HOW SHOULD RADIOS THINK? START WITH SELF-PRESERVATION

Abadie, A. * **and Mehrishi, V.**
George Mason University, Volgenau School of Engineering

*Corresponding author: aabadie@gmu.edu

ABSTRACT
As various communication technologies have taken shape to improve our daily lives, one can begin to ponder if such advancements could also be leveraged to work towards a more sustainable communications infrastructure. Such an endeavor can be achieved through a number of existing advancements, such as simplifying the physical aspect of the architecture or reducing the power consumption of the separate devices. A key enabler of such efforts is the development and maturity of software defined radio technologies. However, these existing technologies alone aren't enough… there needs to be a more creative implementation of them. One possibility is cognitive radio; an intelligent framework incorporated to maximize the flexibility inherent in software defined radio – essentially enabling it to "think." Yet, such abilities can be broadly defined; do we need the complexity of human reason or the simplicity of animal instinct? To facilitate a more thorough discussion, this paper will start with the latter and propose a sense of caution in the device. By incorporating a cognition cycle similar to risk management, the radio can alter its configuration in a manner consistent with self-preservation and in turn fulfill a more sustainable operation.

Keywords: *communication technology, sustainable communication, cognitive radio*

1 BACKGROUND / TECHNOLOGY OVERVIEW

Cognitive radio is an evolutionary technology borne of software defined radio advancements. Simply stated, cognitive radio is the incorporation of a cognition cycle to maximize the capabilities already resident in the software defined radio. And it is how this intelligent framework is designed, the purpose it is given, that offers great potential (and the opportunity for creativity). To explain further, the following section will provide an overview of software defined radio and an explanation of the genesis for cognitive radio. It will conclude with a discussion of current research and an expression of how a more novel approach in risk management is worthy of exploration.

1.1 Software Defined Radio

Any generic communications system performs a series of functions in order to transmit a signal to a distant receiver; source encoding, multiplexing, channel coding, modulation, frequency mixing, amplification, and then transmission. Traditionally, each of these functions has been performed by a single hardware component of the communications system. Each component was crafted with the physical properties to ensure a specific set of performance parameters required by the system design. For example, if designed for a specific range of frequencies, the antenna and power source would be matched according to the properties inherent to that frequency range. If an operational requirement to transmit at a different frequency emerged, the antenna and amplifier would have to be changed... and possibly other components as well. Due to this reliance on non-fungible hardware components, communication systems lacked any inherent flexibility.

Software defined radio (SDR) technologies emerged in the early 1990s [1] [2] seeking to provide flexibility to this general architecture by offering an alternative approach. SDR proposed that the hardware component could be replaced by a software defined component to gain dynamic configuration. Therefore, implementations of SDR are best characterized by the SDR Forum's 5-tier classification scheme [3]. The SDR Forum's definition begins with Tier 0 – termed a 'hardware radio' and defined by fixed functionality (each component has specific performance parameters). This is our accepted legacy model. Tier 1 is termed 'software controlled radio' and defined by offering certain parameters that can be changed via software, but the signal path remains fixed. Tier 2 is termed 'SDR' and defined by the ability for a signal path to be reconfigured in software without hardware modifications. Tier 3 is termed the 'ideal software radio' and represented by more of the signal path resident in the digital domain (i.e., few hardware components). Finally, Tier 4 is termed the 'ultimate software radio' and theorizes that the entire system exists in the digital domain with analogue-to-digital conversion (ADC) occurring at the antenna. Theoretically, the ultimate software radio could provide complete flexibility to a user's dynamic operational requirements by ensuring no single component was fixed in its capability. A high-level abstraction of this tiered description is in Figure 1.

Whereas hardware platforms are essentially fixed, the software approach introduces the greater likelihood that a device can be fungible and therefore hold a longer lifespan. The flexibility offered by software solutions extends to cost figures, form factor, and time-to-market considerations. Compactness and power efficiency significantly enhance the possibilities of more widespread use while software components ease both the initial manufacture and subsequent upgrades of the radio. SDR is not just a better product; it is a better business plan. Considering the growth of mobile devices – key examples of the realization of SDR advancements, the technology is poised to become the accepted standard for digital communications, saturate the market, and eventually become ubiquitous. Yet, the true promise of SDR will not be realized until it includes an intelligent framework and has the ability to make these adjustments autonomously.

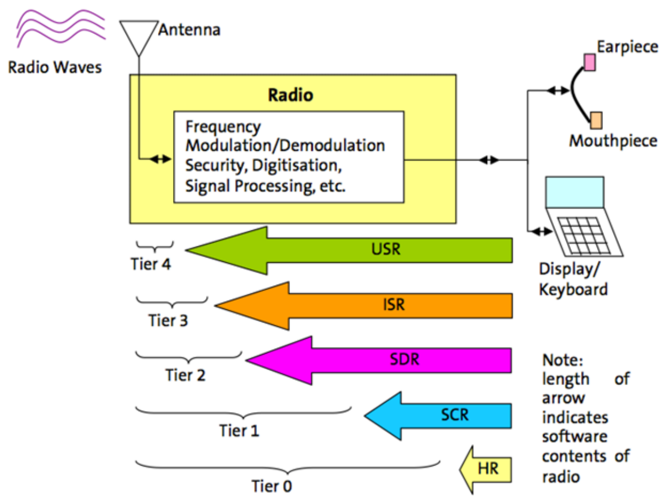

Figure 1: High-level abstraction of the SDR Forum tier definitions [4]

1.2 Radio as an intelligent device

In proposing his original concept of cognitive radios [5][6], Joseph Mitola offered a cognition cycle providing insight to the sequencing necessary for the radio to accurately process external data and enact an acceptable change in state. The holistic view of "Observe-Orient-(Plan-/Learn/-Decide)-Act" demonstrates the inherent flexibility required in the radio's processing. This is portrayed in Figure 2 below. It should be noted that all six behaviors are not necessary for the cognitive radio to adjust its operational parameters based on its external environment, as this sequence can be abbreviated to accommodate priority. Planning and learning may be omitted and in extreme cases, even decision will not occur.

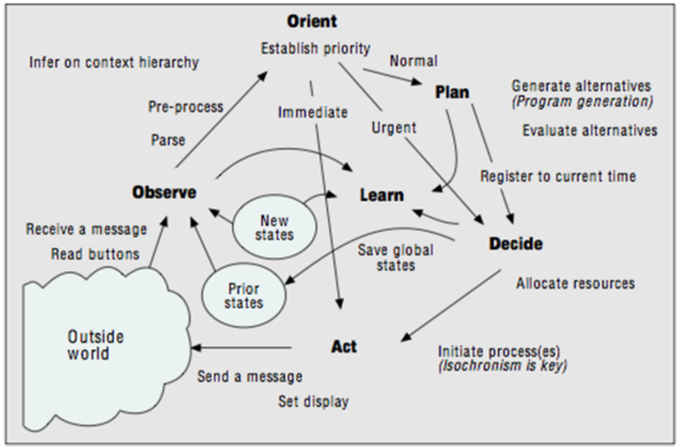

Figure 2: The cognition cycle [5]

The Observe capability of this cycle holds the greatest influence and in doing so adds tremendous complexity. Sensing spectrum, recognition of modulation, capture of signal encoding, or detection of cryptography are technically challenging endeavors. They will magnify the computation requirements of the radio's processor and in turn potentially impact power consumption. However, the data they deliver to the cognition cycle is invaluable. The software defined radio offers advancements for a number of formerly hardware-based components. For each component represented by software, there is a newfound level of flexibility in the radio's operation. But for this flexibility to be exploited, the cognitive element needs to sense the corresponding data points (spectrum, modulation, encoding, etc.) from its current environment. The example proposed later in this paper will call for a "weather service" as the external information source to initiate the radio's cognition cycle.

The Orient portion of the cognition cycle speaks to prioritization, and therefore a decision to abbreviate the cycle if required. This would be the optimum placement of a policy engine, ensuring that a policy screen occurs prior to a potential radio decision to act and change state (i.e. immediate priority). From a security standpoint, the policy engine would offer a sense of right versus wrong to the cognitive cycle. In order to provide the minimum-security parameters, future implementations of cognitive radio must require a policy determination by the radio prior to a change in state. In the coming example, the concept of priority will highlight this stage.

The Decide portion of the cognition cycle provides the final determination by the radio to change its current operating state to a different operating state to improve performance. As with any decision-making process, there is generally a direct correlation between the quantity of information available and the quality of the decision. Both the plan and learn portions of the cognition cycle yield tremendous benefits to the Decide phase in their contribution of additional information for consideration. The cognitive radio can formulate alternatives regarding how the performance parameters can be changed to optimize the communications link and then compare those alternatives to previous states (for that geographic location) to better reason which alternative is best. This paper will discuss four cognition cycles; each deepening the level of decision the radio can perform to mitigate rain in a more efficient manner.

Mitola's cognition cycle allows for the activities to be distinct but permits priority to abbreviate the overall process and omit them. However, the proper attention should be given to the potential benefits found in a formal recognition in the activities of planning and learning. For the radio to truly deliver cognitive capabilities, they are required. Using a priori knowledge of known threats, general security principles, or basic thresholds for change tolerance, the cognitive radio can enhance its understanding of the alternatives identified and temper its performance optimization with respect to the level of risk incurred. Considering tropical environments, the radio may be programmed with an understanding of when the monsoon season occurs so it can plan for the expected rainfall.

1.3 Current work and novelty of this approach

Aside from the initial foundation laid by Mitola in [5] and [6], the research community did not completely embrace the cognitive radio concept until Haykin delivered his seminal paper [8] suggesting its potential for opportunistic spectrum access. Based on the criticality of this need, the research community has focused its efforts on solving the challenge of future spectrum resource challenges through cognitive radio technologies. This effort can be realized by Akyildiz's survey paper [9], an exhaustive description of the research community's embrace of the critical nature in solving the very real dilemma of exponential growth in wireless devices and the ever-present limit of a finite radio spectrum. Yet, none of these research efforts consider the potential in tailoring a cognition cycle towards risk management. Though it immediately contributes to security of the system, this paper will present risk management as a strategy for more efficient use – contributing to a more sustainable communications infrastructure.

2 TROPICAL CLIMATE IMPACT ON COMMUNICATIONS

The implied elements of a risk management process are threat, vulnerability, and impact [10]. In our consideration of tropical environments, this centers on rain as a threat actor and the inherent vulnerability radio communications have to precipitation. The purpose served by the communications link at the time the threat actor is present will shape the impact of the event. The following section provides a brief overview of the impact precipitation has on communications, explains how it has been mitigated by radio design, and suggests that this effort results in an overall inefficiency for the system's operation.

2.1 Impact of precipitation on communications

Rain, snow, or ice in the atmosphere often scatters radio signals resulting in degradation or prevention of their reception by the receiver. Often referred to as refraction or scattering, when the signal hits the water droplet it is redirected and exits at a different angle. In the instances where there is a direct correlation between the wavelength and droplet size, the signal is not refracted and absorption occurs.

2.2 Mitigation through static design

Countering rain-induced attenuation is often achieved through static measures. In some cases, this was accomplished by selecting a frequency range less vulnerable to the effects of precipitation – even if that frequency spectrum was not optimum for the application it served. Or in the instances where the frequency range is vulnerable, elaborate design approaches with multiple transmission schemes attempt to overcome the impact often placed on a single communications link. For example, [14] offers a diversity reception scheme as an effective technique to reduce the large fading margins in satellite communications. Or [15] promotes a 4-beam transmission scheme (vice 1-beam) for free-space optic communications. Each of these approaches demonstrates findings supporting the commitment of additional resources to overcome the natural phenomena that is resident in their operational environment. The latter example presents a block diagram for the 4-beam FSO system, as shown in Figure 3.

2.3 Inefficiencies resultant of this design approach

Theoretically, a communications system designed against free-space loss will be optimally configured. Yet as previously stated, engineers consider the array of external influences that the system may encounter and they are often forced to design against their possible occurrence – impacting the performance when those influences are absent. Therefore, one can presume that there will be a time period where a communication system operates sub-optimally because it was designed with the assumption an external influence is present. Considering the aforementioned designs, the additional resources are taxing the overall system more than necessary resulting in a loss of efficiency even though the signal strength and link performance is improved.

An alternative would be to give the radio a sense of self-awareness to know when it needs the mitigation mechanism, as well as the ability to reconfigure itself in the manner necessary to implement it.

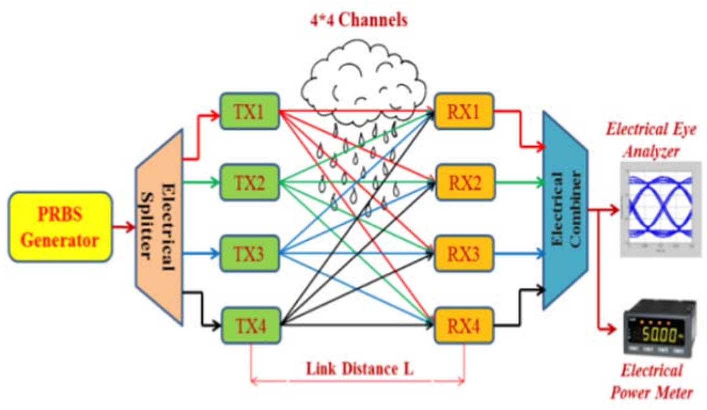

Figure 3: Block diagram for 4-beam FSO System [15]

3 IMPLEMENTATION CASE STUDY (CONCEPTUAL)

It is logical to assume that the aforementioned static mitigation techniques could be improved by a more dynamic approach. Therefore, if we posture the radio to operate at optimum configuration and enable these mitigation techniques only when necessary, efficiency can be gained. The following discussion presents a case-study for a communication system in Malaysia, suggests a series of cognition cycles to improve its mitigation of rain, and follows with potential application for sustainable infrastructures to advance it further.

3.1 Case study with free-space optical channels

In [15], a free-space optical channel communication infrastructure is discussed as a preferred transmission technique for tropical weather environments. This research effort is of specific interest because it claims to be resistant to RF interference [16]. Yet it still accepts a susceptibility to rain. [15] concludes that to overcome the adverse influence of rain in tropical environments, use of a 4-beam system (vice a 1-beam system) is recommended. However, this suggests a continuous use of the configuration requiring the maximum power for operation. If there was an initiative to implement alternative power sources, such as solar panels, then such inefficient power consumption may place the overall system at risk.

3.2 Concept of a cognition cycle reacting to rain

To estimate how much efficiency can be gained by a more dynamic approach to mitigating the risk of rain, we will explore operation of a 1-beam FSO system incorporating a cognition cycle capable of identifying the presence of rain and implementing a 4-beam FSO at that time. Modeled after Mitola's example, the cognition cycle will be structured with four phases (observe, orient, decide, act) though not all may be necessary. First, it will Observe the environment (via input from a weather broadcast system) to determine if it is raining. A binary element, this yes/no question can be answer with a (0/1), whereas a (1) signals the cycle to transition to the next task. That transition indicates a requirement to Orient to the environment. This is a simple logic statement, uses the initial data point from the observe phase which will initiate the transition to the Decide phase. At this point, the radio prepares to adjust to its alternative configuration: 1-beam FSO. Finally, the radio can next Act and adjust the configuration by transitioning to 4-beam FSO in order to increase transmit power. This cognition cycle is graphically portrayed in Figure 4 with its associated pseudo code in Figure 5.

This initial example demonstrates that a radio capable of dynamically changing its configuration to mitigate the adverse effects of rain can perform more efficiently than those static configured for the same purpose. However, to further advance the premise of allowing the radio to think – additional functionality should be considered. If the first question our thinking radio asked was "Is it raining?" what if it also asked, "Does it matter?"

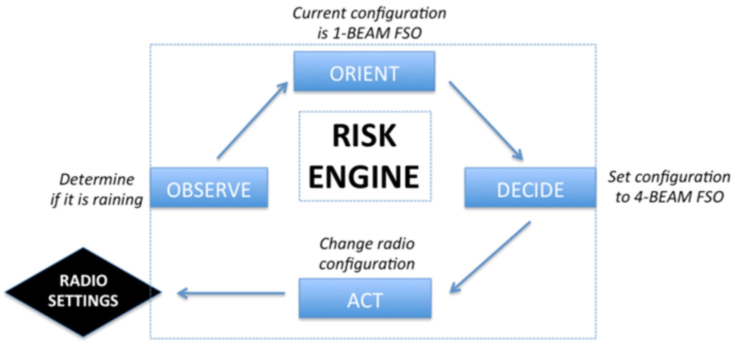

Figure : 4 Rain mitigation cognition cycle

```
//Cognition cycle - Rain determination
//Factor(s) considered: rain status

set the default configuration to 1-BEAM FSO

//OBSERVE phase
get the rain status from the weather source

//ORIENT phase
if it is raining then

        //DECIDE phase
        set new configuration to 4-BEAM FSO

        //ACT phase
        change to new configuration
else
        do nothing
```

Figure 5: Pseudo code for rain mitigation cognition cycle

3.3 Concept of a cognition cycle to consider priority

An advancement to the initial cognition cycle can be made by incorporating a form of decision analysis. To establish a foundation of self-preservation and a future need of the radio to conserve power, a follow-up question would be "how important is the communications link at that time?" The following cognition cycle offers an approach to make this progression in the radio's performance.

First, the radio will Observe the environment to determine if it is raining. But it will also identify the time of day. As before, the yes/no rain question signals the cycle to transition to the next task. That transition indicates a requirement to Orient to the environment. In this phase the radio can compare the time of day to preset priorities. For example, if it is between 2300-0500 there is no compelling need to mitigate the rain. The transition to the next phase would be initiated by passing a metric representing the priority measure of the current operation (based on time of day). The radio will then Decide to proceed with the configuration change by executing a simple logic statement confirming the elevated priority. The radio will next Act and adjust the configuration to 4-beam FSO in order to increase transmit power (or do nothing). This cognition cycle is graphically portrayed in Figure 6 with its associated pseudo code in Figure 7.

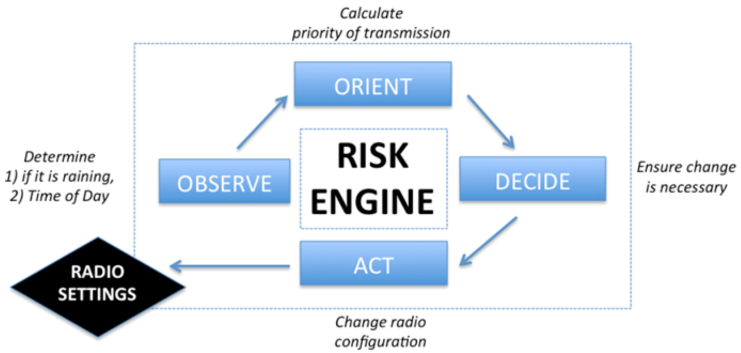

Figure: 6 Prioritization cognition cycle

```
//Cognition cycle - Prioritization
//Factor(s) considered: rain status, time of day

set the default configuration to 1-BEAM FSO

//OBSERVE phase
get the rain status from the weather source
get the time of day

//ORIENT phase
if it is raining then
        if the time of day is between 5am and 11pm then
                set transmission priority to high
        else
                set transmission priority to low

        //DECIDE phase
        if transmission priority is high then
                set new configuration to 4-BEAM FSO

        //ACT phase
        change to new configuration
else
        do nothing
```

Figure 7: Pseudo code for prioritization cognition cycle

Concept of a cognition cycle to adjust for specific loss

To further advance the cognition cycle, additional criteria can be used in the radio's decision analysis. To strengthen the concept of self-preservation, a follow-up question would be "what is the best configuration to use?" To make this progression, we assume that the radio system in our case study can implement a 2-beam FSO configuration. Though [15] demonstrates the ability of 4-beam FSO to mitigate rain, we will rely on their findings to make two assumptions. First, the radio is capable of a 2-beam FSO configuration and it performs better than 1-beam FSO in rain. Second, the 2-beam FSO configuration uses less power than the 4-beam FSO configuration and therefore may offer an advantage to 4-beam FSO if it performs adequately. The following cognition cycle offers an approach to make this progression in the radio's performance.

Extending the previous two sections' approach to cognition, standard equations can be used to calculate the estimated signal loss and then permit the radio to select a configuration best suited to increase its transmit power in order to overcome it. A calculation for estimating the loss due to rain fade is shown in Equation 1.

Equation 1 Loss due to precipitation

Lprecip = 10 1.203 log (f) – 2.290 . R 1.703 – 0.493 log (f)

where Lpre is the loss due to rain fade in dB, f is the frequency in GHz and R is the rain density in mm/hr [11]. This equation permits the estimation of loss and allows measures to be taken to proactively mitigate it. This is a well-understood phenomena with existing work adequately represented by [12] and [13].

Returning to Mitola's example, the cognition cycle will accomplish four tasks. First, it will Observe the environment as before to determine if it is raining and the time of day. In the Orient phase it will determine if the time of day warrants priority. If it does, then the radio will calculate the estimated signal loss. The radio can do so by measuring estimated loss (Lpre) due to the rain. To improve this task, the radio would require a more advanced input from the weather service to provide a metric for the rain rate. With the loss calculation, the radio can next calculate the required increase in transmit power to adequately strengthen the signal to persist through the rain. The metric representing an increase in power is forwarded to the next task, as the radio must Decide the optimum configuration change required. The addition of a 2-beam FSO configuration offers an alternative to the 4-beam FSO, specifically during the instances where rainfall is light. The radio will then Act and adjust the configuration by transitioning to the configuration selected in the Decide phase. This cognition cycle is graphically portrayed in Figure 8 and its associated pseudo code is in Figure 9.

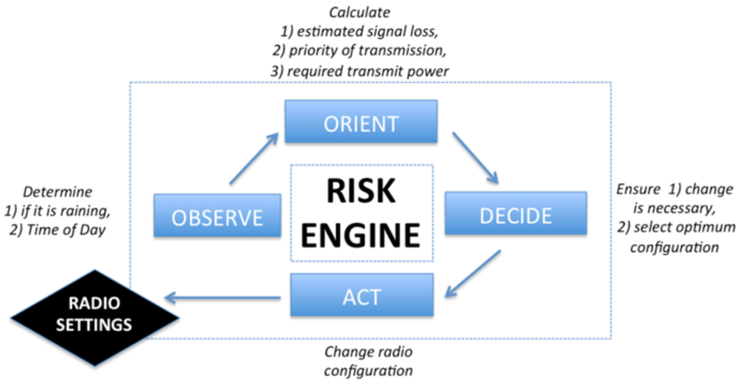

Figure 8: Configuration cognition cycle

```
//Cognition cycle - Vary Configuration
//Factor(s) considered: rain status, time of day, loss estimation

set the default configuration to 1-BEAM FSO

//OBSERVE phase
get the rain status from the weather source
get the time of day

//ORIENT phase
if it is raining then
        if the time of day is between 5am and 11pm then
                set transmission priority to high

                //since priority is high, performing further calculations to aid decision-making
                //loss calculations: R - rain density in mm/hr; f - frequency in GHz
                calculate estimated loss = (10 ^ (1.2303log(f) - 2.290)) * (R ^ (1.703 - 0.493log(f)))
        else
                set transmission priority to low

        //DECIDE phase
        if transmission priority is high then
                if estimated loss < 10dB then
                        do nothing
                else if estimated loss is between 10dB and 50dB
                        set new configuration to 2-BEAM FSO
                else
                        set new configuration to 4-BEAM FSO

        //ACT phase
        change to new configuration
else
        do nothing
```

Figure 9: Pseudo code for configuration cognition cycle

3.4 Concept of a cognition cycle to preserve power

Reflecting on our successive cognitive advances for the radio… it asked "is change needed?" then "is change required?" and finally "how to best change?" To mature the radio to a state of self-preservation, it should gauge the current power level available and the power required by the new configuration and ask "should I change?" Because in a more sustainable, future configuration using solar panels (at times relying on battery power) a configuration change that would exhaust the radio is counter-productive. During rainfall there is signal attenuation and performance degradation, but during power loss there is no connectivity at all. And to wait for sufficient sunlight to recharge and re-establish the connection may compound the outage. Therefore, if the communications infrastructure uses sustainable energy a final cognitive task should be performed.

As before the yes/no rain question signals the cycle to transition to the next task. That transition indicates a requirement to Orient to the environment with rain status and time of day. The radio continues to measure the estimated loss (Lpre) due to the rain and selects the necessary configuration change, but it will also estimate the power required for the configuration change. The transition to the next phase would be initiated by passing a metric representing the necessary increase in transmit power, the expected power consumption by transitioning to either a 2-beam or 4-beam FSO, and a priority measure of the current operation. The radio must Decide to proceed with the configuration change required. To do this, it will weigh the amount power required to mitigate the attenuation against the amount of power remaining to ensure the action does not put future operations at risk. This trade-off analysis will incorporate the priority measure to ensure the action is truly required. Finally, the radio can next Act and adjust the configuration to either 2-beam or 4-beam FSO in order to increase transmit power; or do nothing. This cognition cycle is graphically depicted in Figure 10 and the associated pseudo code can be found in Figure 11.

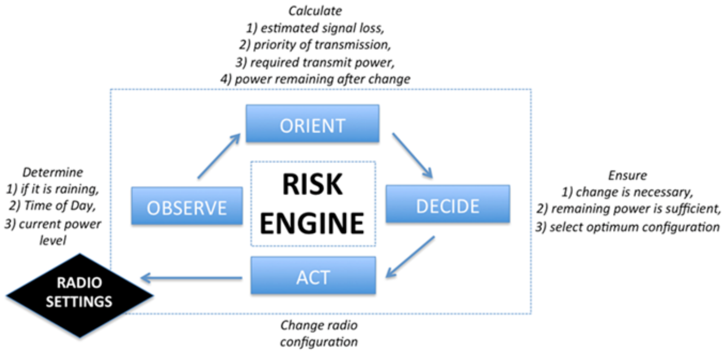

Figure 10: Revised rain mitigation cognition cycle

```
//Cognition cycle - Power conservation
//Factor(s) considered: rain status, time of day, loss estimation, system power

set the default configuration to 1-BEAM FSO

//OBSERVE phase
get the rain status from the weather source
get the time of day
get the current operating power level and current remaining power

//ORIENT phase
if it is raining then
        if the time of day is between 5am and 11pm then
                set transmission priority to high

                //since priority is high, performing further calculations to aid decision-making
                //loss calculations: R - rain density in mm/hr; f - frequency in GHz
                calculate estimated loss = (10 ^ (1.2303log(f) - 2.290)) * (R ^ (1.703 - 0.493log(f)))

                //power calculations
                calculate estimated power increase required to transition to both 2-BEAM and 4-BEAM FSO
                set estimated new power level to (current operating power level + estimated power increase)

                set required remaining power to the amount of power that should be available for future operations
                set estimated remaining power to (current remaining power - estimated power increase)
        else
                set transmission priority to low

        //DECIDE phase
        if transmission priority is high and
           estimated remaining power > required remaining power then
                if estimated loss < 10dB then
                        do nothing
                else if 10dB <= estimated loss <= 50dB and estimated new power level < max power allowed by policy then
                        set new configuration to 2-BEAM FSO
                else if estimated loss > 50dB and estimated new power level < max power allowed by policy then
                        set new configuration to 4-BEAM FSO

        //ACT phase
        change to new configuration
else
        do nothing
```

Figure 11: Pseudo code for power conservation cognition cycle

3.5 Expected results

Though this is a conceptual paper, certain estimates can be made regarding the potential performance of the proposed cognition cycles. With the necessary equipment and test setup, a research paper can be completed to validate their performance in a tropical environment. The first cognition cycle (is it raining?) can be analyzed with recorded rain data. Figure 12 presents a historical summary of rainfall in the Malaysian capital of Kuala Lumpur. Though the graph offers detail regarding the level of rainfall (mm), we are only concerned with the occurrence of rain to estimate the performance of the proposed cognition cycle. Leveraging this data set, we can estimate that a communication system that maintains a 1-beam FSO configuration and only implements 4-beam when it rains will gain over 30% efficiency because it only rained 68% of the time.

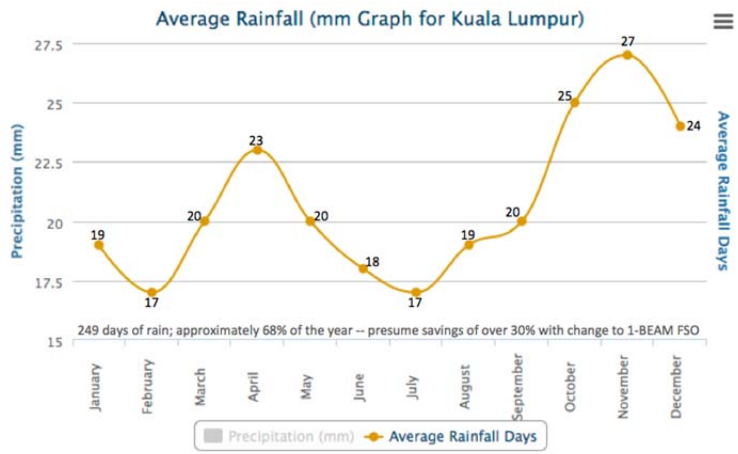

Figure 12: Rainfall Statistics for Kuala Lumpur [17]

The second cognition cycle postulated the radio could prioritize communications based on the time of day, and thus determine if the mitigation action was necessary. To test this hypothesis, we constructed a simple spreadsheet that used a random function to signify the occurrence of rain. To extend the previous testing that presented daily rain occurrences, two simulations were modeled: six data points per day and 24 data points per day (hourly). As before, a random function determined the presence of rain while a second random function was used to determine the time of day. An excerpt of the spreadsheet (6-hr intervals) can be found in Figure 13. The efficiency of a standard 1-beam configuration with the dynamic ability to transition to 4-beam at the occurrence of rain was 61.6% when data was taken every four-hours and 62.4% when it was taken hourly. This simple calculation is flawed in its implementation of a purely random selection of a binary element, which fails to account for the tropical environment's likelihood of precipitation. This could be remedied with some probability function that more closely models the higher likelihood of rainfall. Additionally, it sets the random function against predetermined intervals (0001-0600, 0601-1200, etc) and therefore will only have a possible of two low-priorities each day. Regardless, it does make a statement regarding the potential if the device gains the capability of dynamic reconfiguration.

DAY	TIME	RAINING?	CONFIGURATION
1	0317	1	1-BEAM
1	0628	1	4-BEAM
1	1105	0	1-BEAM
1	1223	1	4-BEAM
1	1637	0	1-BEAM
1	2152	0	1-BEAM
2	0300	0	1-BEAM
2	0741	1	4-BEAM
2	0940	0	1-BEAM
2	1441	1	4-BEAM
2	1802	1	4-BEAM
2	2228	0	1-BEAM
3	0226	1	1-BEAM
3	0704	1	4-BEAM
3	0832	0	1-BEAM
.	.	.	.
.	.	.	.
.	.	.	.
363	1229	0	1-BEAM
363	1820	1	4-BEAM
363	2327	0	1-BEAM
364	0019	0	1-BEAM
364	0452	0	1-BEAM
364	0900	1	4-BEAM
364	1214	0	1-BEAM
364	1937	0	1-BEAM
364	2003	0	1-BEAM
365	0124	1	1-BEAM
365	0708	0	1-BEAM
365	1149	0	1-BEAM
365	1452	0	1-BEAM
365	1828	0	1-BEAM
365	2219	0	1-BEAM

Figure 13: Excerpt from test set to simulate cognition cycle for prioritization

4 CONCLUSION AND RECOMMENDED RESEARCH

Enabling the radio to operate autonomously and mitigate the risk of rain only when the rain is present indicates the possibility of achieving a more sustainable communications infrastructure. This creative radio design indicates great improvement over current inefficient, static mitigation designs or the cumbersome human dependency to make configuration changes when necessary. By assessing the criticality of the operation, selecting the optimum configuration change, and ensuring any action does not exhaust the radio's limited power supply the radio can autonomously optimize its operation. Designing a radio that can think – with a purpose of self-preservation – is a step towards a more sustainable communications infrastructure.

This work can transition from a conceptual paper to a research paper if the necessary equipment was acquired to test the cognition cycles' performance over the course of a year in Malaysia's tropical weather conditions. A single set of radios should maintain a 4-beam FSO configuration throughout the year with a second set capable of the proposed dynamic configurations. If the existing radios are not currently in a software defined state, open-source solutions such as GNU radio [18] can be modified to control the system and implement these cognition cycles. Power consumption and performance metrics could be quantitatively compared to validate the potential of this creative design.

ACKNOWLEDGEMENT

The creative design approach discussed in this paper was inspired by recent lectures at George Mason University's Volgenau School of Engineering in the course CEIE 894, Design and Inventive Engineering taught by Professor Tomasz Arciszewski. The authors found the discussions centered on bioinspiration, "Biomimetics" and "Evolutionary Designing," to be especially provoking. Over millennium, species have survived based on their ability to change and humans have progressed based on their cognitive

prowess. Imagine what our communication infrastructures may be capable of when designed with such aims. Let's begin with a sustainable future.

REFERENCES

[1] J. Mitola, "Software radios: Survey, critical evaluation and future directions." Aerospace and Electronic Systems Magazine, IEEE 8, no. 4 (1993): 25-36.

[2] J. Mitola, "The software radio architecture." Communications Magazine, IEEE 33, no. 5 (1995): 26-38.

[3] ___, "A structure for software defined radio security," SDR Forum Input Document. SDRF-03-I-0010, May 2003.

[4] T. Sturman, "An Evaluation of Software Defined Radio – An Overview," 2006; 10. Retrieved from http://stakeholders.ofcom.org.uk/binaries/research /technology-research/evaluation_sdr.pdf on May 23, 2012.

[5] J. Mitola and G. Maguire, "Cognitive radio: Making software radios more personal," IEEE Personal Communications Magazine 6(4), 1999; 13-18.

[6] J. Mitola, "Cognitive radio: An integrated architecture for software defined radio," Ph.D. Thesis, KTH Royal Institute of Technology, 2000.

[7] ___, "802.22.2-2012 - IEEE Recommended Practice for Information Technology - Telecommunications and information exchange between systems Wireless Regional Area Networks (WRAN) - Specific requirements - Part 22.2: Installation and Deployment of IEEE 802.22 Systems," http://standards.ieee.org/about/get/802/802.22.html

[8] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," IEEE Journal on Selected Areas in Communications, Vol. 23, No. 2, 2005. Retrieved from IEEE Xplore on March 21, 2012.

[9] I. Akyildiz, W-Y. Lee, M. Vuran, and S. Mohanty, 'NeXt generation/dynamic spectrum access/cognitive radio wireless networks: a survey', Computer Networks, Vol. 50, No. 13, 2006. pp. 2127–2159.

[10] J. Talbot and M. Jakeman, Security Risk Management Body of Knowledge, Wiley Publishing: Hoboken, NJ. 2009.

[11] A. Sharma and P. Jain, "Effects of Rain on Radio Propagation in GSM," International Journal of Advanced Engineering & Applications, Jan. 2010.

[12] Green, H. "Propogation Impairment on Ka-Band SATCOM Links in Tropical and Equatorial Regions." IEEE Antennas and Propagation Magazine, Vol. 46, No. 2, Apr. 2004.

[13] Mandeep, J. and Hassan, S. "Slant-path rain attenuation predictions in tropical regions." Journal of Atmospheric and Solar-Terrestrial Physics, 68 (2006) pp. 865-868.

[14] Skraparlis, D., Sakarellos, V., Panagopoulos, A., and Kanellopoulos, J. "Satellite and Terrestrial Diversity Reception Performance in Tropical Regions." Proceedings of the International Workshop on Space and Satellite Communications (IWSSC). Sep. 2009.

[15] Al-Gailani, S., Mohammad, A., Shaddad, R., Jamaludin, M. "Single and Multiple Transceiver Simulation Modules for Free-Space Optical channel in Tropical Malaysian Weather." Proceedings of the IEEE Business Engineering and Industrial Applications Colloquium (BEIAC). Apr. 2013.

[16] Al-Gailani, S., Mohammad, A. and Shaddad, R. "Evaluation of a 1GB/s Free Space Optic system in typical Malaysian weather. Proceedings on International Conference of Photonics (ICP). OCT. 2012. PP. 121-124.

[17] "Kuala Lumpur Weather Averages." World Weather Online. Retrieved on 20 November 2013 from http://www.worldweatheronline.com/Kuala-Lumpur-weather-averages/Kuala-Lumpur/MY.aspx

[18] GNU Radio. www.gnuradio.org