Cognitive Networking with regards to NASA's Space Communication and Navigation Program

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Abstract—**This report describes what Cognitive Networking is and how it applies to NASA's Space Communication and Networking (SCaN) Program. This report clarifies the terminology and framework of cognitive networking and provides some examples of cognitive systems. It then provides a methodology for developing and deploying cognitive networking techniques and technologies. Finally, the report attempts to answer specific questions regarding how cognitive networking could benefit SCaN and describes SCaNs current and target networks and proposes places where cognition could be deployed**

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1.0 EXECUTIVE SUMMARY

The following report is the output to a one-year task given to the Networks and Architectures Branch at NASA Glenn Research Center by the NASA Space Communication and Navigation (SCaN). The goal of the task was to answer the questions below and put together a 5-year roadmap related to Cognitive Networking research – basically define the next steps for Cognitive Networking relative to SCaN. This document does not include a roadmap but does provide guidance on the next steps.

The Questions

- What is cognitive networking? What are the future benefits for NASA? Which nodes would use cognitive networking? Would all nodes be equally cognitive? Could some nodes be non-cognitive?
- How would cognitive networking concepts [Kliazovich] fit into the SCaN network?
- How would the network learn and retain knowledge?
- Where does cognitive networking integrate into software-defined radios?
- What would the dialog between nodes be like and what type of information would be exchanged? How will loss or degradation of a node be handled?

The Answers

What are the future benefits for NASA? Only a cognitive network can be aware of its performance requirements, determine if these requirements are being met, and revise system configurations to better meet them. The network adapts to continuous changes rapidly, accurately, and automatically [Haigh11, Haigh12].

Which nodes would use cognitive networking? One needs a complete, detailed network diagram, operational procedures, security configurations, and network goals to determine this. Given the size and complexity of SCaN's integrated operations network, this information does not appear to exist in its entirety anywhere. SCaN has invested numerous amounts of money to develop Department of Defense Architecture framework (DODAF) documents for the current system (as is) view and target system (to be) view. However, after a thourogh review of the information residing in the current documents, it appears that additional information needs to be collected to be able to provide a network picture detailed and accurate enough to work to.

Would all nodes be equally cognitive? Not necessarily and almost assuredly not.

Could some nodes be non-cognitive? Yes

How would cognitive networking concept fit into the SCaN network? Given the size of SCaN's network(s) and varying operational conditions, automated Artificial Intelligence approaches have the potential to configure, manage and repair the network(s) faster and better than a human communications support team can [Haigh11, Haigh12].

How would the network learn and retain knowledge? One needs to identify the end-to-end network goals to determine this. One also needs a complete, detailed network diagram, operational procedures, and security configurations. In addition, one needs to know what the measurement parameters can and/or should be collected in each system and determine which controls need to be made available for the cognitive machine to control and manipulate.

How does cognitive networking integrate into software defined radios? Actually, the software defined radios (SDRs) integrate into (and become a key element of) the cognitive network, not the other way around. The SDR needs to expose measurable parameters and dependencies and provide access to configuration controls (tuning knobs). In this manner, the local cognitive network engine will be able to manipulate the SDR to obtain the desired effect via continuous measurement and adaptation control.

What would dialog between nodes be like and what type of information would be exchanged? Due to the size and complexity of SCaN's integrated network systems, one needs a complete, detailed network diagram, operational procedures, security configurations, and network goals to be able to determine what type of cognitive systems to deploy and where. Once the candidate system has been identified, the next step will be to determine if information exchange is between layers of a local system or between systems and what information is required. Within a system, information may be exchanged via memory pointers of registers. Between systems, some standard application protocols may need to be developed or one may find commercial or open source software or standards that could be applied. Prototyping a subscale candidate system (as opposed to changing the entire SCaN network infrastructure) would probably be the most reasonable approach.

How will loss or degradation of a node be handled? It is anticipated that system nodes will not all be equivalent. Therefore, the solution will be largely dependent on the particular network or network section affected. For example, one may be able to route around a node, reduce traffic through a node and/or repair the node once one isolates the problem.

Note 1: Applying cognition to a poorly architected network will not fix a poorly architected network. On the other hand, having a well-architected network will greatly simplify infusion of cognition.

Note 2: Adding cognition to a portion of SCaN's network may be able to make that portion operate "better". But one must be able to define "better".

Better Questions

This is an interesting mix of questions: some quite broad and easily answered generically, and others rather specific requiring a complete understanding of the current and future SCaN network, hardware, operational procedures and policies. They are very good questions. However, they do not reflect how complex their questions are relative to a simple network, let alone to the entire SCaN Network(s). In addition, Cognitive Networking has become a catchall phrase for anything that involves a combination of radios and software-based algorithms. Many carelessly equate cognitive network with rules-based dynamically adaptive networks. Probably better sets of questions to start with are:

- What does the network really look like?
- What are the limitations of the network?
- Where should one put automation in the SCaN Network(s)?
- Where should one put autonomy?
- What gains will automation and autonomy provide SCaN? (A question fairly easy to answer and extremely hard to prove or put monetary value to.)
- If one were to then add cognition, where should it go and what is the potential cost/benefit? (An extremely difficult to answer in a "bounded system". One needs to first determine the cost/benefit or automation and obtain some baseline measurement of system performance before one could say how much improvement, if any, cognition would add to the overall network. As is, the SCaN network is, for all practical purposes, unbounded.)

The Way Forward

The next steps required to move Cognitive Networking forward follow below in order of operation:

1. Commitment to invest in the required research.

    a. NASA has to determine whether or not they should be involved in basic Artificial Intelligence and Machine Learning research in any form. This is long-term research and requires programmatic commitment and dedicated resources.

    b. The SCaN Program must decide if it is willing to invest long-term in cognitive networking related AI and Machine Learning.

2. Defining and analyzing the SCaN Network Architecture (current and future integrated system)

    a. Detailed network architectural drawings need to be developed (regardless of use of Cognitive Networking or Automation). To be useful the architecture drawings will need to include all machines, interfaces, and protocols. Note: these documents will not be the high-level view presented in documents such as the Space Communications and Navigation (SCaN) Network Architecture Definition Document [ADD]. Rather, they will present a detailed picture to the level of identifying all addressing, wiring, radios and configuration parameters. Since this will be a substantial undertaking, this can be accomplished by starting with details covering a portion of the larger network, with details on such things as machines,

interfaces, protocols, addressing, wiring, radios and configuration parameters to follow.

b. Identify what parameters are exposed, what should be exposed as well as what controls are accessible and what controls should be accessible.

c. Identify the system goals.

d. Identify measurement points that provide insight as to whether or not the system goals are being met.

3. Automate a candidate system.

4. Gain a full understanding (or at least sufficient understanding) of how systems interact.

5. Determine the AI methodologies that may improve system performance.

6. Implement and deploy the AI cognitive system and measure performance to determine what gains have been obtained and at what cost.

A reasonably bounded problem that may provide the greatest payoff to SCaN, early on, is to investigate use of cognitive networking toward the problem of scheduling/configuring SCaN's major assets within the Near Earth Network (NEN), the Space Network (SN), and the Deep Space Network (DSN). Another bounded problems it to simply apply cognition to point-to-point radio links.

2.0 INTRODUCTION

The following report is the output to a one-year task given to the Networks and Architectures Branch at NASA Glenn Research Center by the NASA Space Communication and Navigation (SCaN). The goal of the task was to answer the following questions and put together a 5-year roadmap related to Cognitive Networking research – basically define the next steps for Cognitive Networking relative to SCaN.

1. What are the future benefits for NASA? Which nodes would use cognitive networking? Would all nodes be equally cognitive? Could some nodes be non-cognitive?

2. How would cognitive networking concept [Kliazovich] fit into the SCaN network?

3. How would the network learn and retain knowledge?

4. Would does cognitive networking integrate into software-defined radios?

5. What would dialog between nodes be like and what type of information would be exchanged? How will loss or degradation of a node be handled?

Cognitive networking is an element of the NASA Office of Chief Technologist's (OCT) new Roadmap for Space Communications and Navigation (C&N) [Figure 1]. It supports OCT's desire for technology development and demonstrations that address NASA's Grand Challenges, one of which is to "unleash the power of machine intelligence". Cognitive networking technology supports roadmap milestones for cognitive radios (2017), self-aware radios (2020), autonomous communications (2023) and cognitive networks (2025).

From C&N Roadmap, Technology Area 5.5 (Integrated Technologies)

"Cognitive radios will be developed that will sense their environment, autonomously determine when there is a problem, attempt to fix it, and learn as they operate…

… Develop a system in which each node is dynamically aware of the state and configuration of the other nodes. Today, most of the decisions in space communications and navigation today are made on the ground. Communications and navigation subsystems on future missions should interpret information about their situation on their own, understand their options, and select the best means to communicate or navigate. For example, a node in such a network might be aware of the positions and trajectories of all other nodes, inferring this entirely through network communications and modeling." [OCT_TA05, OCT_SRTP]

Our aim is to create a Cognitive Network through the incremental application of artificial intelligence to the future NASA integrated network, which includes services as well as assets. Our overall goal is the intelligent and judicious application of artificial intelligence to the system with the purpose of:

- Reducing network operating costs,

- Providing more dynamic, flexible user services,
- Increase performance and reliability, and
- Increasing security and resiliency.

3.0 COGNITIVE NETWORKING

Researching various articles, books and research papers on cognitive networking, it is apparent that "Cognitive" is the new buzzword. COGNITIVE is GAME-CHANGING! Even within chapters of the same book on Cognitive Networking, the definition varies greatly [Mahmound]. However, when consulting the noted recognized experts in the field, there is a common aspect: "Cognitive Networks include artificial intelligence (AI) and machine learning." In order to ground ourselves we define what Cognitive Networking IS and IS NOT.

2.1 What Cognitive Networking IS.

The two descriptions that best define cognitive networking are from R. W. Thomas el al [Thomas].

"In a cognitive network, the collection of elements that make up the network observes network conditions and then, using prior knowledge gained from previous interactions with the network, plans, decides and acts on this information. Cognitive networks are different from other "intelligent" communication technologies because these actions are taken with respect to the end-to-end goals of a data flow. In addition to the cognitive aspects of the network, a specification language is needed to translate the user's end-to-end goals into a form understandable by the cognitive process. The cognitive network also depends on a Software Adaptable Network that has both an external interface accessible to the cognitive network and network status sensors. These devices are used to provide control and feedback."

"A cognitive network has a cognitive process that can perceive current network conditions, and then plan, decide and act on those conditions. The network can learn from these adaptations and use them to make future decisions, all while taking into account end-to-end goals."

A cognitive network is guided by network end-to-end goals and policies. It can *reason and learn* to improve network performance. It uses experience to create novel rules and actions. It takes advantage of unpredicted events. It can predict events and act accordingly. It allows new knowledge to be inferred from experience and resolves problems with the appropriate solution (rules-based or machine learning).

A cognitive network could enable networks to: reconfigure network and radio operating parameters; monitor, diagnose and repair system level anomalies; and, provide autonomous security mechanisms such as detecting and isolating network intruders.

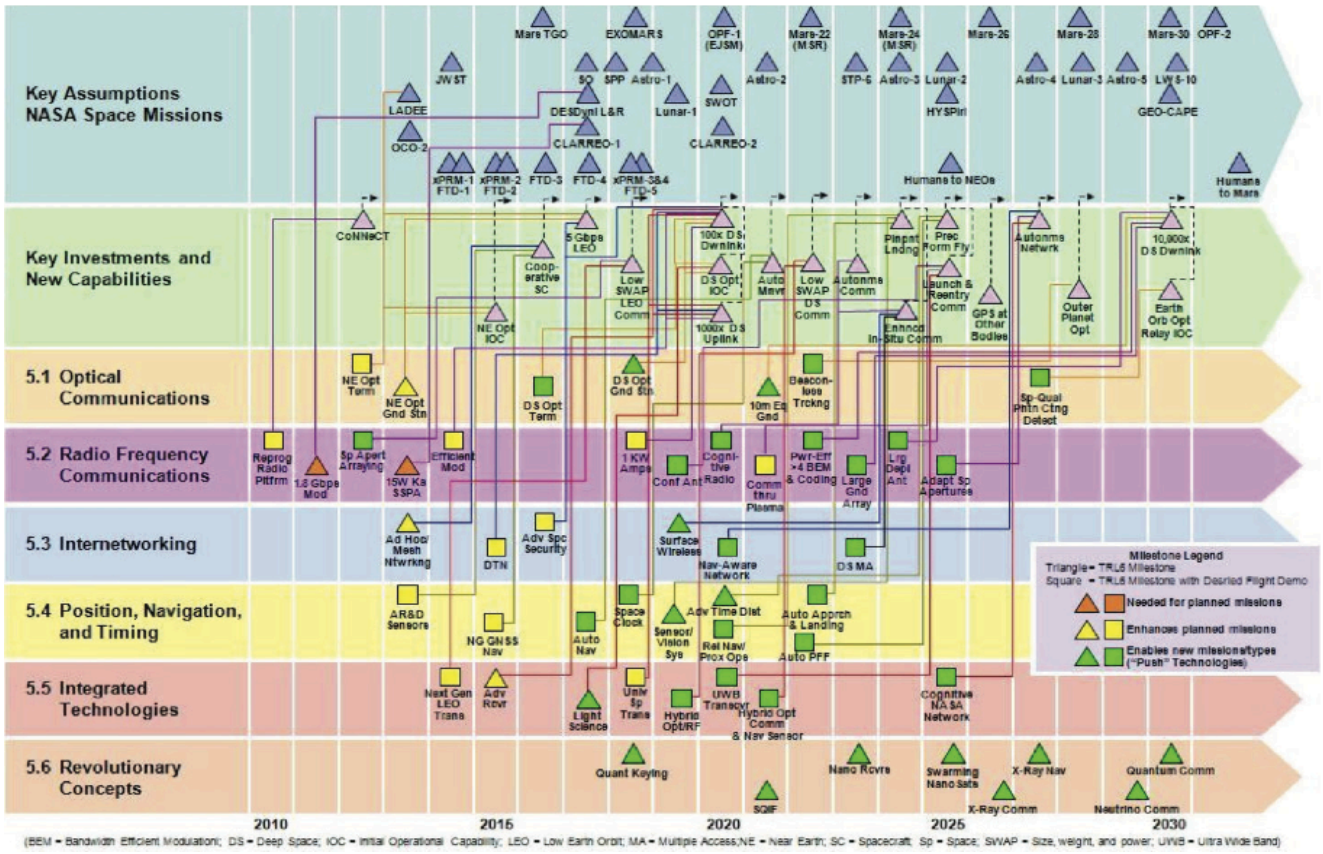

Figure 1 - NASA Space Communication Roadmap

It is imperative to remember, a cognitive network learns and *true learning requires that mistakes be made!* Learning remains one of the challenges in artificial intelligence research.

2.2 What Cognitive Networking IS NOT.

A cognitive network is **NOT** a network of cognitive/adaptive radios.

Having a radio that performs Dynamic Spectrum Access (DSA) does not make it a cognitive radio. DSA can be performed simply via some rules-based or central control-based system. Only if learning is involved does the radio become cognitive. In the same manner, having a network of radios that use cross-layer communications does not make it a cognitive network. "Cognitive networks are likely to employ cross-layer optimizations and act simultaneously on parameters belonging to multiple layers in the protocol stack. However, cognitive networks are more than cross-layer design." [Thomas]

Software Defined Radio (SDR) and cognitive radio are often used interchangeably – incorrectly so. An SDR is simply a radio that puts much of the radio functionality, including waveform synthesis and perhaps intermediate frequency (IF) and Radio frequency (RF), into the digital domain using technologies such as field programmable gate arrays (FPGAs). This allows for great flexibility and re-programmability of the operation. An SDR does not necessarily have intelligence. A Cognitive radio has an intelligent engine that utilizes the reprogramability and reconfiguration aspects of the SDR to adapt the radio to perceived changes in the operating environment as well as the system goals. The cognitive radio maintains situational awareness (feedback) and makes behavior choices from the feedback and external inputs. It then monitors and measures the performance in order to learn how better to adapt.

It has been argued that network routers are cognitive and that the TCP protocol is cognitive. Both have memory and sense their environment to infer global situational awareness that provides an input to fixed algorithms to adapt the routing or transmission to the perceived conditions. Is this learning? Perhaps. However, given the same sequence of input conditions (albeit difficult to do in networking) one will perceive the same output. In other words, the algorithms and weighting of parameters within those algorithms is fixed. Thus, we argue that a group of router running routing protocols and routing algorithms is not a cognitive network and that the TCP protocol is not cognitive. Rather, we view these along the lines of reflexes. For example, when a child touches something hot, their reflexes make them pull their hand away. The learning process is what happens over a much longer timeframe. Eventually the child will feel the heat radiating from an object and learn via some reasoning process that that touching a hot object is painful and causes damage and thus is an undesirable action. For a routing protocol to be cognitive, the weighting within the algorithms or the algorithms themselves will need to autonomously adapt to environmental conditions. Work in ongoing in this area; in particular, with regard to mobile ad hoc networking [DLEP, modemPLA]. One way that the TCP protocol could become cognitive is if the actual TCP algorithm (for which there are many) would adapt per information flow or via an ability to sense the network characteristics and determine which TCP algorithm best suits those conditions such as using more aggressive congestion control or no congestion control depending on the current situational (deployment environment).

2.3 Examples of Cognition

The following two examples of cognitive systems have been chosen to show the complexity involved in what are relatively simple, bounded problems. The entirety of cognitive networking is nearly unbounded. Thus, initial progress must be confined to subsets of the entire network in order to understand the system well enough to infuse cognition.

The first example is of machine learning from Resilient Machines Through Continuous Self-Modeling [Bongard]. Here, we strive to provide an understanding of what cognition is and what it takes to learn. In this example, the goal of the simple machine is to move forward. "The legged robot learned how to move forward based on only 16 brief self-directed interactions with its environment. These interactions were unrelated to the task of locomotion, driven only by the objective of disambiguating competing internal models." This machine uses actuation-sensation relationships to indirectly infer its own structure, and it then uses this self-model to generate forward locomotion. A short video is available that shows the experiments. It can be found at:

http://ccsl.mae.cornell.edu/research/selfmodels/videos/resilient_720x480.wmv

Note: learning is not perfect and that many mistakes and trials are necessary before a reasonably good result is obtained. The important items that this research shows is that a cognitive system using 16 simple self-directed interactions performed quite well whereas "Without internal models, robotic systems can autonomously synthesize increasingly complex behaviors or recover from damage through physical trial and error, but this requires hundreds or thousands of tests on the physical machine and is generally too slow, energetically costly, or risky."

The second example illustrates how a biological system learns and how multiple biological systems interact to reach a desired "Goal". Note, there must be some "Goal" for which the entire system is attempting to reach. In their example, the goal is to get the puppy to go to its mat. The link below is to a video that illustrates this in the first 6 minutes of the video[1].

http://www.thedogtrainingsecret.com/the-first-step/

Note the amount of feedback required for training. The goal of the controlling system, the trainer, is to get the subsystem to perform at its optimum. In this case, to get the dog to behave

[1] This is not intended to be an endorsement of the product. Rather, the video illustrates simple cognition and interaction between controller system (the trainer) and a subsystem (the dog)

according to the trainers desires – specifically to "go to the mat."

It is imperative that the controller understands the behavior of the subsystem in order to provide proper stimuli to train the subsystem and obtain the desired outcome. In this case, the subsystem is the puppy and the stimuli are attention (or lack thereof) and food (treats).

The algorithms are very simple.

Subsystem (Dog's) Algorithms:

- I am a pack animal. I want to be accepted as part of the pack. I hate being ignored. I will consider receiving attention as a measure of goodness.
- I like treats. I will consider receiving a treat as a measure of goodness

Controller's (Trainer's) Algorithms:

- Give dog treat when dog makes appropriate progress toward goal (sit on mat on command). Note, as the dog progresses, what is considered progress is modified – i.e. a weighted algorithm.
- Ignore dog if it performs inappropriate behavior (barking, nipping, etc...).

Having the wrong set of algorithms will make the system go unstable or end up with unintended results. For example: people often wonder why they cannot stop their dog from jumping on people or nipping or barking.

People Algorithms:

- If the puppy (or mature dog) jumps up on people or nips, than push back on them get excited and say NO.
- If the puppy continues, get more excited and push back more.

Unbeknownst to the person they are rewarding negative behavior. The problem with these algorithms is that the dog really does not understand the word "No". The dog thinks the person is playing with him because the person is giving him attention by pushing back and getting excited. The dog thinks, "Obviously the person is having fun because are excited and playing with me." The end result is the dog has trained the person to play with him by jumping up and nipping at them. The system has gone unstable.

2.4 Learning

Learning requires time, memory and feedback. Learning requires that mistakes be made. Learning occurs on a much longer time scale than simple algorithms such as rules-based adaptation. One can use a cognitive system to determine algorithms and weights that may be applied to the algorithms thus combining the best of cognition with the best of automation and rules-base algorithms.

2.5 Why Is Cognition Needed

Networks, even simple networks, are extremely complex. The intricate interactions between subsystems and nodes are difficult to model. The scale can be massive. For example, in a SDR network used in BBN's Adaptive Dynamic Radio Open-Source Intelligent Team (ADROIT) project, individual nodes had approximately 600 observable parameters as well as 400 controllable parameters. However, the current system did not expose all the parameters (the highest was about 100 parameters, of which 30 were controllable) [Haigh08]. Because of the complexity of large systems, poorly understood interactions among parameters, complex temporal feedback loops and the inability to obtain full situational awareness – due to latency, constrained communications and rapid decision cycles – use of artificial intelligence (AI) and cognitive engines is imperative. Human network engineers cannot handle this complexity.

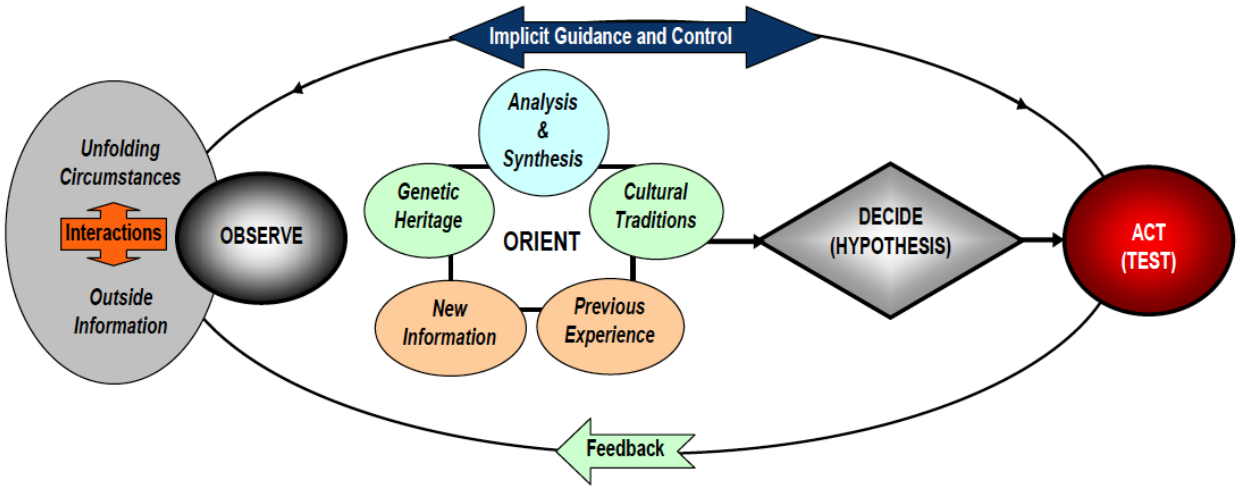

Figure 2 - OODP Loop (source - Dr. Thomas A. Lifvendahl)

Modern network theory suggests that the underlying connectivity of a complex network has such a strong impact of its behavior that no approach to complex systems can succeed unless it exploits the network topology [Barbasi]. Again, human network engineers cannot dynamically handle this complexity.

2.6 Cultural Issues

There are a number of significant cultural issues that have to be overcome in order for Cognition and AI to be deployed in networks. Networking engineers are reluctant to allow and outside autonomous controller to operate the network. However, for AI to realize its full potential, AI must be allowed to control the system. Thus, "failsafe" mechanisms must be developed to sense runaway conditions and prevent further performance declines or catastrophic failures. Also, traditional networking has very clear boundary between "network" and "application" whereas cognitive networking blurs that boundary. The networking engineer is uncomfortable with this due to the complexity and inability to model and predict performance. Cognitive networking and AI need this blurring of boundaries in order to obtain full system benefit [Haigh08].

4.0 METHODOLOGY

3.1 OODA Loop

A reasonable place to begin understanding a methodology for developing cognitive systems is to understand the OODA loop [Figure 2]. OODA is an acronym for Observe, Orient, Decide, and Act. The OODA loop is attributed to Colonel John R.Boyd who developed it as in information strategy concept for information warfare [Boyd]. This is a process often applied at the strategic level in military operations as well as to understand commercial operations and learning processes. The diagram shows that all decisions are based on observations of the evolving situation. The Observed information (inputs) must be processed to Orient the system prior to making a Decision and Acting upon that decision. The Actions cause the situation to change, which, in turn, alters the inputs that are used to re orient the system. Thus there are continuous adjustments being made based on actions taken. Note, this loop does not show any learning mechanism.

3.2 Cognitive Cycle

The Cognitive Cycle (later know as the OOPDAL Loop) [Figure 3] was introduced by John Mitola in his 2000 Dissertation, "Cognitive Radio An Integrated Agent Architecture for Software Defined Radio." [Mitola2000]. OOPDAL is an acronym that stands for Observe, Orient, Plan, Decide, Act and Learn. The OOPDAL loop builds off the OODA loop and add and aspect of planning and learning. Although originally used to describe the cognitive radio architecture, this is an open architecture framework for integrating agent-based control, natural language processing, and machine learning technology into a variety of systems including cognitive networks. "Cognitive radio (or system) is a goal-driven framework in which the radio (or system) autonomously observes its environment, infers context, assesses alternatives, generates plans, supervises services, *and learns from its mistakes* [Mitola1999]."

During the Observation Phase, inputs are received both externally and internally to provide situational awareness. That information is analyzed in order to assess the situation (i.e. Orient, or obtain situational awareness). Once the system is Oriented, it enters the Planning Phase where goals are set depending on the situation and a variety of plans and schedules are made. During the Decision Phase, a plan is selected and the necessary system resources are allocated to achieve the plan. The Acting phase is where the plan is implemented. Within this outer loop is the Learning Phase. Learning receives inputs from the Observations, Plans and Decisions. Learning requires continuous feedback including the ability to analyze inputs (measure results) and correlate those with the previous plans and decision and assess how close the system came to reaching its goals. This information is then used to modify the system inputs and plans in order to converge on the set goals.

3.3 Approach

Before we can attempt to apply cognition to a network or system, one must thoroughly understand the system and subsystems and establish the goal or goals of the system. One needs to understand what they want the system to accomplish. (It may be useful to also understand why.) Thus, one needs a Concept of Operations (CONOPS). In addition, a detailed network architecture needs to be developed to the level of addressing, wiring, radios and configuration parameters. Preferably that would include all machines, interfaces and protocols. This is of primary importance because characterizing the underlying network structure is required for understanding the system. Since may be difficult to obtain, at least sufficient detail is needed to identify a portion of the network that one can then go back and obtain the above detail from (e.g. machines, interfaces, protocols, addressing, wiring, radios and configuration parameters).

Two critical elements are required to develop a cognitive network. The first is the ability to have sufficient self awareness and situational awareness (Observe) to determine whether or not goals are being met or if one is converging on or diverging from those goals (Orient). The second is to be able to provide inputs into the system to make appropriate adjustements to the network such that the goals are obtained within some bounds (Plan and Decide). Thus, we need to identify what parameters are exposed, what should be exposed as well as what controls are accessible and what controls should be accessible.

Since a network is such a complex entity with many intricate interactions and observable parameters, it is difficult to understand what to observe and what to ignore in order to assertain whether or not goals are being met within appropriate bounds. The use of data mining, the process that attempts to discover patterns in large data sets, is essential to distill down the number of potential observables to a managable set. An example of this is occurred in NASA's "Secure, Network-Centric Operations of a Space-Based Asset" mobile networking experiments [Ivancic2005]. In this experiment, a commercial router was deployed on a low-earth orbiting spacecraft. Multiple ground stations were uses from various service providers with most of the assets under the control of each of the service providers. None of the ground assets was in

control by NASA (with the exception of the home-agent routers, located at Glenn Research Center). Test engineers had access to hundreds of observable parameters including router statistics, modem parameters and RF equipment parameters (e.g. steering, transmitter ON, modem lock, modulation and coding formats, packet counts, frame counts, etc…). After numerous tests, trials and tribulations, it was determined that only one parameter needed to be monitored to indicate everything was operational (i.e. goal was met). That parameter was mobile network registration in the mobile-ip home agent. Furthermore, if the system was not operaitonal, observing the DCE line in the ground station router would indicate if the RF chain was operaitonal or not. Thus, 100s of observables where distilled down to two manageable observables.

Once we understand what SCaN network system parameters are useful to observe and what inputs are available, we can begin to automate the system. Initially, rules-based algorithms may be deployed to gain a full understanding (or at least some understanding) of how various subsystems interact. By instrumenting the system and measuring performance we can obtain sufficient information to help determine which AI methodologies to deploy that may improve system performance. Most likely a rules-based system would be followed by supervised learning system to gain experience and confidence in the cognitive system. This would be followed by a full autonomous unsupervised learning system. Finally, once we implement and deploy the AI cognitive system and measure the performance we can determine what gains have been obtained over simple automation and at what costs.

5.0 NASA's SCaN Network

"The SCaN Network is the sum of NASA's space Communication and Navigation (C&N) infrastructures that are managed and operated by the SCaN Program, regardless of the evolutionary phase of the network. The SCaN Network is mainly composed of the three networks: the Space Network, Deep Space Network, and Near Earth Network. User missions negotiate services according to their mission requirements with the individual network, or set of networks that can provide them.

The NASA space communications infrastructure as a whole offers an extensive repertoire of capabilities, including launch/tracking range support, early orbit tracking, routine user mission services, data relay, emergency support, and science services (e.g., radar science). SCaN provides services to user mission platforms at locations ranging from the surface of the Earth to deep space.

The SCaN Network provides services to user mission ground systems and user mission platforms. The standard ground end point for delivery of service is typically at the user mission operations center (MOC), and the end point in space is the user mission platform." [SRD].

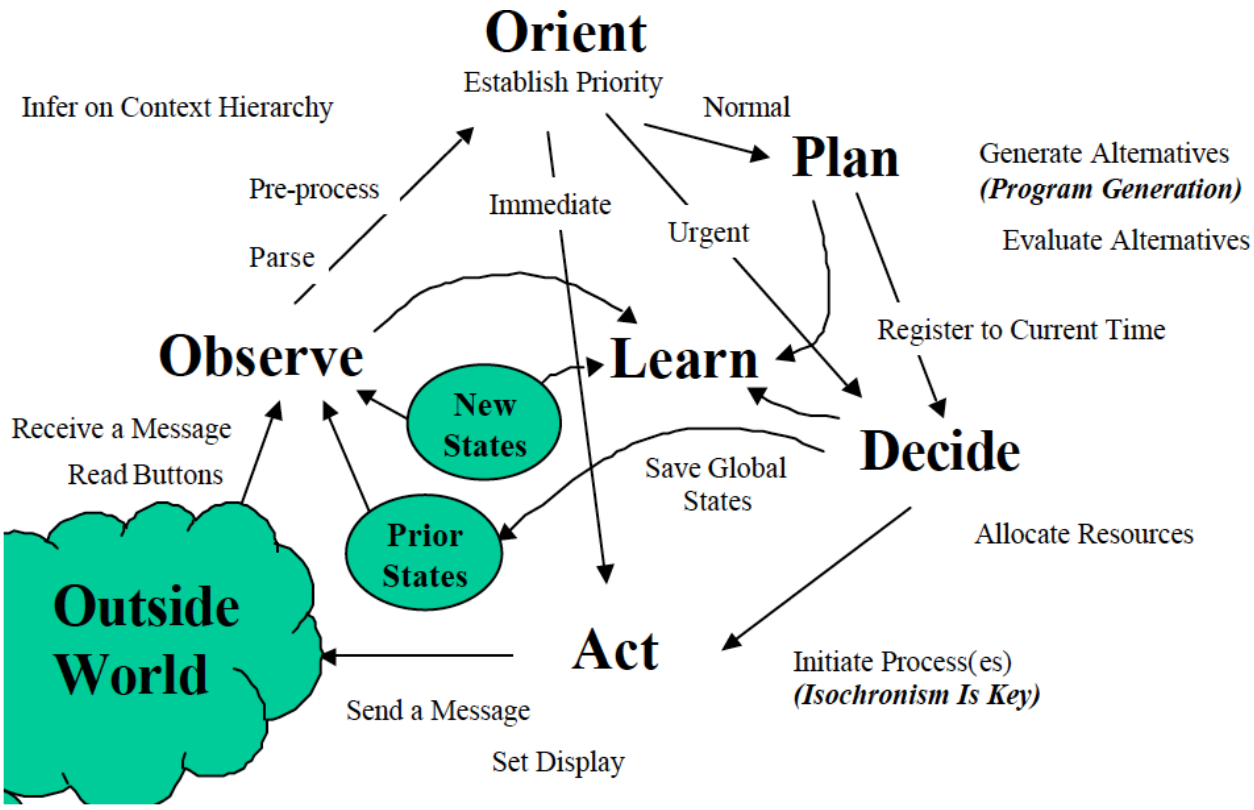

Figure 3 – Cognitive Cycle (source - Joseph Mitola III, *Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio*, PhD Thesis, Royal Institute of Technology (KTH), 2000)

SCaN's current and future are architectures are described it the Architecture Development Document [ADD], which provides a high-level overview.

4.1 SCaN Goals?

Although there are numerous SCaN documents that describe their networks at very high levels as well as the requirements [ADD, SRD], since SCaN's systems do not currently utilize cognition, none of the documentation was written in such a way as to describe what are SCaN Goals with regard to cognitive networking. What goals should be set for a cognitive network system? For a cognitive system, what exactly should the network measure? What metrics should be used to determine if the goals are being met? With no formal document to draw upon, we will assume some generic goals and comment on implementation at an abstract level. The generic goals that could be addressed include:

- Reducing operations costs
- Providing more dynamic, more flexible user services
- Increasing performance (i.e. increase information throughput – goodput)
- Improving reliability
- Increasing security
- Increasing asset utilization

4.1.1 Reduce Operations Costs

It is generally agreed that in order to reduce the cost of operations one must reduce labor costs. There may be some savings in better utilization of hardware, buildings, utilities, etcetera; but it is insignificant relative to the cost of labor. The way to reduce labor is to simplify the architecture and automate processes. Note, a simplified, well thought out architecture will be easier to automate, more reliable, and require much less manpower to operate than one that requires constant manual configuration. Applying cognition to automation may further reduce operations cost; however, that reduction is likely to be much less than the reduction associated with simply automating systems.

Applying cognition to reduce the cost of labor is certainly and interesting problem for a cognitive system; but, one that is more related to general business than computer networking. One would have to instrument the system in a manner to enable measurement of costs relative to stimuli. The needed observables would probably be obtained from the business system database and would include labor and utilities to name a few. Determining the stimuli would be quite interesting. Control parameters could include such things as wage increases, days off, flexible work schedules or free lunches.

4.1.2 Provide more dynamic, more flexible user services

Providing more dynamic, more flexible user services is a user goal. This is a scheduling problem – how best to discover which assets are available under a certain set of conditions and schedule those assets to meet the demands of the user. Depending on the customer requirements, this may be in conflict with 4.1.1, Reducing Operations Costs. Various users will most assuredly have different demands that are also in conflict with each other. In that case the network can provide more flexibility by enabling the procurement of third party services to increase capacity. That will also mean that SCaN will need to assess which facilities and services it should keep and which it should outsource. Unfortunately, it is unclear how a system would be instrumented determine whether or not the goal is being met (what observables and stimuli are available?) and this topic is probably a major study unto itself. This, as is, is much too broad and ambiguous a goal as stated.

4.1.3 Increase Performance (Increase information throughput – goodput)

Increasing performance is certainly a goal that can be measured – particularly if performance is defined as increasing information throughput (goodput[2]). In addition, there are numerous controls that can be adjusted to effect goodput such as scheduling of assets combined with storage, and manipulating radio parameters (e.g. modulation, coding, transmission power, transmission rate, etc…). In addition, this can be done within portions of the network so as to put bounds on the problem. Simply working within the bounds of the point-to-point radio link may provide significant performance improvements. The degree that cognition will add to simple rules-based algorithms is most likely dependent on specific deployment scenarios, which could be modeled and implemented in simulations and in a laboratory environment for relatively low cost. Instrumentation and controls should be readily identifiable for this bounded system.

4.1.4 Improve reliability

A cognitive system has the potential to improve reliability because a cognitive system has to have very good local situational awareness and most likely has additional regional situational awareness and perhaps some global situational awareness. Thus, a cognitive system may be able to autonomously self-repair or autonomously sense a failure within the network or route around that failure. Others have demonstrated this such did BBN in their ANDROIT project [Haigh11].

4.1.5 Improve Security

Cognitive engines have been applied to pattern recognition as well as anomaly detection. Both of these are used in intrusion detection systems (IDS). Furthermore, one can deploy distributed intrusion detection agents where each minimal agent can monitor its own reasoning and reconfigure parts of itself dynamically. Each agent makes a decision on whether a network object is acting according to its behavior specification, which is based on the security policy. These same reflective operations are provided between agents. Thus the management of the whole system is distributed and mutual [Kennedy].

Debar devotes and entire chapter to Intrusion Detection in Cognitive Networks [Mahmound]. Here three OODA loops run concurrently on three operational planes: the Policy plane, the Management plane, and the Network (Device) plane. Each plane exchanges information with the lower and higher planes. The policy plane represents interactions between the network and its operators. The policy plane is built around the security

[2] Goodput is useful information throughput and does not include protocol overhead, coding, or retransmission.

policies and business objectives and associated legal and technical constraints. The management plane takes polices and analyzes and segments the policies according to enforcement capabilities and requirements. The network plane receives policies from the management plane as configuration files.

4.1.6 Increased Asset Utilization

Increasing asset utilization is most likely best accomplished by improving scheduling of the asset or assets. This is a fairly bounded problem with measurable outputs and realizable controls on inputs. Thus, deploying cognitive engines to perform this task is quite reasonable.

Scheduling activities are carried out in the numerous domains of industry including production scheduling, personnel and transportation. Scheduling is a particularly complex activity. From the point of view of the mathematical theory of complexity, it is considered an NP-Difficult problem[3]. Within scheduling, many experts have noted that up to 90% of this time is devoted to the identification of the relevant constraints, with only 10% spent on building the schedule. Thus, it is extremely important to be able to identify relative constraints. Furthermore, schedulers often seek "satisfactory" performance rather than optimal results as this provides a greater degree of freedom and allows schedulers to perform well, even in very complex situations with often-conflicting objectives (constraints). Also, the number of variables that have to be controlled is, in fact, not a very good indication of complexity. This is because the more resources available, the greater degrees of freedom that exist [Cegarra].

Applying cognitive engines to scheduling has great promise because of the numerous degrees of freedom available, the imprecise measure of "goodness" and the ability to terminate the solution once a "satisfactory" result has been obtained.

4.2 SCaN Current Architecture.

In SCaN's current architecture, known as Phase 0, SCaN is an equipment interface provider, not an Internet Service Provider (ISP) or even a Network Service Provider [Figure 4]. Under Phase 0, SCaN manages radios, ground stations, and the Earth Based Relay Element (EBRE) also known as the Tracking and Data Relay Satellite System (TDRSS). Missions use SCaN as a pass through. The mission controls all addressing of mission assets. In fact, this is the basis for current CCSDS datalink protocols [CCSDS135]. As such, there is no unique or global addressing understood by intermediate points and no easy way to route end-to-end. Everything has to be manually configured. The system is basically brain-dead since addressing is mission unique and forwarding is manually configured (albeit perhaps with scripts); thus, it is difficult and probably pointless to put cognition into the communication path except perhaps within the radios.

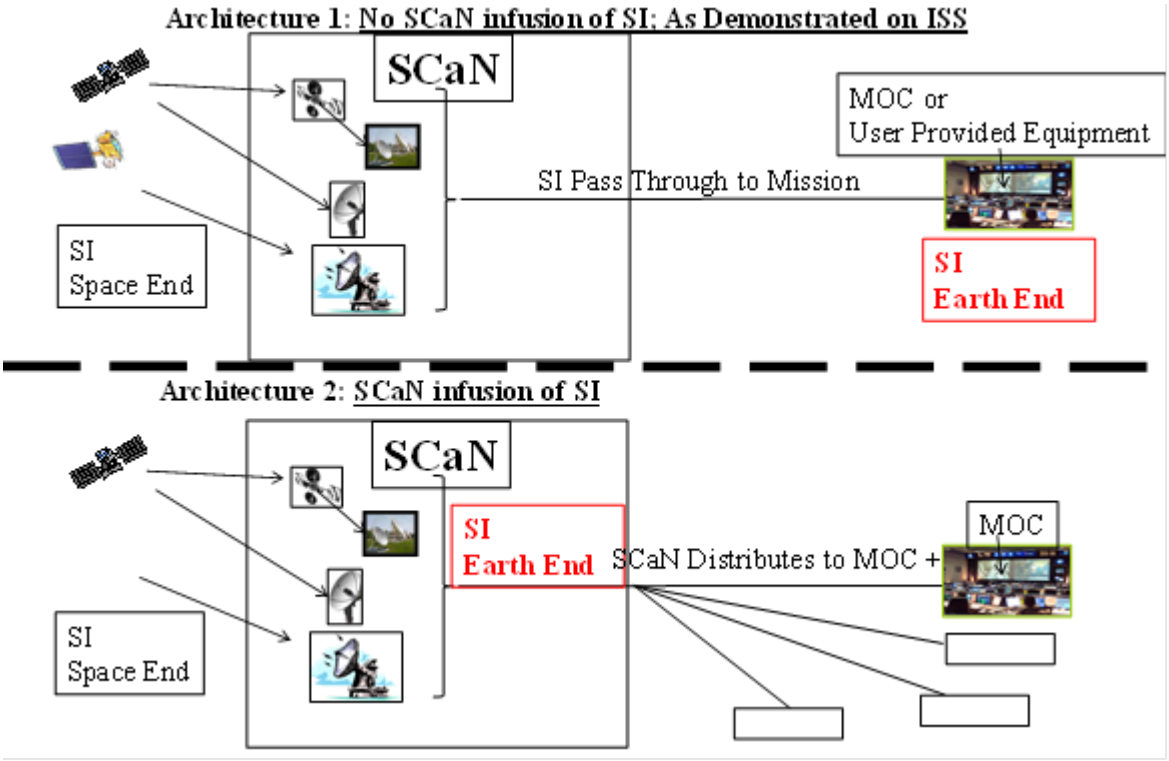

Figure 4 - SCaN Architecture

[3] NP refers to "nondeterministic polynomial time." NP is one of the most fundamental complexity classes in computational theory.

It is important to note that the CCSDS Space Packet Protocol is not routable because it has no global addressing scheme. Rather, it is switchable at the data-link layer with forwarding tables manually configured. Thus, when the Space Packet Protocol is used for end-to-end routing, Space Packets are usually transferred with a Space Link Extension (SLE) Service in the ground subnetwork as SLE enables extension of the datalink between spacecraft and mission operation by effectively encapsulating the datalink into Internet Protocol packets and routing over the Internet. It is also important to note that use of Delay Tolerant Network (DTN) protocols and the DTN network overlay combined with use of CCSDS datalink protocols end-to-end (Mission Operations Center "MOC" to Spacecraft) via SLE is architecturally unsound.

Applying cognition to a poorly architected network will not fix a poorly architected network. On the other hand, having a well-architected network will greatly simplify infusion of cognition.

In SCaN current architecture, "There is no existing SCaN capability or network infrastructure to support Space Internetworking (SI). Since users do not see SI implementations or plans for implementation, their confidence that SI capability will work as advertised is reduced. Lack of SI infrastructure also reduces future user confidence that the SI capabilities will be available when they are needed to support future missions. However, the SGSS project is holding requirements to implement IP over Advanced Orbiting System Encapsulation (AOS/ENCAP) and High-Level Data Link Control (HDLC) for forward and return links—requirements that can be leveraged for implementation of SI." [SI][4]

4.3 SCaN's Target Architecture.

SCaN's target architecture is established in SI study during cycle 3 of the level-2 Program Systems Engineering (PSE) set of architecture studies. Focus was on establishing a reference design for implementing the Disruption Tolerant Networking (DTN) and Internet Protocol (IP) data flow capabilities internal to the network elements [Figure 4, Architecture 2]. Supposedly, this approach essentially covers forward and return data flows within network elements over DTN/IP. The point of the reference design was to provide meaningful information to the Goddard and JPL contractors that do the SN/NEN/DSN engineering in order for those groups to provide cost estimates. It was not an intention that Architecture 2 to be a prescriptive design of what to build, but rather a basis for establishing system costing data.

One requirement presented in the report drives the network architecture design and severely restricts any true networking. That requirement is "No changes at the customer interface on the space link or Mission Operations Center (MOC) sides." This implies a continued use of end-to-end CCCSD datalink protocols from MOC to Spacecraft. Thus, it precludes properly architecting IP and/or DTN networking. Apparently, this requirement was to keep the "status quo" as, on the surface, it appeared too risky and expensive for SCaN to provide layer-3 services. Rather, SCaN could keep doing what SCaN does and if customers wanted to do layer-3 networking, they will have to do it on their own over the existing interfaces. Unfortunately this approach results in the SI model being a "bolt-on" solution, rather than a reworking of the system. As such, it is utterly impossible to show anything but a dramatic cost and complexity increase over the existing architecture.

Also indicated in the report is that Integrated Network Management (INM) and Integrated Service Execution (ISE) were not included in the study's technical or cost data. Network management, address pool management, and other services that an Internet Service Provider (ISP) would normally provide such as time services (Network Time Protocol - NTP), name resolution services (Domain Name Server -DNS), routing (static or dynamic/protocols), security administration (Access Control Lists - ACLs, firewalls, Network Intrusion Detection System - NIDS, etc.) were not considered. Network Management, routing, data prioritization, DTN and security are the areas where cognitive networking is likely to help.

As is, the SCaN target architecture is likely not much better or perhaps no better than the current architecture.

4.4 Request for Information

NASA Glenn Research Center issued a Request for Information (RFI) on February 15th, 2012 seeking information related to "cognitive networking" technologies related to:

- Biologically-inspired networking, autonomic networking, and adaptive networking.
- The application of machine learning and distributed reasoning to network systems.
- Cross-layer design and optimization.
- Dynamic security and intrusion detection.

Responders were asked to address two key area central to our understanding: 1) the application of artificial intelligence to network systems; and, 2) quantifying the effects of added complexity to existing SCaN network systems. In particular, some of the key questions were:

- In what sense are cognitive networks truly "intelligent"? Is it possible to establish a methodology for quantifying the intelligence of these networks?
- Can cognitive networks have a strategy for establishing initial network security parameters and later dynamically modify that strategy after recognizing attempts to disrupt or suppress the data flows in these networks (or gain access to sensitive information)?
- Can cognitive networks be developed that create, process, share, and interpret system information that spans multiple layers of the OSI model?
- Quantification of the computational requirements for cognitive networks. Can cognitive network technologies be reasonably accommodated by

[4] Recent discussions with technical reviewers indicate that the HDLC requirement may be removed from SGSS.

existing systems (including both ground and flight systems)?

- To what extent can cognitive networking tools be used to dynamically allocate system resources or provide automated scheduling of resources?
- How does the introduction of cognitive network technologies impact the modeling and simulation of integrated systems? Will new modeling and simulation tools need to be developed?
- What metrics can be applied (or need to be developed) to be able to quantify the performance gains (or losses) associated with the addition of cognitive networking technologies?

Input was received from several different groups including industry and academia. There was consensus in a number of areas:

- NASA can benefit from further automation of its systems.
- Use of cross-layer communications (Layer-2 triggers) can also be used to improve system performance (throughput) and reduce data loss.
- Cognition, applying learning processing to integrated systems, can provide benefits, with a key caveat: Fast acting processes (millisecond response times or faster) will likely have a difficult time converging with cognition and may be best handled with reconfigurable algorithms whose inputs are controlled by cognitive processes.

4.5 Application of Cognitive Networking to SCaN's Networks

As has been shown in 4.2 and 4.3, SCaN's current and target architectures have very little automated networking. As such, deployment of cognition within the SCaN Network is extremely difficult as cognition is generally applied to add intelligence to automation. There are two areas where cognition may be deployed early on: the scheduling of assets and point-to-point radio communications.

4.5.1 Scheduling

NASA's Deep Space Network (DSN) consists of three deep-space communications facilities placed approximately 120 degrees apart around the world: at Goldstone, in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. It supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The network also supports selected Earth-orbiting missions [DSN]. The mission user committee performs early scheduling. Current tools can generate schedule and identify conflicts, but cannot resolve conflicts. The active scheduling is tightly tied to operational support and is predictive due to latency. For the DSN, network scheduling and network asset scheduling are automated over long time horizons as this is the nature of deep space operations.

"The Space Network consists of a Space Segment composed of the Tracking and Data Relay Satellite System (TDRSS) and a Ground Segment that includes the White Sands Complex (WSC) and the Guam Remote Ground Terminal (GRGT). … The Space Network is operated 24x7, 365 days per year. Operations on the network run above 99.5% proficiency every month." [SN] The Space Network (SN) is highly automated with IT-facilitated early scheduling, which can identify conflicts. Network assets scheduled by software including resolution of conflicts. There is active scheduling with some situational awareness of network configuration and automated configuration & control. There is also capability for real-time decisions on TDRSS operations including real-time reconfiguration and flexible start/stop capability.

"The NEN provides services to a wide variety of mission customers with missions in low-earth orbits (LEO), geosynchronous orbits (GEO), highly elliptical orbits, Lagrange orbits, Lunar orbits, Lunar surface and transfer, sub-orbital and launch trajectories, at multiple frequency bands through all phases of a mission's lifetime." [NEN] The Near Earth Network (NEN) consists of NASA owned ground stations and commercial assets. NASA provides a significant portion of its space communications services by contracting commercial ground station providers to support NASA missions. The NASA portion of the NEN is mostly manual scheduling with intensive early scheduling. There is also manual active schedule integration for NASA and commercial assets and manual data entry for some network equipment scheduling with semi-automated network asset configuration and control via scripting. The commercial portion of the NEN is highly automated within the commercial entity.

It is evident that scheduling of asset is a major concern to SCaN and the automation has been put into place for each of the major radio networks: DSN, SN and NEN. However, for a number of reasons, these various scheduling systems are not integrated. For example, the DSN have very long time profiles with planning occurring years in advance whereas the NEN and SN may include much more near-term and opportunistic scheduling. Some gain may be possible by integrating the systems or by adding cognition.

In order to add cognitive engines to the scheduling system, one must be able to gain knowledge of the improvements (or reductions) in operations via system monitoring; and use those metrics to adjust inputs. One must also identify the goals of the scheduling system such as reduced overall operations costs or increased science. Tuning controls need to be identified that allow the scheduler to autonomously modify schedules or, more likely, use assisted learning to suggest modifications to a human scheduler – at least initially. By monitoring the systems, one may find that users are scheduling assets more often than needed or perhaps at time slots where another could operate more efficiently or at times that a simply convenient for the human operations and research groups. By charging different prices for different operations times (prime time, etc...) one may provide additional degrees of freedom to the cognitive scheduler. The cognitive scheduler may even suggest the optimal costing model.

4.5.2 Cognitive Radio

Unlike many military tactical radio networks or commercial wifi radio systems, which are point-to-multipoint or broadcast, NASA's current deployed radio systems are simple point-to-point links. There is no layer-2 routing or switching taking place and very little adaptation. Nearly everything is preconfigured via mission operations. The most sophisticate radio that NASA currently deploys are those using the Proximity-1 protocol, all others are basically use predefined configuration settings.

The Proximity-1 protocol controls and manages data interchange across the communications link. Proiximity-1 enables the automated selection of communications frequencies, data rates, modulation, coding, and link directionality (full duplex, half duplex, and simplex). The key items are a Hailing channel and the Communication Operations Procedure for Proximity links (COP-P). Hailing is a persistent activity used to establish a Proximity link by a caller to a responder in either full or half duplex. (It does not apply to simplex operation.) Note, it is the responsibility of the caller to use the correctly pre-determined coding, modulation, and data rate in this process. Once communications via hailing is established, both nodes follow their respective operations plans move off the hailing channel and on to an agreed upon working channel The COP-P includes both the Frame Acceptance and Reporting Mechanism for Proximity links (FARM-P), for Sequence Controlled service carried out within the receiver in the Proximity-1 link and the Frame Operation Procedure for Proximity (FOP-P) links for ordering the output frames form Sequence Controlled service carried out in the transmitter in the Proximity-1 link [CCSDS210].

To date, Proximity-1 has performed dynamic configuration control based on rules. Most recently the Mars Science Laboratory (MLS) demonstrated Adaptive Data Rate (ADR) data return technology by monitoring the signal strength between the Mars Relay Orbiter (MRO) and MSL (a.k.a. Curiosity) and then adapting the rover's data transmission rate to maximize the throughput [ADR]. There currently are no known deployments that have incorporated a learning system (cognition) into the radios. However, this is a reasonable place to investigate use of cognition if computational resources are available to handle the additional processing. The Proximity-1 protocol could certainly be used by the cognitive process to implement the negotiations between systems.

SCaN should find rules-based adaptive algorithms to be quite useful in improving performance of point-to-point radio links and may find Proximity-1 to be an effective protocol to use to negotiate radio configurations for all forms of point-to-point radios, not just rover-relay communications as is done by Mars missions. However, Proximity-1 possesses a number of CCSDS properties that may not be necessary such as CCSDS specified identifiers. These identifiers are mission controlled and mission specific which is an undesirable characteristic for generic network deployment.

The next steps that need to be taken for development of a cognitive radio technology are to:

1. Expose meaningful measurable radio parameters to the network controller
2. Provide inputs to the radio to allow the network controller to adjust radio parameters
3. Define the system goals that are to be obtained
4. Perform data mining to determine what parameters provide the greatest gain and under what conditions
5. Automate the radios with rules-base algorithms
6. Finally add a cognitive engine and determine if the additional computation and complexity justifies the improvement in performance.

This should be initially performed in a terrestrial testbed where one can easily control environmental parameters and instrument the systems. Only after thoroughly understanding the problem and solution space should such a system be considered for flight-testing as the cost and effectiveness of terrestrial testing is orders of magnitude better than restrictive space-flight tests. These results will provide input to software defined radio implementations and should serve as a guide for what parameters and controls should be made available in a Space Telecommunications Radio System (STRS) architecture.

4.6 Recommendations for SCaN Cognitive Networking Research

This study concentrates on Cognitive Networking. However, from SCaN's perspective it would be more appropriate to approach the problem of automating systems in a more generic sense. SCaN should approach the problem with regard to Dynamic Adaptive Networking (DAN). DAN includes simple automation, rules-base algorithms, cross-layer communications as well as application of learning systems (cognition) where appropriate.

NASA has to determine whether or not they should be involved in basic Artificial Intelligence and Machine Learning research in any form. This is long-term research and takes real commitment of at least a small team of 4 or 5 full-time researchers.

A detailed network architecture needs to be developed (regardless of use of Cognitive Networking or Automation). This should include all machines, interfaces and protocols with sufficient detail to identify: addressing, wiring, radios and configuration parameters. Minimally, this detail is needed for the portion of the network that one would incorporate cognition into. This detail is required to gain a full understanding of how systems interact. From this information and the system goals, one can identify: what parameters are exposed, what parameters should be exposed as well as what controls are accessible and what controls should be accessible.

With the above information one should be able automate the system and strategically measure performance in order to determine what inputs should be controlled and provide insight as to whether or not the system goals are being met.

The last piece of the research is to move from automation to cognition – adding a learning system.

A reasonable bounded problem that may provide the greatest payoff to SCaN, early on, is to investigate use of cognitive networking toward the problem of scheduling SCaN's major assets within the Near Earth Network (NEN), the Space Network (SN), and the Deep Space Network (DSN) or to simply concentrate on point-to-point cognitive radios.

6.0 SUMMARY

This report clarifies the terminology and framework of cognitive networking and provides some examples of cognitive systems. It then provides a methodology for developing and deploying cognitive networking techniques and technologies. The report attempts to answer specific questions regarding how cognitive networking could benefit SCaN and describes SCaNs current and target networks and proposes places where cognition could be deployed. Finally we conclude that SCaN would be better served to open up the spectrum of solutions for automating their networks by incorporating all aspects of Dynamic Adaptive Networking of which cognitive networking is a subset.

REFERENCES

[ADD] Space Communications and Navigation (SCaN) Network Architecture Definition Document Volume 2 (ADD-V2) Effective Date: November 7, 2011, Expiration Date: November 7, 2016

[ADR] "NASA's Curiosity Rover Maximizes Data Sent to Earth by Using International Space Data Communication Standards," August 2012, https://www.aiaa.org/SecondaryTwoColumn.aspx?id=13350

[Bongard] Bongard J., Zykov V., Lipson H. (2006), "Resilient Machines Through Continuous Self-Modeling", Science Vol. 314. no. 5802, pp. 1118 – 1121, http://ccsl.mae.cornell.edu/papers/Science06_Bongard.pdf

[Boyd] Boyd, John R., "Destruction and Creation," U.S. Army Command and General Staff College. (September 3, 1976). http://www.goalsys.com/books/documents/DESTRUCTION_AND_CREATION.pdf

[CCSDS135] "Space Link Identifiers," Recommended Standard CCSDS 135.0-B-4, October 2009 http://public.ccsds.org/publications/archive/135x0b4.pdf

[CCSDS210] "Proximity-1 Space Link Protocol—Rationale, Architecture, and Scenarios." Recommended Standard CCSDS 210-0-G-1, Green Book. Issue 1. August 2007, .http://public.ccsds.org/publications/archive/135x0b4.pdf

[Cegarra] J. Cegarra, "A cognitive typology of scheduling situations: a contribution to laboratory and field studies," Theoretical Issues in Ergonomics Science Vol. 9, No. 3, May–June 2008, 201–22 http://julien.cegarra.free.fr/docs/ceg-ties2008.pdf

[DSN] NASA's Deep Space Network, September 2012

http://deepspace.jpl.nasa.gov/dsn/index.html

[Haigh08] Haigh, K.Z., Hussain, T.S., Partridge, C. and Troxel, G.D. "Rethinking Networking Architectures for Cognitive Control," Microsoft Research Cognitive Wireless Networking Summit 2008 (June 5-6, Snoqualmie, WA) http://openmap.bbn.com/~thussain/publications/2008_MSRCognitiveWireless_paper.pdf http://openmap.bbn.com/~thussain/publications/2008_MSRCognitiveWireless_slides.pdf

[Haigh11] Karen Zita Haigh, "AI Technologies for Tactical Edge Networks," keynote presentation for MobiHoc 2011 Workshop on Tactical Mobile Ad Hoc Networking, May 2011. Paris, France. Paper: http://www.cs.cmu.edu/~khaigh/papers/Haigh-MobiHoc2011.pdf and slides: http://www.cs.cmu.edu/~khaigh/papers/11-mobihoc.ppt.

[Haigh12] Karen Zita Haigh, "Artificial Intelligence for Cognitive DSA," invited presentation for International Waveform Diversity & Design Conference, January 2012. Kauai, Hawaii.

[Ivancic2005] William Ivancic, Phil Paulsen, Dave Stewart, Dan Shell, Lloyd Wood, Chris Jackson, Dave Hodgson, James Northam, Neville Bean, Eric Miller, Mark Graves and Lance Kurisaki: "Secure, Network-Centric Operations of a Space-Based Asset: Cisco Router in Low-Earth Orbit (CLEO) and Virtual Mission Operations Center (VMOC)," NASA/TM-2005-213556, May, 2005

[Kennedy] Catriona M. Kennedy, "An Experimental Intrusion Detection Prototype based on Cognitive Architectures," School of Computer Science,University of Birmingham, UK, 2008

[Kliazovich] Dzmitry Kliazovich, Fabrizio Granelli, Nelson Luis Saldanha da Fonseca,"Which Architectures for the Cognitive Networks of the Future?" ICaST - ICSTs Global Community Magazine Article, Sat, 09/25/2010 - 10:40

[Mahmound] Cognitive Networks: Towards Self-Aware Networks, John Wiley and Sons, Copyright 2007

[Mitola1999] Mitola, J., III, "Cognitive Radio for Flexible Mobile Multimedia Communications," 1999 IEEE International Workshop on Mobile Multimedia Communications (MoMuC '99) 1999 Page(s): 3 - 10

[Mitola2000] Joseph Mitola III, Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio, Phd Thesis, Royal Institute of Technology (KTH), 2000

[NEN] Near Earth Network (NEN), September 2010 http://esc.gsfc.nasa.gov/space-communications/NEN/nen.html

[OCT_TA05] NASA Communication and Navigation System Roadmap Technology Area 05, April 2012, http://www.nasa.gov/pdf/501623main_TA05-ID_rev6_NRC_wTASR.pdf

[OCT_SRTP] NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space, National Academy of Sciences, 2012, http://www.nap.edu/catalog.php?record_id=13354#toc

[SI] D. Israel, et el, "Space Internetworking Trade Study for the SCaN Integrated Network Architecture," May 2012 – Draft

[SN] NASA's Space Network, September 2012 https://www.spacecomm.nasa.gov/spacecomm/programs/space_network.cfm

[SRD] "Space Communications and Navigation (SCaN) Network System Requirements Document (SRD) Version 1 – Pre-Integrated Network Phase," Revision 1, November 2011

[Thomas] R. W. Thomas, L. A. DaSilva, and A. B. MacKenzie, "Cognitive networks," in IEEE DySPAN, (Baltimore, Maryland), pp. 352–360, Nov. 2005.

[RFI] NNC12ZRH011L, http://prod.nais.nasa.gov/eps/eps_data/150176-OTHER-001-001.docx

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Mr. Ivancic is also principle of Syzygy Engineering, a small consulting company specializing in communications systems and networking as well as advanced technology risk assessment. Mr. Ivancic is currently performing research and development on Identity-based security and key and policy management and distribution for tactical networks - particularly mobile networks.

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