Initial Draft of SDR, SDN, and Cognitive Radio Literature

J.D. McCormack

I. RTL-SDR

The RTL-SDR is a recent tool discovered by the DIY and hacking community. Its original purpose is to be used as a digital TV tuner. However, it was discovered that this system could also be used to general SDR purposes. There is now a large community dedicated to using this tiny SDR to recieve various different signals. Prior to the creation of the open source drivers for the RTL-SDR, the most popular devices for SDR came from USRP. The USRP devices are fantastic products, but cost at least $1,000 and can cost quite a bit more with additional features. The RTL-SDR is based on rhe Realtek RTL2832U chip. This device can often be purchased for between $20 and $30 [1]. The range for the RTL-SDR is typically 64 MHz to 1700 MHz, however this varies depending on which tuner the manufacturer paired with it. The authors in [1] paired the RTL-SDR with a mixer in order to lower the range all the way to DC. For this, they used the NE6062AN chip.

Starting with Release 2013b, MATLAB/Simulink now have a support package that targets RTL-SDR devices. In Simulink, the package contains a single block called "RTL-SDR Receiver." This block allows the user to tune the center frequency, change the tuner gain, set the sampling rate, and alter the frequency correction factor. The block can then output the complex envelope (IQ) of the recieved signal in both floating point and integer formats[2]. Due to the open nature and low cost of the RTL-SDR, the authors in [3] propose using this as a tool set for teaching DSP and Communications principles to students.

When the cost of the system is far less than that of a textbook, it is easy to see why this could become a valuable learning tool for many students. UC Berkley has already begun to use the RTL-SDR as one of the project assignments in their digital signal processing course. There have been efforts to use the RTL-SDR with the popular Raspberry Pi computing platform. However, at least with the B+ model there is not enough power available to process the signal. Instead, it has to be used as a TCP server that is then able to forward the data on to a more powerful computer[4]. Currently, it does not appear as though anyone hast tested this with the Raspberry Pi 2 microcomputer. Other work has been done to estimate the cost savings of using a USRP in conjunction with several RTL-SDRs to replace existing DSP lab infrastructure [5].

The most unfortunate downside to using the RTL-SDR is that it is unable to transmist. However, researchers in [6] proposed a system in which a USRP SDR is used as a master device that broadcasts out to a series of slave nodes that can only listen for information. In their system they used a tool called GStreamer to pass video data into GNURadio. This information was then broadcast to multiple computers in a room running an RTL-SDR with GNURadio. The nodes were all able to view the video stream in near real time.

It is interesting to note that an IEEE search for the RTL-SDR turned up 6 results, but a search on Funcube Dongle returned 0 results. These devices were in competition with one another for awhile, but the Funcubes prices continues to rise as the RTL-SDR's continues to drop. The Funcube has a larger range than the RTL-SDR but it seems the cost is still the key factor.

II. GNU Radio and Mesh Networks

In [7] and [8] the authors use GNU Radio as a way to verify the succesful use of algorithms for mesh networking.However, they do not specify that they are using SDR's and it seems like they use GNU Radio for simulation. GNU Radio has also been used with the USRP to create a device capable of communicating with both Bluetooth and WiFi devices. However, this does not create a mesh network or attempt to bridge communication between the two protocols. However, a significant amount of information about communicating with each type of network is presented [9]. This also presents the concept of Police Nodes which monitor traffic in an attempt to block out improper use of the spectrum.

Research has been done in using the GNURadio toolset along with the USRP to test Mesh Network routing protocols. One test used varied data transmission rates to exploit opportunities in physically close proximity Nodes [10]. The GNU Radio toolset was also used to test using cognitive radio within a mesh network. USRPs were used as nodes trying to communicate on a "shared" frequency. A separate USRP was used to replicate a primary user, or one that had a license to operate in that spectrum. Whenever the primary user began to transmit in the spectrum, the other nodes would use reinforcement learning to move to an unoccupied channel automatically and continue transmitting [11]. A similar test bed is also presented in [12].

In [13] researchers at UCSB investigated using an SDR with GNURadio to improve upon the needs of rural networks. The topic was found while search for mesh networks but seems to be mostly focused on non-mesh applications. They created the solution WhiteRate which allows for the changing of the PHY layer without changing any other components.

In [14] the authors utilize GNU Radio to implemenet a PHY layer that is able to broadcast and recieve on several channels simultaneously. The paper tests using 2 USRP boards and also simulates a larger scale.

The CONFINE platform uses Batman-adv as the routing protocol for their mesh network testbed. However, this testbed does not utilize GNU Radio or any cognitive radio tool sets. [15]

III. Gamification

There are a number of TV white spaces in rural communities. That is, empty spaces left for the UHF TV spectrum that dont actually have anything broadcasting on them. The team in [16] created a Raspberry Pi system that is able to scan for these blank spaces, and geotag them. Using an RF Explorer and GPS, the system is able o scan for open bandwidth and then tag the location. The authors mention wanting to put these units in the hands of as many people as possible to create a distributed measuring system.

The authors in [17] present a game called Spectrum Wars. This game involves two teams competing to send data in a crowded environment. Players can vary Frequency, Bandwidth, and Gain of the signal. The first player to successfully transmit the signal wins the points. The author's present an earlier version of their work in [18].

IV. Cognitive Radio based Mesh Networks

The authors in [19] present an overview of several cognitivate radio transmission strategies and discuss the pros and cons of each method. In Mesh networks, the MAC protocols are essential to prevent data "Deafness" where two nodes try to transmit at the same time on different frequencies, preventing communication. There are a few different standards for this discussed in [20].

It is reported that video on demand services make up about 27% of internet traffic. Therefore, for any Mesh Network to be successful, it would have to be able to handle this type of traffic. The author's in [21] present a method for routing video data over multiple paths of the mesh to the user to increase effectiveness of data transmission. An improvement upon this algorithm is presented in [22].

V. Low Cost SDR and Cognitive Radio Platforms

The Communications Research Center in Ottawa, Canada has created a cognitive radio platform that they have nicknamed CORAL. This is a custom created platform that is capable of performing cognitive radio type tasks at the 2.4GHz and 5GHz license exempt bands.[23]. Further research done in [24] introduces a tool called CogFrame. This platform uses traditional computers and wifi cards to create a congitive mesh network capable of running tests. They compare the tool to a test bed made of USRP's as well as pure simulations and found it to outperform the simulation and be on par with the USRPs. The authors in [25] provide a wonderful overview of everything one could want to know about cognitive radio. Including some major platforms that exist such as WARP from Rice University, BEE From Berkley, and CORAL from the communications research center in Canada. They also present their own platform based of the BeagleBoard. This article would be great for anyone just starting out to read. A group from Germany has created a cognitive radio based wireless microphone system [26].

VI. Cognitive Radio and Robots

The authors in [27] discuss using a distributed group of spectrum sensing tools with a UAV to find a target using RF localization. They use a technique called compressive spectrum sensing to make the task less computationally intensive. They then have a group of sensors attempt to find the source of the RF signal and then work to find it using localization techniques. The group performed MATLAB testing. They also ran some brief field tests without a UAV using GNURadio and USRP SDRs. The authors in [28] discuss the benefits of using a cognitive network with a UAV. The discuss many of the benefits that the technology would bring including security.

VII. Cognitive Radio Standards

In [29] the authors discuss a MIMO scheme for transmission of packets using cognitive radio. The system is then simulated and results are prsented. In [30] the authors discuss using a USRP device with GNURadio to test out several routing algorithms.

There does not appear to be any particular "standard" cognitive radio protocl yet. Various research institutions are all working on different protocols with each having various strengths and weaknesses. PHY Layer protocols usually focus on the actual sensing and changing of of operating frequency [31]. Upper layer protocols may focus on creating a more roboust way to deal with these changing features by replacing existing protocols like TCP [32] [33]. Many of these protocols assume point to point communication, but newer protocols are beginning to address mesh network architectures [34].

VIII. Mesh Networks and Robots

Researchers have begun to examine the problems of using UAVs to communicate on a mesh network. Part of the problem lies in the fact that communicating with a moving node can be difficult. One way to combat this is to use multiple nodes on the UAV that exploit the spatial and temporal diversity of the wireless channel.They ran their tests on a 110" wingspan UAV with 4 mesh nodes on it. They used the 802.11 adhoc mode for their network. [35] The same team presented a test of creating a network with a UAV using the Load, Carry, and Deliver paradigm. This UAV would "pick" up data from one node, fly to the next node, and then drop it off. [36]

Work present in [37] demonstrates a great overview of the current "state of the art" in regards to UAV based networking. The author discusses the main routing formats and many of the challenges that go along with UAV network. This should be seen as a good starting point for people first learning about this topic. In [38] the author's discuss the concept of a cloud computing and software, platform, and infrastructure as a service environment. They discuss abstracting out significant parts of the UAV system, such as navigation, so that they can be done in the cloud. This would allow for most of the computation to be done in a single format off board, allowing for easier integrationg of heterogeneous swarms of robotics.

IX. Signal Processing Techniques

In [39] H.T. Kung presents partial compressive sensing, a signal processing technique which reduced the frequency needed to sample a signal. This conecpt is presented again by this research group in another paper discussing using it for communicating within a mesh network.

X. Applications of Cognitive Radio

The authors in [40] present a cognitive radio based wireless cabin management system for airplanes. The team created an actual system based off of an FPGA and a transciever to demonstrate the basic functionality needed by an airplane cabin management system. Their paper also presents a detailed testing plan and the results of the test.

XI. Security in SDR and CR Networks

A major portion of our work revolves around what we believe is a new concept in SDR security. SDR and cognitive radio devices suffer from traditional security flaws of wireless transmission in addition to many of their own. The authors in [**?**] present their idea of securing an SDR transmission using a Gigabit Ethernet AES (Advanced Encryption Standard) Encryption Engine. This is implemented on an FPGA. AES is a standard means of encryption that uses cipher keys to hide data. In [**?**] the author's discuss concerns in validating whether an SDR system is secure or not. They discuss separating the certification into two separate blocks so the hardware and software can be evaluated separately. Peter Hillmann and Bjorn Stelte have presented a unique way to share cryptographic keys over SDR systems [**?**]. Their system uses the Secure Communications Interoperability Protocols (SCIP). In NATO's current configuration, each user has a public and private cryptographic key component. In the proposed system, each SDR has a minimum of two available channels, ”x” and ”y”, where one is used for local operations such as voice and data and the other is used to relay communications data to and from other units. A secure communication channel is established by borrowing time and bandwidth on channel ”y” for a certificate based asymmetric key negotiation with a lead radio. Once the secure link is established, the symmetric net key is transmitted to the new users. This will then allow for the new radios to communicate fully on ”x” and ”y”. The paper continues to discuss numerous methods employed for ensuring the secure transfer of keys.

References

[1] M. Sruthi, M. Abirami, A. Manikkoth, R. Gandhiraj, and K. Soman, “Low cost digital transceiver design for software defined radio using rtl-sdr,” in *Automation, Computing, Communication, Control and Compressed Sensing (iMac4s), 2013 International Multi-Conference on*, March 2013, pp. 852–855.

[2] A. Sergienko, “Software-defined radio in matlab simulink with rtl-sdr hardware,” in *Computer Technologies in Physical and Engineering Applications (ICCTPEA), 2014 International Conference on*, June 2014, pp. 160–161.

[3] B. Uengtrakul and D. Bunnjaweht, “A cost efficient software defined radio receiver for demonstrating concepts in communication and signal processing using python and rtl-sdr,” in *Digital Information and Communication Technology and it's Applications (DICTAP), 2014 Fourth International Conference on*, May 2014, pp. 394–399.

[4] R. Danymol, T. Ajitha, and R. Gandhiraj, “Real-time communication system design using rtl-sdr and raspberry pi,” in *Advanced Computing and Communication Systems (ICACCS), 2013 International Conference on*, Dec 2013, pp. 1–5.

[5] M. Abirami, V. Hariharan, M. Sruthi, R. Gandhiraj, and K. Soman, “Exploiting gnu radio and usrp: An economical test bed for real time communication systems,” in *Computing, Communications and Networking Technologies (ICCCNT),2013 Fourth International Conference on*, July 2013, pp. 1–6.

[6] S. Nimmi, V. Saranya, G. Theertha Das, and R. Gandhiraj, “Real-time video streaming using gstreamer in gnu radio platform,” in *Green Computing Communication and Electrical Engineering (ICGCCEE), 2014 International Conference on*, March 2014, pp. 1–6.

[7] R. Alimi, L. Li, R. Ramjee, H. Viswanathan, and Y. Yang, “ipack: in-network packet mixing for high throughput wireless mesh networks,” in *INFOCOM 2008. The 27th Conference on Computer Communications. IEEE*, April 2008, pp. –.

[8] L. Li, R. Alimi, R. Ramjee, H. Viswanathan, and Y. Yang, “munet: Harnessing multiuser capacity in wireless mesh networks,” in *INFOCOM 2009, IEEE*, April 2009, pp. 2876–2880.

[9] R. Miller, W. Xu, P. Kamat, and W. Trappe, “Service discovery and device identification in cognitive radio networks,” in *Sensor, Mesh and Ad Hoc Communications and Networks, 2007. SECON '07. 4th Annual IEEE Communications Society Conference on*, June 2007, pp. 670–677.

[10] C. Yu, T. Shen, K. Shin, J.-Y. Lee, and Y.-J. Suh, “Multihop transmission opportunity in wireless multihop networks,” in *INFOCOM, 2010 Proceedings IEEE*, March 2010, pp. 1–9.

[11] A. Syed, K. Yau, H. Mohamad, N. Ramli, and W. Hashim, “Channel selection in multi-hop cognitive radio network using reinforcement learning: An experimental study,” in *Frontiers of Communications, Networks and Applications (ICFCNA 2014 - Malaysia), International Conference on*, Nov 2014, pp. 1–6.

[12] P. Nagaraju, L. Ding, T. Melodia, S. Batalama, D. Pados, and J. Matyjas, “Implementation of a distributed joint routing and dynamic spectrum allocation algorithm on usrp2 radios,” in *Sensor Mesh and Ad Hoc Communications and Networks (SECON), 2010 7th Annual IEEE Communications Society Conference on*, June 2010, pp. 1–2.

[13] V. Pejovic and E. Belding, “A context-aware approach to wireless transmission adaptation,” in *Sensor, Mesh and Ad Hoc Communications and Networks (SECON), 2011 8th Annual IEEE Communications Society Conference on*, June 2011, pp. 592–600.

[14] E. Chai and K. Shin, “M-polar: Channel allocation for throughput maximization in sdr mesh networks,” in *INFOCOM, 2010 Proceedings IEEE*, March 2010, pp. 1–9.

[15] (2015) Confine project. [Online]. Available: http://confine-project.eu/

[16] A. Arcia-Moret, E. Pietrosemoli, and M. Zennaro, “Whisppi: White space monitoring with raspberry pi,” in *Global Information Infrastructure Symposium, 2013*, Oct 2013, pp. 1–6.

[17] P. Sutton and L. Doyle, “The gamification of dynamic spectrum access and cognitive radio,” in *Global Engineering Education Conference (EDUCON), 2014 IEEE*, April 2014, pp. 107–113.

[18] ——, “Spectrum wars gamification of dynamic spectrum access and cognitive radio,” in *Dynamic Spectrum Access Networks (DYSPAN), 2014 IEEE International Symposium on*, April 2014, pp. 370–371.

[19] H. M. Almasaeid and A. Kamal, “Receiver-based channel allocation for wireless cognitive radio mesh networks,” in *New Frontiers in Dynamic Spectrum, 2010 IEEE Symposium on*, April 2010, pp. 1–10.

[20] Y. Guo, T. Zhao, J. Zhou, Y. Ge, and Y. Sun, “Research on multi-channel mac protocol in cognitive mesh network,” in *Computer and Information Technology (CIT), 2012 IEEE 12th International Conference on*, Oct 2012, pp. 833–837.

[21] Y. Ding and L. Xiao, “Video on-demand streaming in cognitive wireless mesh networks,” *Mobile Computing, IEEE Transactions on*, vol. 12, no. 3, pp. 412–423, March 2013.

[22] Y. Xu, D. Hu, and S. Mao, “Relay-assisted multiuser video streaming in cognitive radio networks,” *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 24, no. 10, pp. 1758–1770, Oct 2014.

[23] J. Sydor, A. Ghasemi, S. Palaninathan, and W. Wong, “Cognitive, radio-aware, low-cost (coral) research platform,” in *New Frontiers in Dynamic Spectrum, 2010 IEEE Symposium on*, April 2010, pp. 1–2.

[24] A. Saeed, M. Ibrahim, K. Harras, and M. Youssef, “A low-cost large-scale framework for cognitive radio routing protocols testing,” in *Communications (ICC), 2013 IEEE International Conference on*, June 2013, pp. 2900–2904.

[25] A. Young and C. Bostian, “Simple and low-cost platforms for cognitive radio experiments [application notes],” *Microwave Magazine, IEEE*, vol. 14, no. 1, pp. 146–157, Jan 2013.

[26] S. Schroeter, L. Zimmermann, O. Schwender, G. Fischer, and A. Koelpin, “Demonstrator of a scanning receiver subsystem for cognitive professional wireless microphone systems,” in *Telecom World (ITU WT), 2011 Technical Symposium at ITU*, Oct 2011, pp. 193–198.

[27] H.-C. Chen, H. Kung, D. Vlah, D. Hague, M. Muccio, and B. Poland, “Collaborative compressive spectrum sensing in a uav environment,” in *MILITARY COMMUNICATIONS CONFERENCE, 2011 - MILCOM 2011*, Nov 2011, pp. 142–148.

[28] H. Reyes, N. Gellerman, and N. Kaabouch, “A cognitive radio system for improving the reliability and security of uas/uav networks,” in *Aerospace Conference, 2015 IEEE*, March 2015, pp. 1–9.

[29] P. Kumar, S. Malarvizhi, and M. Hariprasath, “Low cost reception scheme for mimo cognitive radio,” in *Electronics and Communication Systems (ICECS), 2015 2nd International Conference on*, Feb 2015, pp. 43–46.

[30] A. Mate, K.-H. Lee, and I.-T. Lu, “Spectrum sensing based on time covariance matrix using gnu radio and usrp for cognitive radio,” in *Systems, Applications and Technology Conference (LISAT), 2011 IEEE Long Island*, May 2011, pp. 1–6.

[31] L. Sun, W. Zheng, N. Rawat, V. Sawant, and D. Koutsonikolas, “Performance comparison of routing protocols for cognitive radio networks,” in *Modeling, Analysis Simulation of Computer and Telecommunication Systems (MASCOTS), 2013 IEEE 21st International Symposium on*, Aug 2013, pp. 454–464.

[32] K. Chowdhury, M. Di Felice, and I. Akyildiz, “Tp-crahn: a transport protocol for cognitive radio ad-hoc networks,” in *INFOCOM 2009, IEEE*, April 2009, pp. 2482–2490.

[33] A. Al-Ali and K. Chowdhury, “Tfrc-cr: An equation-based transport protocol for cognitive radio networks,” in *Computing, Networking and Communications (ICNC), 2013 International Conference on*, Jan 2013, pp. 143–148.

[34] K. Chowdhury and I. Akyildiz, “Crp: A routing protocol for cognitive radio ad hoc networks,” *Selected Areas in Communications, IEEE Journal on*, vol. 29, no. 4, pp. 794–804, April 2011.

[35] H. Kung, C.-K. Lin, T.-H. Lin, S. Tarsa, and D. Vlah, “Measuring diversity on a low-altitude uav in a ground-to-air wireless 802.11 mesh network,” in *GLOBECOM Workshops (GC Wkshps), 2010 IEEE*, Dec 2010, pp. 1799–1804.

[36] C.-M. Cheng, P.-H. Hsiao, H. Kung, and D. Vlah, “Maximizing throughput of uav-relaying networks with the load-carry-and-deliver paradigm,” in *Wireless Communications and Networking Conference, 2007.WCNC 2007. IEEE*, March 2007, pp. 4417–4424.

[37] O. Sahingoz, “Mobile networking with uavs: Opportunities and challenges,” in *Unmanned Aircraft Systems (ICUAS), 2013 International Conference on*, May 2013, pp. 933–941.

[38] S. Mahmoud and N. Mohamed, “Collaborative uavs cloud,” in *Unmanned Aircraft Systems (ICUAS), 2014 International Conference on*, May 2014, pp. 365–373.

[39] H. Kung and S. Tarsa, “Partitioned compressive sensing with neighbor-weighted decoding,” in *MILITARY COMMUNICATIONS CONFERENCE, 2011 - MILCOM 2011*, Nov 2011, pp. 149–156.

[40] C. Heller and C. Blumm, “A cognitive radio enabled wireless aircraft cabin management system,” in *Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd*, Oct 2013, pp. 3A4–1–3A4–13.