**The Signal Kinetics using Wi-Fi Signals**

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***Abstract−−* In this review, we will delve into a collection of cutting-edge research papers that demonstrate the different versatility and innovative usage potential of radio frequency signal applications. In the first we learned about X-AR, it is an augmented reality system which is used to enhance visibility beyond human sight, including non-line-of-sight perception with the help of the RF-technology. The second paper explores about the method used by the wireless, a battery-free underwater imaging systems that is used for harvesting energy from the environment which offers a self-sustaining energy solution which helps in long-term oceanic observation and monitoring times. The third one is about EQ-Radio, a technology capable of recognizing emotional states using the RF signal reflections, which offers a new dimension in emotion tracking without any need of the physical contact. Lastly, the fourth paper discusses about Vital-Radio is a wireless system adaption which is used for monitoring vital signs in a living being like breathing and heart rates from a distance, without the need of any physical contact, through environmental motion and skin vibration analysis. These papers not only extends the understanding of RF technology in diverse contexts but also talks about a future where non-intrusive, continuous monitoring and enhanced perception could transform healthcare, environmental science, and human-computer interaction.**

***Index Terms*—X-AR, EQ-Radio, RF-technology, Vital-Radio**

Introduction

***What is a signal?***

The radio signals can be defined as the form of electromagnetic energy that propagates or travels through the medium in general air which enables wireless communication over long distances. They operate by sending energy using waves which is similar to how sound travels through the air but at the speed of light. This transmission occurs without any need of physical, wired connection, making it a cornerstone technology for devices like radios, cellphones, and even wireless internet. The process involves a transmitter sending out the radio wave, which then travels until it reaches a receiver that captures the signal with an antenna. Within the receiver, electronic circuits select and process the desired signal from among all available broadcasts, converting it back into recognizable sounds [1].

Next Wi-Fi can transmit on any frequency band or rapidly frequency hop between different bands. Which can help in reducing the interference and allowing multiple users to use it at the same time. With Wi-Fi may different devices can connect to one single router to get access to the internet. This provides a virtual connection but might have some interference or connectivity issue’s which can occur if the router fails or have so many users using high-bandwidth applications at the same time. However, the newer standards like 802.11ax can help solve issues like this [3].

Wi-Fi Hot Spots

A Wi-Fi hot spot can be defined as an area which as an accessible wireless network signal. This term generally used to denote the public wireless networks found in place’s like airports, coffee shops, hotels and other public/private locations [12]. Some of these hot spots can be free to use or require payment but in the end they allow all the user’s to access the internet while on-the-go without the need of any physical wired connection every time [11]. To connect to a Wi-Fi hot spot the computer or mobile device need to have hardware designed particularly for it known as wireless adapter or Wi-Fi module already integrated into. Now-a-days the modern laptops, smartphones and tablets all come with the Wi-Fi module already built into it. We can have older devices use Wi-Fi by purchasing the external wireless USB adapter or one that we can plug into the computer's expansion slots. Once we have it installed and configured correctly even older device can automatically detect available Wi-Fi networks within it’s range when it’s turned on. We can then connect to open hot spots or sign in to secure Wi-Fi networks [4].

Building Home Wireless Network

In today’s world, we have many ways for getting home connected to internet which range from using the copper wire based connections like ASDL, HDSL, satellite communications and using optic fiber. Below is the figure [fig 1] explaining the different options available for building a Home network [13].

To build a wireless network in our home. We can follow the steps:

1. We need a wireless router. This single device can act as a router, ethernet hub, firewall, and wireless access point depending on the configuration, hardware and model of the wireless router.
2. It will have a port to connect to the modem and RJ45 jacks to connect all your computers through wired connection for faster access.
3. And to connect to phones, TVs and other devices using Wi-Fi hotspot to connect to the internet.
4. In general, Home wireless routers can have range around 100 feet of coverage which can pass though walls but will have reduced in signal strength.

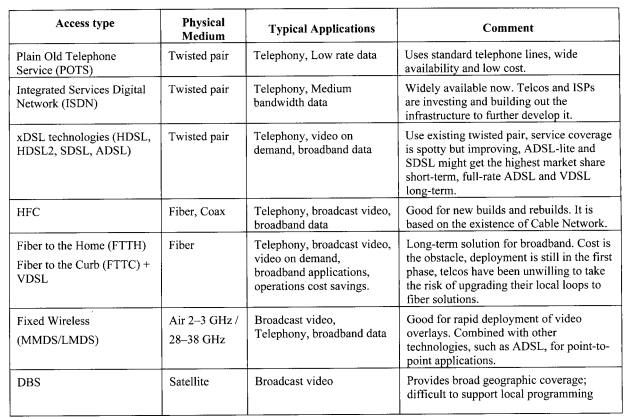


Fig 1: Table showing Alternative options for Home network setup [13]

We can have multiple access point setup depending on the need of user. By using the available frequency ranges 2.4GHz and 5GHz. As we know that the 5GHz has less range but higher speeds. So, it’s important to setup the route in a optimal place like shown in the below figure [fig 2]. This helps in covering more area and devices in the room. If the room is very large or strength is much less than expected we can upgrade the route which has higher capacity or we can use tools likes Wi-Fi range extender or get a secondary router and setup the connection from main device to the secondary router.

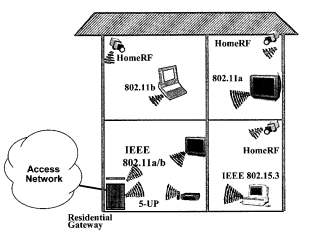


Fig 2: Digital Wireless House Network [13]

Wireless Standards

The Wi-Fi standard’s have evolved and are marked by significant improvements through various versions with each defined by IEEE 802.11 standards. These versions are defined to according to the different needs like offering enhancements in speed, range and efficiency. The list of the primary Wi-Fi versions and their characteristics listed below [5]:

1. ***802.11 (1997)*** - The original Wi-Fi standard has offered speeds up to 2 Mbps using 2.4 GHz radio frequency.
2. ***802.11b (1999)***- Continued to use the 2.4 GHz frequency with up to 11 Mbps, offering better range than 802.11a but with slower data rates. It is also known as Wi-Fi 1.
3. ***802.11a (1999)***– In this version, the frequency of 5 GHz which can provide faster data rates up to 54 Mbps is introduced but has only shorter range due to higher frequency which has less power to penetrate walls/obstacles. It is also called has Wi-Fi 2.
4. ***802.11g (2003)***– This has both the combined benefits of both 802.11a and 802.11b with offering up to 54 Mbps at 2.4 GHz and also providing compatibility to older devices with higher speeds of transfer. This is also called has Wi-Fi 3
5. ***802.11n (2009)***– It is also known as Wi-Fi 4. In this version, they introduced Multiple Input Multiple Output (MIMO) technology which uses both 2.4 GHz and 5 GHz bands to offer speeds up to 600 Mbps. It also has improved and reliable signal and range.
6. ***802.11ac (2013)*** – Also known as Wi-Fi 5. It uses only the 5 GHz band but not the 2.4GHz band and has expanded the usage of MIMO technology with more channels up to 160 MHz with much higher speeds up to several GB per second.
7. ***802.11ad (2012)***– It also known as WiGig, this version of Wi-Fi utilizes the 60 GHz frequency band which can offer extremely high transfer rates of up to 7 Gbps but it has short coming of only covering very short distances and speed decreases if they any obstacle’s in between like walls.
8. ***802.11ax (2019)***– Also known as Wi-Fi 6. This is the most recent version or standard used currently in use now-a-days. It has improved efficiency and throughput even in congested areas. It used both 2.4 GHz and 5 GHz bands. It introduced Target Wake Time aka TWT to improve device battery life and can offer speeds up to 9.6 Gbps
9. ***802.11be***– Also known as Wi-Fi 7. It is still in development phase with estimated timeline to be completed in sometime in this year. It is expected to further enhance speeds by 4x times, have more efficiency with 2x bandwidth and which reduces the latency significantly using existing or new frequency bands [14]. We can see the main features of Wi-Fi 7 shown below [Fig 3].

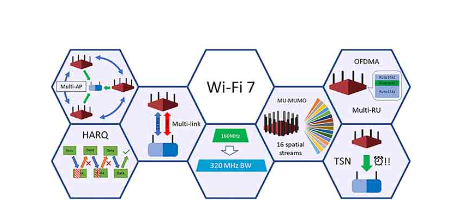


Fig 3: Showing main features of Wi-Fi 7 [14]

Each version has made contribution to the widespread and adoption of Wi-Fi into various different fields and environments like from home networks to large-scale commercial/Industrial areas to answer the increasing demands for the need of data and connectivity in these modern times.

Applications of Wireless Signals

***Underwater Imaging using Wireless***

Underwater imaging is one of the important thing for advancing our understanding of the marine ecosystem, climatic impacts and the biological diversity. However it having a very important role on environments globally but they remain largely unexplored due various reasons like depth, water pressure and many more. The traditional imaging techniques depend on tethers for power and data transmission which are depended on battery lifespans for them to function which can hinder the long-term and scalable observation efforts due to need to be charged for them to be working agian. These challenges has limited the ability to conduct continuous observations that are essential for monitoring dynamic underwater processes and the health of marine/aquatic organisms. As underwater images of marine animals, plants, oceanic basins, coral reefs and marine debris are key elements in understanding marine environments and how they impact the global climate. Underwater imaging helps us to discover the new species and help us understand the impact on climate change and human activity on the underwater. Underwater imaging can also support aquaculture food production as it’s the world’s fastest-growing food sector. We can use underwater imaging to detect diseases like sea lice and monitor harmful algae blooms and regulate fish feeding patterns to have control growth. More over underwater imaging has applications across oceanography, marine biology, climatology, underwater archeology and many more.

As you understood the importance and need for the underwater imaging. To overcome the difficulties had with the traditional approach they introduced the new methodology which doesn’t rely on batteries known as “**underwater backscatter imaging**”. In this method for scalable and real-time imaging using cameras that are fully merged and which can operate independently without any external power sources. By only using the energy cultivated from wave currents which makes these cameras to function indefinitely without the need for any battery replacements which solves by overcoming the huge barrier faced by traditional underwater imaging technologies. In this system they not only reduced the operational costs and the environmental footprint but also have significantly expanded the potential for long-term ecological monitoring which can help in studying deep water’s which require huge equipment and issue with water pressure which can damage the power source that is battery if there’s a crack or air gap.

Augmenting Augmented Reality with Non-Line-of-Sight Perception

***Augmented Reality Systems***

Augmented Reality can be abbreviated has AR. It is a technology that overlays digital information likes images, data and animation onto the real world. When compared to virtual reality aka VR which replaces the user's real-world environment with a simulated environment. The AR enhances person’s perception of reality by superimposing the digital content onto the physical environment meaning onto the real world. This is done by using the devices like smartphones, tablets, AR glasses which are specially designed or head-mounted displays like Oculus quest by Samsung, Meta quest by Facebook aka Meta and the latest one into this list of devices is Apple Vision pro [10].

Use Cases of AR

1. ***Retail***: AR can be used to transform the retail experience by allowing customers to try things even before they buy. For example, furniture giants like IKEA offer AR apps that let customers visualize how a does the furniture would look in their own living space before even making the purchase. Which can help customer to more flexibility and choice in selecting the item right inside their house.
2. ***Education and Training*:** We can use AR to provide an interactive and immersive learning experiences by making education more engaging and effective. For example, anatomy students can use AR to project 3D models of the human body which can help them in exploring layers of organs and systems without needing real specimens.
3. ***Gaming***: The AR has greater impact on gaming industry by providing a more immersive and interactive user experience. We can take Pokémon Go as a well-known example. In which players can catch virtual creatures that appear in the real-world.
4. ***Healthcare***: In healthcare it can assist with complex surgical procedures by projecting 3D visualizations of a patient’s anatomy of the body which can help by guiding the surgeons in real-time when performing operations.
5. ***Maintenance and Repair*:** It can help technicians to do maintenance and repairs more effectively by overlaying digital schematics just like it can do when helping anatomy students understand the human body but this time it is applied to on a device or appliance with the instruction set onto the equipment being fixed which can reduce downtime and errors.
6. ***Navigation***: It can also help in enhancing the navigation systems by having directions onto the real world which can simplify the navigation process into unfamiliar locations. As it get hard understand when we have wrong device orientation and having need to convert the 2D navigation with the real world while one is stuck in traffic. This can also be very useful to pedestrian’s navigation.

As the interest for the AR systems is increasing from past few years. Major tech giants have invested in the development of the technologies. Some of them are Apple, Samsung, Nintendo, Leia, Meta, Amazon, Google and many other. But they are they limited or not used to fully potential due to the limitation of the line –of-sight (LOS) which can be caused due to objects or things which limit the visibility to the AR systems. To overcome this they have designed an AR systems with NLOS which can help in finding any item or things even when it doesn’t have the direct line of sight to it. For this is to work, they have used the concept of radio frequency signal which can travel even when it has obstructions like cardboard, plastic, clothes etc..,

They introduced system known as X-AR which is setup over an AR headset is an ultra-lightweight and wideband antenna. Which still maintains and has no issue’s with mobility and user friendly. The X-AR uses the RF signal from the RFID of the object we want to locate and uses the AR headset to guide the user in the direction of the location of the object.

Emotion Recognition using Wireless Signals

***Emotion Recognition***:

Emotion recognition can be referred has the ability to identify and interpret the emotional state using the expressions and feeling of others which is the key aspect for the emotional competence. The skill’s for recognizing the emotions is considered valuable across different cultures for many underlying reasons may be different based on cultural orientations. In some cultural contexts that emphasize on the social engagement for emotions like sympathy and children can learn to recognize what others are feeling by emotions in order to display their cultural with responses of concern and the connection. Conversely in some other cultural’s prioritize individual freedom where children may need learn on their own to recognize others' emotional states in order to allow them their privacy from their own emotional experiences [15]. While research on emotion recognition abilities in early stages of the childhood across various cultures is very limited. In paper the study finds the 4-year-old children in China were significantly more accurately able to recognize the emotion compared to the children from Australia of the same age. The children from some culture’s can actually gain more experience from reading subtle micro-expressions of emotion which can be observed from the sensitivity to facial cues of emotion recognition from an early age. The study suggests that the emotion recognition capabilities have high rise at very early age in development in people but due to different indications of their potential cultural differences plays an important role in this skill as develops across different cultural contexts.

***Emotion Recognization Applications***:

Emotion recognition has various number of important applications across various different fields like smart homes, entertainment, advertising, and healthcare. The already existing approaches rely on the audiovisual hints like facial expressions and speech which cannot give accurate measure due to inner feelings and are impacted by individual difference’s of expressiveness. To address these limitations, They tried using the wireless method known as EQ-Radio that recognizes emotions by analyzing the radio frequency signals reflected from the person's body directly and measuring the interaction between emotions and physiological signals without the need of any body sensors.

EQ-Radio

EQ-Radio can be defined as an advanced signal processing algorithm that can be used to extract an individual’s heartbeats from the captured Radio frequency signal reflections. The RF signal is modulated from both the breathing and heartbeat of the person. The large breathing sometimes might mask the individual heartbeats which lack the sharp ECG-like peaks. The algorithm first tries to mitigate the issue of breathing effects by working on the acceleration of the RF signal. It then design an optimization problem to recover the optimal segmentation between the individual heartbeats and updating the segmentation and template to decrease the variation across different segments while allowing flexible for warping [8].

For emotion classification, EQ-Radio adopts a 2D model with valence (positive vs negative) and arousal (excited vs calm) axes to classify emotions into four quadrants - sadness, anger, joy, and pleasure. It extracts 27 relevant features from the heartbeat sequence and respiration signal, calibrates these features against a baseline neutral state for each person and day, performs feature selection, and employs an SVM classifier on the selected features. My implementation consists of custom FMCW radio hardware transmitting swept RF signals from 5.46-7.25 GHz to capture body reflections, and software algorithms running on a computer system to process the signals for heartbeat extraction and emotion classification.

Extensive user studies with 30 participants validate EQ-Radio's ability to accurately extract heartbeats from RF signals and recognize emotional states with accuracy comparable to state-of-the-art ECG-based emotion recognition systems. My EQ-Radio system pioneers an innovative non-invasive wireless approach to emotion recognition by directly measuring internal physiological signals without any body sensors, overcoming key limitations of prior techniques. This expands the capabilities of wireless systems and advances the field of emotion recognition.

We have many more other application’s of the wireless signal’s like for Health monitoring for measuring the breathing and heart rates, Precise finding of the location of the objects on the other side of the wall and many more [9].

Conclusion

In this paper review, we explored the collection of research papers that showcase the incredible versatility and innovative usage of radio frequency (RF) signal and it’s applications. They highlight, the way RF signals can overcome the traditional wireless communication to unlock it's groundbreaking capabilities across various different domains.

In the 1st paper introduced we studied how wireless can be used for battery-free underwater imaging system that harnesses energy from its environment. This self-sustaining solution is a game-changing approach for performing the long-term oceanic observation and monitoring which frees us from the limitations of battery-powered systems. It’s applications can range from marine biology, oceanography, aquaculture, and many more which can enable unprecedented into the depths of our oceans.

In second paper, we learned about X-AR an augmented reality system that improves the visibility beyond the constraints of line-of-sight resulting in finding things which are present in NLOS. By using the power of RF technology, X-AR can find and guide users to locate the objects that are obstructed or not present in the LOS for direct view which helped in overcoming a very important limitation of conventional or traditional AR systems. This technological breakthrough has opened up many more possibilities.

The other paper tells us about EQ-Radio which is a capable of recognizing emotional states through RF signal reflections. This approach to emotion tracking introduces a new dimension to human-computer interaction and the psychological research which eliminates the need for physical contact any other specialized equipment. This can be used by AI robots to interact with the human depending on their emotion which can give rise to new entirely new field to explore, offering new advances for understanding and responding to human emotions in more natural ways.

The other important application of the wireless signal’s is Vital-Radio which is a wireless system designed for enabling the remote monitoring of vital signs like breathing and heart rates of a person from a distance without need of any physical contact with the person or any specialized equipment. It is done by analyzing motion and skin vibrations using the RF signals. The Vital-Radio gives rise to usage in wide range of fields for the potential of continuous monitoring of living beings which can be used for revolutionizing healthcare, military and remote monitoring applications.

These are some of the example of research that give one’s understanding of RF technology and it’s application in various different fields and also it provide how it can shape not just communication but also transform other industries like healthcare, environmental science and human-computer interaction. Which can help us overcome limitations and enables new capabilities with these technologies to pave the way for a world where the boundaries of perception and monitoring are continuously pushed forward in the new era of innovation and discovery.

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