small greenhouse area. Here we are going to conduct a real test bed experience with these devices. The details are described in section IV (Figure 5).

Figure 5. Use case scenario for smart green house.

RF powered energy harvesting in 6G

5G enabled technologies can degrade their performance when a lot of small tinny devices perform their activities in a smart environment with massive data. According to the volume of data traffic c will reach up to 4394 EB by 2030, and 5G technology will become failed to provide the network services to these thousand devices. 6G technologies can solve the problems raised in 5G technology such as data transmission and higher throughput. So, 6G is a promising technology for small edge networking and can provide power to zero energy devices by harvesting the energy from Radio Frequency (RF). Energy harvesting is the front runner for smooth and ineffective communication in IoT based networks. There are two types of energy harvesting technologies, dedicated EH and ambient EH. In ambient EH, the energy sources are available in the environment and the receiver of EH-enabled nodes can sense such sources. In dedicated EH, the energy is available from specific devices such as Powercast technology company devices. In this work, our focus will be on dedicated EH for which stat of the art technology is available such as Powercast, Apple, etc.

Energy harvesting in 6G technology is an open research problem because it has several challenges, such as advanced computation technologies, standard computing architecture such as cloud, interoperable communication protocols, advanced hardware support, high level antenna technology, smart base stations, and AI-enabled intelligent computation and communication for its full deployment. EH model and technical background.

There are three components of the energy harvesting model, energy source (RF, solar, thermal. etc), energy harvesting hardware (Powercast TX91501 Powercaster transmitter, P2110 receiver), and energy storage devices. Shows the dedicated energy harvesting model.

RF transmitter: RF Powercast transmitter omitting both data and power in the form of RF signals with unique ID and 915 MHz frequency. The Powercast company provides the transmitter covered in a black box with fixed output power and settings. The user cannot make changes to the transmitter.

Wireless sensor board: The board can measure and transmit light, temperature, humidity data, and external inputs. The sensor board is connected with the evaluation board through a 10 pin connector to obtain the energy from the evaluation board for the transmission of data. We can set the ID of the sensor nodes from 0 to 7 by using ID select switches. The sensor board has a PICkit connector through which the PICkit programmer can be connected.

P2110 evaluation board: The evaluation board performs the responsibility of energy harvesting. The board contains the functionality of energy storage JP1 (C3, C4, C5 jumpers), a 10 pin connector (J2) for wireless sensor board connection, a rectifier to convert the RF energy into DC, SMA connector for antenna or RF input (J1), and visual LED indicator. The sensor board obtains the harvested energy from the evaluation board.

Powercast antennas: Powercast development kit comes with two types of antennas, dipole and patch. These antennas are connected with the evaluation board through an SMA connector for the antenna (J1). The dipole antenna has the RF connector at the bottom and the patch antenna has the RF connector at the middle. The dipole antenna is flat, omnidirectional, vertically polarized, and gain power is 1.0dBi with beam pattern 360 degree reception. The patch antenna is two layered, directional, vertically polarized, and gain power is 6.1 dBi with beam pattern 120 degree reception.

Information transfer from real testbeds

In our testbed model, we are using the Powercast P2110-EVAL-01 development kit, which is used for energy harvesting. Power Transmitter TX 91501-3W-ID (transmitter) transmits the power, P2110 Evaluation Board P2110-EVB (receiver) received this power, Wireless Sensor Board WSNEVAL-01 plugin with P2110 Evaluation Board P2110-EVB sends the sensed data to access point and hyper terminal is used to show the sensed data on computer/laptop screen. Transmitter TX 91501-3W-ID is responsible to transmit the energy signal to P2110 Evaluation Board P2110-EVB. The evaluation board obtains the energy signal, converts it to DC, and recharges the supercapacitor, and then the harvested energy is used for sending data by the wireless sensor board. In our model, we changed the position of the sensor board according to different distances from the energy transmitter but the position of the energy transmitter remains constant. In our experiment, we have checked the received power and the incoming data time for one to three-meter distances in outdoor as well as the indoor environment. During the indoor experimental setup, we used two types of box, box 1 (of size 5.5 cm), and box 2 (of 1.5 cm) which is kept under the evaluation board and transmitter. During the outdoor experimental setup, we used only box 1. Our experiments are based on two antennas, dipole and patch antenna. We have made some points of meters on the ground and started the experiment by moving the receiver in ascending order to the meters numbers accordingly. In this paper, we aim to study the relationship between distance, RSSI, recharge time of capacitor, angle impact on the packet transmission time and energy harvesting, and the routing of the packet to the access point.

Indoor experimental setup and observations: Before going into details of the description of experimental observations, we want to discuss the experimental setup of the indoor environment. The indoor experiment was conducted in one of the cabins of size made for teachers who are situated underground. The cabin walls are made from plywood and do not touch the ceiling which is made from concrete. The floor is made from mosaic and is smooth. In our experimental setup, we performed the operations on both dipole and patch antennas.

Experimental setup with dipole antenna: In the first experiment, the transmitter and receiver are placed on the mosaic made floor, and nothing is put under the receiver and transmitter. We observed that the sensed data packets take a long time to receive on the terminal. This means that the receiver does not harvest enough energy for a sensor to transmit the sensed data. This is because the dipole antenna does not receive full signals due to Line of Sight (LOS) transmission. So we put the different sizes of boxes under the transmitter and receiver at different times, consequently finding that box 1 (of size 5.5 cm) under the receiver and box 2 (of size 1.5) under the transmitter worked efficiently. So the receiver receives strong signals emitted by the transmitter due to box 1 and box 2 under the receiver and transmitter and can harvest much energy as required by the sensor board for sending the sensed data. We have observed that when the distance is small (1ft), the receiving rate of packets is high but as we go away from the transmitter, the receiving rate decrease.

Experimental setup with patch antenna: As discussed in the previous section, the transmitter and receiver are placed on the mosaic made floor, and nothing is put under the receiver and transmitter. We observed that the sensed data packets take a long time to receive on the terminal. This means that the receiver does not harvest enough energy for a sensor to transmit the sensed data. So we put box 1 (of size 1.5) and box 2 (of size 5.5 cm) under the transmitter and receiver. Data receiving time increase as the receiver goes away from the transmitter. We also have observed that the receiver goes more than 122 degrees from the transmitter (as a central point) does not harvest any energy and so the receiving time of packets goes high.

Outdoor experimental setup and observations

Outdoor experiments are conducted on open ground and devices are put down on a concrete build bench at Bahria university. One side of the bench was closed by a bench wall and the other side was open. There is no obstacle nor source of reflection for the transmitter energy to reach the evaluation board, except the environment negligible parameters, such as wind, ground reflection, etc. So this is an ideal situation for RF energy harvesting.

Experimental setup with dipole antenna: Initially, we set the evaluation board one foot far away from the transmitter on the concrete build bench. We observed that the sensor board transmits the sensed data packets taking a long time for both dipole and patch antennas. This means that the receiver does not harvest enough energy for the sensor to transmit the sensed data. So we put the box (of size 5.5 cm) under the receiver and hence the packet receiving rate increased on the terminal. Data receiving time increases as the receiver goes away from the transmitter.

Experimental setup with patch antenna: The setup and environment for the patch antenna are the same as the dipole antenna. The devices are put on the concrete build bench and we put a box (of size 5.5 cm) under the receiver.

Analysis of RSSI in indoor experiment

We are presenting the average RSSI of indoor experimental setup experiment in Table 1. The RF transmitter transmits the signals and the evaluation board receives the signals to harvest the energy for data transmission as shown. The data can be accessed through the access point and displayed on the laptop.

Distance	Dipole		Patch	
	RSSI (avg)	Tx	RSSI (avg)	Tx
1	8.88	915 MHz	29.95	915 MHz
2	2.46	915 MHz	2.27	915 MHz
3	0.99	915 MHz	1.31	915 MHz
4	0.45	915 MHz	0.75	915 MHz
5	0.24	915 MHz	0.32	915 MHz

Table 1. Analysis of indoor RSSI.

Analysis of RSSI in outdoor experiment

Table 2 shows that the signal power in an outdoor environment is strong as compared with the indoor environment.

Distance	Dipole		Patch	
	RSSI (avg)	Tx	RSSI (avg)	Tx
1	21.87	915 MHz	0	915 MHz
2	4.34	915 MHz	12.77	915 MHz
3	2.04	915 MHz	4.93	915 MHz
4	1.04	915 MHz	2.28	915 MHz
5	0.91	915 MHz	1.1	915 MHz

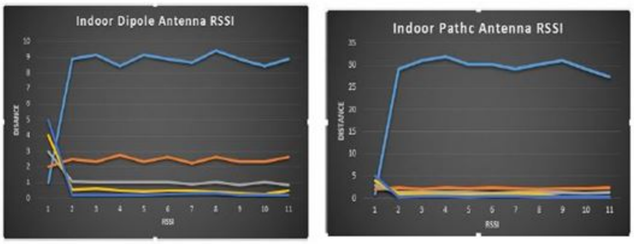
Table 2. Analysis of outdoor RSSI.

Analysis of indoor experimental data

We are presenting some graphs that have been obtained from an indoor experimental setup experiment. The RF transmitter transmits the signals and the evaluation board receives the signals to harvest the energy for data transmission as shown in Figure 6. The data can be accessed through the access point and displayed on the laptop.

The transmitter transmits the energy and the receiver receives the energy, then the receiver converts it to DC and charged the capacitor. When the capacitor has enough energy then the sensor board becomes able to transmit the sensed data otherwise it will wait until the capacitor got the required energy. So the charging is dependent on transmitter signals and received signal strength at the receiver which is also called the Received Signal Strength Indicator (RSSI). The capacitor stores the harvested energy and the sensor used this energy for transmission. When the capacitor has zero energy then it tries to harvest energy until the required energy is obtained, at this stage the sensor board waits. As the capacitor got enough energy, the sensor starts transmitting the data packets as well as the evaluation board harvest the energy. We can divide this scenario into three modes, harvesting-harvesting (h-h), and harvest-utilize (h-u), and full (f). Initially, the capacitor has zero energy thus it waits for some energy but how much? We have seen that the evaluation board nearest to the transmitter can harvest more energy and the packet sending rate is high and when the evaluation board goes farthest packet transmission process becomes slow. This means that t the received signal strength is inversely proportional to the square of transmission distance. During the indoor experiment, in patch antenna set up as we move from transmitter 90 to 180 degree (considering transmitter as on center point) the rate of harvesting energy decrease and hence transmission of packets.

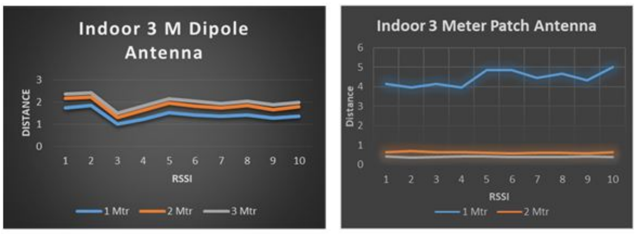
Figure 6 shows the graphs for an indoor experiment in which first we put the evaluation board and sensor 1 feet away from the transmitter and then 5 feet away. Figure 7 shows the graph for indoor dipole antenna RSSI and 3b shows the graph for indoor patch antenna.



(a) (b)

Figure 6. Indoor 5 meter RSSI Graph.

Figure 7 shows the graphs related to 3 meters experiments.



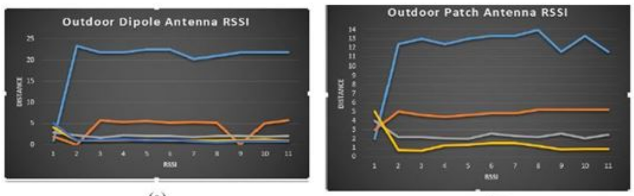
(a) (b)

Figure 7. Indoor 3 meter RSSI Graph.

Analysis of outdoor experimental data

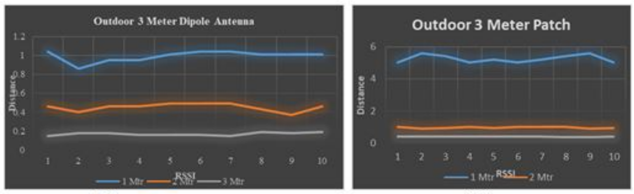
We are presenting some graphs that have been obtained from an outdoor experimental setup experiment. The RF transmitter transmits the signals and the evaluation board receives the signals to harvest the energy for data transmission as shown in Figure 6. The data can be accessed through the access point and displayed on the laptop.

Figure 8 shows the graph for an outdoor experiment in which first we put the evaluation board and sensor 1 feet away from the transmitter and then 5 feet away. Figure 9 shows the graph for outdoor dipole antenna RSSI and 9 shows the graph for outdoor patch antenna.



(a) (b)

Figure 8. Outdoor 5 meter RSSI graphs.



(a) (b)

Figure 9. Outdoor 3 meter RSSI graph.

Conclusion

Electric energy is an essential source to spend life in this world. There are many sources to generate electricity. Electricity is used in many important fields of daily life. One of the important fields is IoT based WSN. IoT based WSN has several applications such as smart health, smart cities, and smart agriculture. However, the storage capacity of the sensor is very low. This problem can be solved by using the energy harvesting technique.

In this study, we have presented an experimental study based on state of the art actual devices of powercast technology company. Powercast company provides a complete development kit P2110 for research to enhance the reliability of IoT based network devices including sensor board, energy transmitter, patch and dipole antenna, access point, and PIKCIT programmer. We have conducted experiments for both patch and dipole antennae in indoor as well as outdoor environments. The results are presented in the table as well as in graphs.

In this report, Powercast devices can improve the IoT based WSN lifetime. So there is a need for restructuring the traditional WSN routing algorithms that can improve further the performance of WSN.

Energy harvesting is an open research challenge in 6G technology.

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