Making the Switch to 5G and 60 GHz in mHealth Applications Using USRP Hardware

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***Abstract*—The 5G networks will see implementation in mHealth in the upcoming years, and it becomes increasingly important to be able to test and develop software for the new generation of hardware. This new generation will likely utilize higher frequency bands in order to be considered 5G. The proposed method of utilizing USRP devices as testbeds should inform researchers of possibilities of emulating new software in real-world environments, to test for various parameters. This article uses other sources to explain the extent of 60 GHz communication capabilities of USRP devices in modern 5G research.**

BACKGROUND

With the ever evolving component of connected health, that is, mHealth and its applications comes the need to test and develop new technologies as old ones become obsolete due to the shift of technologies. With 5G networks on the rise, mHealth devices such as EEGs, ECGs, fitbit trackers, and other wireless communication devices may be required to make the switch, be it due to increased speed, security, accuracy, or other factors and promised benefits of switching to 5G. Research on 5G technologies, especially those in higher, less populated frequencies (unlike the highly populated 2.4 GHz frequency) such as 60 GHz frequencies, aims to prepare the next generation of devices for the switch to 5G. With mmWave technology and 5G devices, a new era of wireless communication is about to begin, making testing and the preparation of testing environments increasingly necessary. This article aims at these testing opportunities, mostly utilizing the mostly utilizing the Universal Software Radio Peripheral (USRP) family of devices. USRPs are

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Software-Defined Radios (SDRs) that are capable of creating 60 GHz communication testing environments and enable not only simulation of newly developed software, but also emulation of that technology, allowing for real-world stress-testing and implementation. There is not too much research combining 60 GHz, USRPs and mmWave technologies, especially with mHealth applications as of the writing of this article. This article introduced various different ways of combining USRPs and software to enable testing and computing in a research environment and embark on 5G research.

STATE OF mHEALTH

The technologies surrounding mHealth applications and devices have largely already been implemented into society and can be seen on various different occasions. With devices such as fitbit trackers, heart rate sensors, portable EEGs, and ECGs and various features in other portable devices, mHealth has already been presented to society and widely accepted as medical devices. These mentioned devices operate as on-body technology collecting data from movement, heart rate, activity, and other useful metrics for users to analyze.[1] The use of these devices is accepted widely and some use it casually to improve their own health while others may receive from physicians a prescription of using or wearing on-body sensors for the collection of data. The latter often occurs in hospital settings for when patients need to be monitored over time using EEGs, ECGs, or other medical equipment. In either case, sensitive data are handled and may be sent to other devices for analysis. The evolution of the Internet of Things (IoT) allows users to send this data to servers that analyze the data and provide useful metrics back to the user or patient.

There are four subcategories for mHealth data analysis.[2] Self-healthcare management is the lowest level of analysis where data collected by an on-body device is transmitted wirelessly to and analyzed by an app on the user's phone. This technique allows for direct self-monitoring and keeps data well within personal reach.

Another technique is Assisted Healthcare, where data are sent to a caregiver's phone or other analysis device instead of the user's direct phone. This caregiver may take on the role as analyst and aid the primary user/patient of the mHealth device in adjusting their routines or give feedback. This often occurs when users are elderly and prone to forgetting information or details and prefer to have a caretaker to adjust the device instead.

A step beyond Assisted Healthcare is Supervised Healthcare. In this subcategory the caretaker may be at a remote location (most commonly a hospital) and receive data from the body sensors remotely. This way the caretaker can oversee, analyze, and act on the received data and may potentially be able to alter the configurations and settings of the body sensors remotely. This simplifies the process of patient care for patients that require devices such as EEGs or ECGs as they are allowed to leave the hospital and continue with their lives in natural environments without worrying about adjusting the devices or sending reports as it is all automated.

The deepest level of automation occurs at the last subcategory of mHealth: continuous monitoring. This subcategory is very similar to Supervised Healthcare, but it removes the human caretaker component. Instead of a caretaker analyzing data, an automated process uses analysis models and deep learning techniques to analyze the received data and make adjustments to the body sensor remotely, just as the caretaker would have done. This automated process is also supervised by another hospital member, however, not as frequently as Supervised Healthcare requires this person to.

These differentiations in techniques show that mHealth is being implemented in a hospital environment. However, as time changes, so do demands of software, hardware, and patient care. Issues that are currently at the surface of mHealth, body sensor network, and wireless body area network (WBAN) research are security, battery life, transmission attenuation, and speed. Security measures are important since important, personal medical data are in question of transmission. Battery life matters significantly since devices should run at least 24 h and should not be required to be charged frequently (especially when considering implant sensors). Battery life is affected by the protocols running inside an on body sensor, type of transmission, and security features. Any calculation depletes the battery inside and finding accurate, yet cost efficient algorithms and applications is a big point of research in this field. This in turn affects transmission speed, accuracy, and attenuation. Transmission also requires battery power for successful, accurate execution. Research is being conducted in all of these fields to improve performance of body sensors and WBANs.

mm-WAVE OF 60 GHZ AND mHEALTH

A subject that is always a field of interest is wireless communication. Cheaper and faster transmission is the goal of a lot of research surrounding this field. The next wave of improvement is aimed at 5G networks utilizing frequencies such as 60 GHz to transmit more data more rapidly. Looking at mHealth and body sensor products, the switch to 60 GHz could mean much more than a performance increase due to higher speeds and accuracy. The most significant point of improvement lies within attenuation of messages, especially in the current day and age. Many machines use the near overpopulated frequency of 2.4 GHz. Microwaves, Internet, Bluetooth, and other wireless communications operate on the 2.4 and 5 GHz frequencies, causing interference to other machines and transmissions that are occurring nearby. WBANs use an internal structure in the case a network has multiple nodes within. For example, an EEG and ECG may both attempt to communicate the collected data with a third node within the network that can then send these data to an analysis center over Wi-Fi. This communication network is local and is currently affected by attenuation of any 2.4 GHz signal that interferes. Hence, switching to a higher frequency such as 60 GHz and upgrading sensors to internal 5G networks would improve communication tremendously, with less packages lost and, therefore, less battery power required to resend data.

The 5G networks and 60 GHz communication are currently being researched in various different ways, but only some connect mHealth and 60 GHz communication together. There are, however, technologies available to test, develop, and potentially deploy 60 GHz node networks. While many of these devices are prototypes or currently expensive equipment, they are still a good way of testing and emulating code that can work within a 60 GHz network.

USRP TESTBED AND APPLICATIONS WITH 5G

USRP Device

The Universal Software Radio Peripheral from Ettus Research consists of a variety of software-defined radios (SDR) that can be used as a testbed with various different parameters and capabilities. Combined with GNU Radio or MATLAB, USRPs can emulate different testbed scenarios with different frequencies (2.4, 5, 30 GHz, etc.) depending on the installed daughterboard. These daughterboards and the customizability of USRP devices make them an extremely strong testbed and testing environment. Using multiple USRPs at the same time to configure a network can aid in emulating multinode WBANs and other mHealth networks. While there are currently no publicly released node networks operating at 60 GHz wavelengths, these USRP devices can foster research of methods that may potentially be implemented in such a network once it is created/released publicly. USRPs are SDR, which means that they can be easily coded and altered through coding the test environment. This allows for the implementation and emulation of deep-learning algorithms, pathfinding, encryption, frequency adjustments, and many more variables within the USRP device and its underlying network. This high customizability can cover the settings of various different devices and their respective features. Setting up a USRP to emulate an EEG sending data to a second USRP emulating a transmission node in a network that uses 30 GHz or higher frequencies for communication is made incredibly easy due to the customizability of features, limitations, and parameters within a USRP and its daughterboard using GNU Radio or MATLAB.

Figure 1. Two USRPs, each with one antenna connected to either RF1 or RF2.

A sample setup of two USRP devices can be seen in Figure 1. Here, two USRPS are connected to a single host computer with the help of a Gigabit Ethernet switch (as seen in Figure 2) and their respective Ethernet cables. Each device is

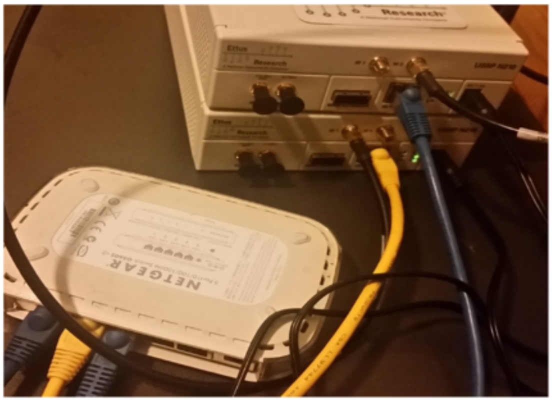

Figure 2. Connection of the USRPs to the Gigabit Ethernet Switch that is connecting the devices to the host.

connected to a 850 MHz–6.5 GHz antenna to allow them to communicate and emulate a range of different frequencies. This setup could be altered to exclude antennas altogether if the USRPs were linked directly with a cable instead of antennas for transmission, but since attenuation and package loss do not occur realistically in that case, antennas are still being used to be more accurate to real-world parameters. One antenna is set up to be a Transmitter while the other is connected to the receiver port of the USRP.

Past Simulations/Emulations Demonstrated With USRP

Due to the impending switch to 5G networks, experimentation with software and hardware capable of communicating at those frequencies is becoming incredibly important. There are various USRP models on the Ettus Research website that are capable of communicating at frequencies above 5 GHz and giving this exact testing environment for a rather low price. Research has been performed in various different fields utilizing USRP hardware and different daughterboards to adjust for trial parameters. This article mainly focuses on showcasing and elaborating on recent research utilizing USRPs and test environments that utilize higher frequencies (including 60 GHz) to prove viability in using these devices to test, not only for high-frequency communication, but also to showcase potential for mHealth application tests. To our knowledge, few research has been done combining this high-frequency testing environment, the USRP capability of emulating and simulating this environment and applying it to the field of WBANs and other mHealth applications.

Initial Exposure to USRPs at 60 GHz

Since Ettus Research allows for higher frequency capabilities in their USRP devices, daughterboards and antennas, testing has become widely acceptable and easy for any research team. Dating back to 2015, USRPs started seeing exposure to research teams attempting to utilize the USRP at higher frequencies. A certain study[3] has developed and implemented their own hardware and circuits in combination with USRP motherboards (most commonly using the USRP N200/N210 series) to allow other research groups access to 60 GHz experimentation and testing. Alongside a guide on how to set up the hardware and software environment, the group released extra functions for MATLAB/Octave to test this setup at 60 GHz to allow other groups to successfully replicate findings of the study. This initial step toward 60 GHz research utilizing rather inexpensive USRPs was one of the major starting points for initiating research in the 60 GHz field. While there may have been some issues with the distribution of these additional C++ based, 60 GHz enhancing files, they should still work if installed correctly into MATLAB or Octave. However, there have been more recent research experiments that utilize completely different environments and settings to achieve 60 GHz capabilities with USRPs.

USRP and GNU Radio

The most commonly accepted software development environment for USRP devices is the free GNU Radio application. It features similar features as Simulink within MATLAB does, but focuses more deeply on SDRs such as the USRP families. GNU Radio is most easily installed on Linux and Mac devices but may run into some issues if installed on windows. The official GNU Radio website gives detailed instructions on how to set up the environment and it connects directly to USRPs through an Ethernet connection if set up and referenced correctly. Similarly to other SDR-based programs such as Simulink, GNU Radio is a block diagram based environment where nodes are connected to modify waves sent out from the USRP including decryption/encryption, frequency and wavelength adjustments, and many more. Users have

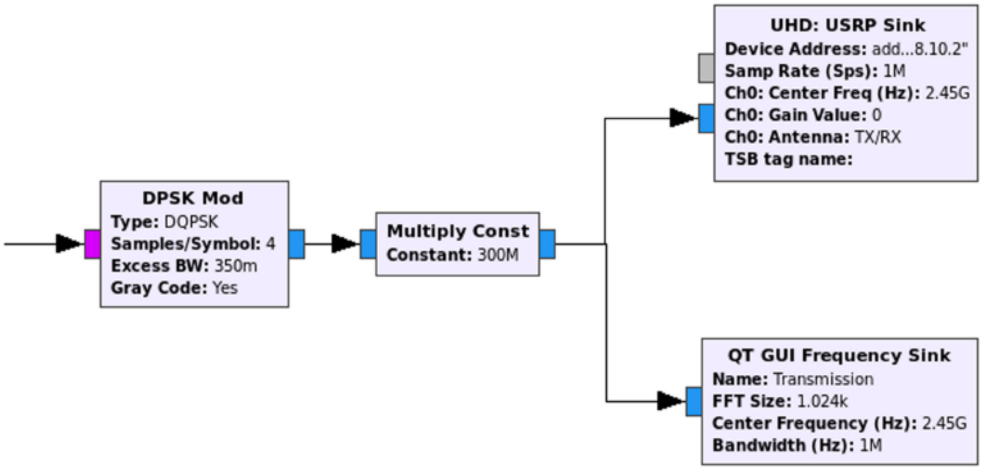

Figure 3. Example of a setup for a Tx Program in GNU Radio.

to set up Tx and Rx programs, respectively, if two or more USRPs are desired to communicate with another. It is possible to run both these programs concurrently using one or more computers connected to multiple USRPs. An example of a 2.45 GHz Tx Program can be seen in Figure 3. This diagram uses blocks to modulate an input, multiply it to make it more stable for transmission, and then uses the USRP Sink to send the data while graphing results using the QT GUI Node (results can be seen in Figure 4).

Studies use GNU Radio to emulate their software on USRPs, which can serve as experimental testbeds and environments to prove the efficiency of their software. As opposed to normal simulation in a computer-based software environment, the USRPs can take this developed code and run it with the help of GNU Radio in a much stronger, more realistic hardware-based environment. This gives a large benefit to testing applications that may run into issues when implemented in real life. These issues include, but are not limited to, attenuation, packet loss, battery life, interference due to obstacles or other signals and the effect of distance on speed and accuracy of transmitted signals, especially at niche, new fields including 5G communication, 60 GHz frequency, and networks combining them through two or more nodes (especially in WBANs).

In the case of this study[4] GNU Radio was used to develop AG mmWave channel sounding measurements to establish air-to-ground (AG) channels for communication with aerial vehicles. The study

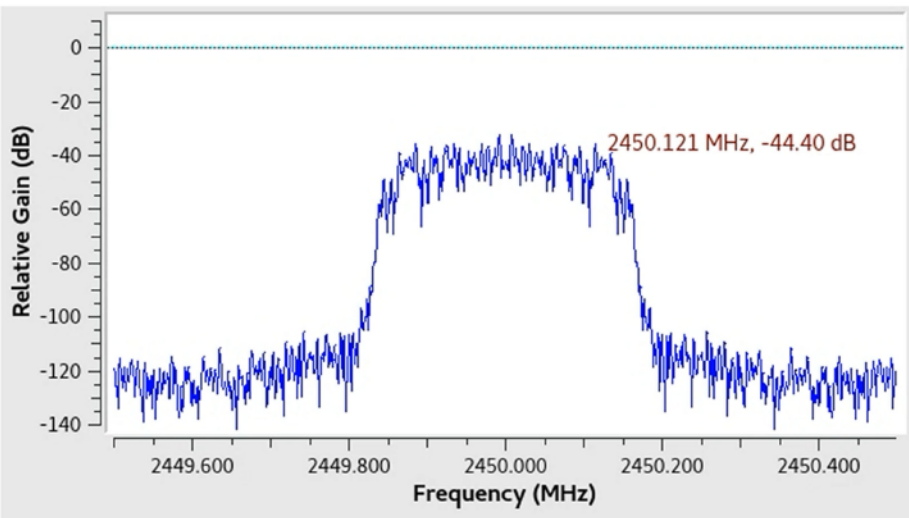

Figure 4. Result of QT GUI frequency sink.

was aimed at testing higher frequencies including 60 and 28 GHz, which was very well suited for USRP devices. A 60 GHz communication is made easier to code and implement through the GNU Radio software tool. Communication links between USRPs and receivers make communication with aerial vehicles easy due to the minimal weight and signal strength of the USRP.

The authors of this study[5] create a USRP-based video streaming communication link between two USRP N210s running with 60 GHz capable Tx/Rx Frontends. This study directly implements 60 GHz on the USRPs instead of emulating the frequency. The hardware setup includes the two USRP N210s, 30 db Attenuators, RF Single-Ended Differential Converters, 60 GHz converters, and 60 GHz capable horn antennas. Details about the setup are given within this article. The study found that the transmission strength was highly dependent on the direction and angle of the antennas, but that the system could still perform above average. A large issue within this study was to cancel noise and keep a clean signal for transmission. This alongside previous studies showcases the availability of equipment that can correctly and accurately emulate and simulate 60 GHz communication using USRPs.

While the implementation of USRPs is not too far beyond testing and not too widely used as of 2019, it cannot be neglected that these first steps of progress and implementation of 60 GHz capable devices using GNU Radio and USRPs makes future research easier and grants a head start on experimentation with new 5G capable devices that are to come.

Other Software

USRPs work with other software [SPDAR (simulation only)] (python + labView)

Another capability that USRP devices offer, now that research and technology have evolved to encompass them, is modification of beam shape through beamforming at the high frequency, 5G networks. Beamforming focuses the signal sent out by devices by utilizing antennas and centering the beams to a specified location. This boosts accuracy and transfer speed of data, which could come in very handy for new 5G devices to test maximum capacity, speed, and other parameters of antennas attached to 5G capable devices. This study[6] utilized two USRP-RIO 2921 devices alongside Python and LabVIEW to set up this environment for laboratory settings. Knowing the limits of new technology can help predict viability of implementation of this new software/hardware in professional settings, such as hospitals aiming to use WBANs and other mHealth technologies to communicate wirelessly across patient's bodies and data collection devices.

Another similar study[7] tackling beamforming capabilities for 5G networks aims to aid research for phased array systems in mmWave and 5G networks. Utilizing the USRP B200mini alongside other hardware, Python, MATLAB, and GNU-Radio a software-defined phased array radio (SDPAR) is created to create a modifiable beamforming setup for future researchers to use and test. Both of these studies use different setups utilizing different USRP models and different software to arrive at the same core result of aiding researchers improve 5G networks at mmWave levels. In return, all this development aids mHealth research as well, since it boosts knowledge and research that can be used to implement similar hardware into WBANs, fitbits, and other digital medical devices.

DISCUSSION

Current research on USRP devices aids tremendously in advancing mmWave research due to its strong communication capabilities, especially at higher 5G frequencies including 60 GHz, which is currently in high demand. Utilizing communication software such as GNU-Radio, Python, LabVIEW, and MATLAB, most of which are completely free and accessible to the public, USRP devices are very cheap research devices for 5G technology that is on the rise. The head start that these machines give on developing tools for 5G networks is undeniable and highly recommendable. The promised improved speed, accuracy, security, and others incentivize this research further and would improve technology used for mHealth significantly. The 5G technology will allow commonly used key devices within hospitals to operate with these improvements. The increase of devices operating on a 2.4 GHz basis are overpopulating locations that require the extensive use of wireless equipment, such as hospitals, which increases the demand for technologies that allow for faster, more private networks that 5G promises. Devices that benefit from this technology include, but are not limited to, EEGs, ECGs, tracking and monitoring devices, fitbit and other wrist sensors, cardiac sensors, ultrasound sensors, and many more that utilize a wireless communication network, sensor or node network to transmit data. Most of these devices, if not all, transmit on Bluetooth or Wifi at 2.4 GHz frequencies, causing interference with other devices, calling for a solution with devices operating 5G networks. Even though there are technologies that are being developed to tackle mHealth problems, only a few consider this issue of overpopulation of the 2.4 GHz frequency. Researching and developing technologies communicating using 5G networks now can create stronger devices that can outperform current technologies if implemented. Yet, since this improved hardware does not directly exist as of now, all that can be done is experimentation with simulators and, as is the case for these USRP devices, hardware emulators capable of testing 60 GHz frequencies and other 5G communication networks.

There are still many new research breakthroughs for lower frequencies, including the close-to-overpopulated 2.4 GHz frequency band. Testing these algorithms, path-finders, protocols, security measures, attenuation adjustments, etc., is close to untouched in 5G network emulation. USRPs offer an opportunity to replicate these research experiments in an actual, real-life emulation setup, which may in turn lead to more research breakthroughs or further adjustments of these code-snippets to better suit 60 GHz and 5G networking requirements. In other words, breakthroughs for mHealth at 2.4 GHz frequencies may be easy to implement and emulate on USRP, mmWave capable hardware to observe viability of these same breakthroughs in a 60 GHz setting. With the abovementioned setups, this experimentation should be rather easy to replicate, test, and evaluate with USRP equipment, leading to an improved understanding of not only the USRPs capabilities but also 60 GHz frequency, 5G networks, and possible implementation of this software in mHealth applications once technology is available to allow for implementation.

A 5G research is being performed with USRPs capable of communicating at higher frequencies such as the 60 GHz waveband. This research fosters breakthroughs for 5G networks and may aid in development of further software and hardware for mmWave and mHealth applications and implementations. Moderately easy to setup and not too expensive, USRPs invite researchers to apply 5G algorithms and emulate them in real life settings to investigate if a 5G network implementation is viable or not. The field is constantly evolving and so are USRPs and their capabilities. With 5G networks on the horizon, USRPS will aid immensely in getting ahead of the curve on research and implement new software capable of 5G communications early, especially in fields such as mHealth, which already utilizes mmWave communication technologies. Once these new technologies are released, USRPs can stay ahead of the curve as well, due to their modularity. As mentioned in,[5] USRPs and their transmission range can be scaled up to 60 GHz, but may be capable of even more than that. The USRP is a testbed capable of implementing hardware and software alike and test new equipment. USRPs will stay relevant due to this ease of implementation and testing of new technology on a testbed that is rather inexpensive for its potential uses.

This article was meant to emphasize the importance of 5G technologies and to encourage researchers to utilize existing technologies to help innovate solutions for problems created by the overpopulation of technologies using 2.4 GHz frequencies. Fields such as mHealth and communication technologies are in immediate need for these new technologies operating at 5G. The tools mentioned in the sources mentioned above are meant to aid this process of research and discovery, so that software can be developed that can be deployed on 5G capable hardware, or to develop 5G capable devices to implement that software.

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