Abstract—In this paper, an analysis is carried out for a method to mitigate the path loss through the dynamic spectrum access (DSA) method. The path loss is a major component which determines the QoS of a wireless link. Its effect is complemented by the presence of obstruction between the transmitter and receiver. The future cellular network (5G) focuses on operating with the millimeter-wave (mmW). In higher frequency, path loss can play a significant role in degrading the link quality due to higher attenuation. In a scenario, where the operating environment is changing dynamically, sudden degradation of operating conditions or arrival of obstruction between transmitter and receiver may result in link failure. The method analyzed here includes dynamically allocating spectrum at a lower frequency band for a link suffering from high path loss. For the analysis, a wireless link was set up using Universal Software Radio Peripherals (USRPs). The received power is observed to increase by dynamically changing the operating frequency from 1.9 GHz to 830 MHz. Finally the power is observed to increase by dynamically changing the modulation and coding (MCS) for the communication. This is controlled by the eNodeB (eNB) and helps tackling path loss in downlink. In downlink, eNB usually transmits with the maximum power [2], [3]. In the uplink, PC provides the way to handle the path loss. The PC in uplink includes determining PL by user equipment (UE) through the received symbol received power (RSRP) from the eNB. The UE then compensates for the PL by changing its transmit power accordingly (open-loop PC). The transmit power of UE also includes an MCS dependent offset determined by the eNB (closed-loop PC) [2].

With the next generation cellular network, 5G, looking to exploit the higher frequency (or mmW), the problem of path loss can prove to be a bottleneck [4]. The operating environment is highly dynamic. It can encounter sudden degradation in the operating conditions or the arrival of obstruction between transmitter and receiver, resulting in link failure, especially at high operating frequency. In this paper, an analysis of a specific scenario is considered where the already established method to tackle PL proves to be insufficient.

The method analyzed here includes using software defined radio (SDR) with multi-band reconfigurable antennas (automated by the field programmable gate array of the SDR [5]) at the RF front end of the communication systems. The SDR system is capable of dynamic spectrum allocation (DSA) for the communication. This is used to dynamically lower the operating frequency of a communication system operating at high frequency, in case of degradation of link quality. In the conventional communication system, it is not possible to lower the frequency on the fly as it will require to completely reconfigure the architecture of the communication system. SDR provides the freedom of dynamically changing the parameters of the components at the RF front end so as to operate in various frequency bands. This is analyzed in the paper by creating a wireless link using universal software radio peripherals (USRP).

The paper is organized into four sections. In section 2, the description of the experimental setup and observations for the model tested at Signal Processing and Communication Research Center (SPCRC) in IIIT Hyderabad is discussed. The deployment of the system in real scenario is analyzed in Section 3. In the end, conclusions are presented in Section 4.

II. EXPERIMENTAL SETUP

A. Setup Requirements

Universal Software Radio Peripherals (USRPs) and a 64 bit PC constitute the hardware requirements for the experimental setup. In our SPCRC lab, Ettus USRP N210 was used. The N210 hardware is ideally suited for applications requiring high RF performance and great bandwidth. Its architecture includes a Xilinx Spartan 3A-DSP 3400 FPGA, 100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit Ethernet connectivity to stream data to and from host processors. The RF front end of the USRP consists of a daughter board which act as a
transceiver and antennas used to receive the RF signals. Here WBX daughtercard and VERT900 antennas were used. The WBX provides 40 MHz of bandwidth capability and is ideal for applications requiring access to a number of different bands within its range: 50 MHz to 2.2 GHz. VERT900 antennas operate at 824-960 MHz and 1710-1990 MHz bands. The PC used in the experiment was Lenovo ThinkCare with 64 bit processor and 2 GB RAM. The software requirements for the setup require GNU Radio which is an open source software.

Note: Though the VERT900 antenna is said to operate in 824-960MHz and 1710-1990 MHz bands, yet during the experiment, reliable data transmission was observed using the VERT900 antenna for the complete band of 824-1990MHZ.

Fig. 1. The path loss experimental setup at SPCRC lab in IIIT Hyderabad

B. Deployment of the Setup

For the deployment of hardware, as shown in Fig. 1, two USRP N210 were connected to the PC through a LAN switch. The LAN switch was connected to the gigabit Ethernet port of the PC. All the connections are made using the Cat 5e cables. The WBX daughter board was used with the USRPs. VERT900 antennas were connected to the RF1 and RF2 of the USRPs. One of the USRP was used as transmitter and the other as a receiver. Both USRP was at a distance of about 2m from each other. The transmitter was placed 1.5m above the floor and the receiver was placed 1m above the floor. There was no line of sight (LOS) between the transmitter and receiver and they both were separated by two wooden slabs in the lab. The USRPs were interfaced with the PC using the GNU Radio software. The noise floor in the receiver USRP was measured to be -90 dB.

There are two basic experiments conducted to show the utility of SDR for combating the path loss. In the first experiment, the effect of path loss on the received power or received signal strength (RSS) with respect to operating frequency was studied. For the experiment, an unmodulated sinusoidal signal of frequency 1 KHz was transmitted from transmitter to receiver. The RSS was measured for four operating frequencies: 830MHz, 1.2GHz, 1.6GHz and 1.9GHz. The ITU indoor propagation model was used to analyze the path loss and interpolate values of RSS for other operating frequencies. The ITU indoor model is given by

\[ \alpha = \beta(t) \]

where \( \alpha = P_t - N \log d + 28 \).

\[ P_r(t) = \alpha(t) - 20 \log f \]

In the experiment, the transmitted power and the distance were kept constant and therefore equation (3) can be represented as:

\[ P_r = \alpha - 20 \log f \]

where \( \alpha = P_t - N \log d + 28 \). Though every factor is kept constant, there can be slight variation in value of the PL with time due to changing environmental conditions which result in minor variation in RSS. Hence equation (3) can be represented as a function of time:

\[ P_r(t) = \alpha(t) - 20 \log f \]

In the second experiment, the dynamic variation of RSS, of an OFDM system, with changing operating frequency is analyzed. The analysis is carried out according to the LTE standards. For transmission, random bits were generated and were modulated using 16-QAM. The modulated bits were then mapped on to the OFDM symbols. An FFT size of 512 was used for OFDM, out of which 200 tones were occupied. A cyclic prefix of size 128 was used. The OFDM symbols were then transmitted through the USRP. At receiver the reverse procedure was employed to recover the transmitted bits. In the experiment, the operating frequency of both the transmitter and receiver was kept as a variable, i.e., it can be varied on-fly between 830MHz and 1.9GHz using the variable slider. Also, the transmitter RF chain gain was set as a variable which can be varied from 0 dB to 40 dB using a slider. The receiver RF chain gain was constant at 10dB.

C. Observations

The RSS at frequencies of 830MHz, 1.2GHz, 1.6GHz and 1.9GHz for four sets measured at regular interval of 30 minutes is tabulated in table I. For each set, in order to compensate for possible variation due to changing environment, the \( \alpha_{avg} \) is
obtained by taking the average value of $\alpha$ obtained from the four measured RSS using (3).

### TABLE I

| Frequency | 830MHz | 1.2GHz | 1.6GHz | 1.9GHz | $\alpha_{avg}$ |
|-----------|--------|--------|--------|--------|----------------|
| Set1      | -43.09 | -53.53 | -60.85 | -63.15 | 126.59         |
| Set2      | -43.09 | -55.92 | -61.84 | -62.50 | 126.20         |
| Set3      | -41.44 | -56.57 | -62.14 | -62.82 | 126.03         |
| Set4      | -42.70 | -56.57 | -61.84 | -62.10 | 126.23         |

The plot, using MATLAB, for RSS for the four sets in the frequency range of 830 MHz to 1.9GHz obtained using the interpolation is shown in fig.2. It can be observed as we go higher in the operating frequency, more is the attenuation suffered by the transmitted signal and hence lesser is the RSS.

![Received signal strength w.r.t. operating frequency](image)

**III. SYSTEM DEPLOYMENT**

### A. SDR in Future Cellular Networks

Extensive research is being done in small cells deploying millimeter-wave (mmW) for communication in future cellular networks. The small cell systems are considered suitable due to low transmit power, short distances and low mobility [4], [7]. The use of large chunks of underutilized spectrum in the mmW bands has gained significant interest in realizing the aforementioned 5G vision and requirements. Specifically [4] considers the 28- and 38-GHz bands to be initial frequencies where mmW cellular systems could operate. In many dense urban areas, cell sizes are now often less than 100-200 m in radius, possibly within the range of mmW signals based on measurements in [4].

For mmW, path loss plays a significant role in degrading the link quality due to higher attenuation. In a scenario, where in the small cell the operating environment is changing dynamically, sudden degradation of operating conditions or arrival of obstruction between transmitter and receiver may result in link failure (fig.6). In such a scenario, one solution could be dynamically allocating spectrum resource at a lower operating frequency for a link suffering from high path loss. As observed from the experiment carried out in the previous section, as the operating frequency is decreased, the RSS increases. This is quite helpful when the RSS is below the noise floor due to high attenuation at higher operating frequency. One technology which will complement the deployment of SDR in future cellular network is full-duplex communication [8], [9]. The full-duplex communication will allow same spectrum resource for both uplink and downlink operation. This allows simultaneous change to the same operating frequency for both uplink and downlink [9].

The change in the operating frequency of the communication system is dependent upon metrics which can be decided by the network operators. For example, the decrease in block error rate (BLER) below the desired level or the decrease of RSS below the noise floor can trigger the change in the operating frequency to lower values. Also, as discussed in the previous section, the RF chain gain of both transmitter and receiver can also be dynamically changed to maintain the RSS.
Fig. 4. FFT plot for received signal strength in pass band for operating frequency of a) 1.9GHz b)1.6GHz c)1.2GHz d) 830MHz

Fig. 5. FFT plot for received signal strength in pass band at 1.9GHz for transmitter RF chain gain of a) 13dB b)26dB c)40dB

Note: These methods include some challenges and are considered only when current methods of adaptive MCS and PC fails to tackle the problem of path loss at higher operating frequencies.

Fig. 6. Drop in received signal strength due to the obstruction between eNB and UE

B. Challenges in Deployment of the System

There are many challenges when deploying SDR in cellular networks. Some of the important challenges include: 1) As the operating frequency is decreased to lower range, there will be increased requirement of bandwidth at lower frequency. Hence it should be ensured that the operating frequency is decreased only when there is availability of enough spectrum resource at lower frequency. 2) The deployment of SDR requires the use of programmable architecture at the eNB and UE front end along with multi-band reconfigurable antennas. This will allow dynamic shift in operating frequency. 3) Use of full-duplex in cellular network will increase the computational complexity of the communication system [8].

IV. CONCLUSION

In this paper, an analysis was carried out for a method to mitigate path loss through the dynamic spectrum access (DSA) method. The method analyzed included dynamical allocation spectrum at a lower frequency for a link suffering from high path loss. For the analysis, a wireless link was set up using Universal Software Radio Peripherals (USRPs). The RSS is observed to increase by dynamically changing the operating frequency from 1.9 GHz to 830 MHz. Also the RSS was observed to increase for an increase in transmitter RF chain gain. Finally the utility of software defined radio (SDR) in the RF front end, to combat the path loss in the future cellular networks, was studied.

REFERENCES

[1] Rappaport, Theodore S. Wireless communications: principles and practice. Vol. 2. New Jersey: prentice hall PTR, 1996.
[2] Simonsson, Arne, and Anders Furusk. “Uplink power control in LTE overview and performance, subtitle: principles and benefits of utilizing rather than compensating for SINR variations.” In Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th, pp. 1-5. IEEE, 2008.
[3] Xu, Xiang, Gledi Kutrolli, and Rudolf Mathar. "Dynamic Downlink Power Control Strategies for LTE Femtocells." In 2013 Seventh International Conference on Next Generation Mobile Apps, Services and Technologies. 2013.

[4] Rappaport, Theodore S., Shu Sun, Rimma Mayzus, Hang Zhao, Yaniv Azar, Kevin Wang, George N. Wong, Jocelyn K. Schulz, Mathew Samimi, and Felix Gutierrez. "Millimeter wave mobile communications for 5G cellular: It will work!.” Access, IEEE 1 (2013): 335-349.

[5] Christodoulou, Christos G., Youssef Tawk, Steven Lane, and Scott R. Erwin. "Reconfigurable antennas for wireless and space applications.” Proceedings of the IEEE 100, no. 7 (2012): 2250-2261.

[6] Propagation data and prediction methods for the planning of indoor radio communication systems and the radio local area networks in the frequency range 900 MHz to 100 GHz, ITU-R Recommendations, Geneva, 2001.

[7] Jungnickel, Volker, Konstantinos Manolakis, Wolfgang Zirwas, Berthold Panzner, Volker Braun, Moritz Lossow, Mikael Sternad, and T. Svensson. "The role of small cells, coordinated multipoint, and massive MIMO in 5G.” Communications Magazine, IEEE 52, no. 5 (2014): 44-51.

[8] Bharadia, Dinesh, Emily McMilin, and Sachin Katti. "Full duplex radios.” In Proceedings of the ACM SIGCOMM 2013 conference on SIGCOMM, pp. 375-386. ACM, 2013

[9] Pradhan, Chandan, Kunal Sankhe, Sumit Kumar, and Garimella Rama Murthy. "Full-Duplex eNodeB and UE Design for 5G Networks.” Accepted in Wireless Telecommunications Symposium (WTS), 2015: Available: arxiv.org/abs/1506.02132.