Systems architecting and engineering processes and methodologies: essential enablers for the acceptance of SDR into "the mainstream"

James Rodenkirch, Senior Technical Advisor to Diversified Technology, Inc.
Bill Bolick; Federal Programs Manager, Diversified Technology, Inc.
Members of the SDR Forum and the Public Safety SIG
Contact information:
James Rodenkirch; e-mail: Rodenkirch_llc@msn.com
(Cell phone: 435-773-1486)
Bill Bolick; e-mail: bbolick@dtiruggedpower.com

Abstract. Future mainstream users of Cognitive Radios are eager for solutions to the problems and constraints associated with wireless space. Myriad user activities and functions, legacy communication systems and competing agencies overseeing the user communities signal a rich environment for Systems Architected solutions. Cooperation between the user and the builder, along with a melding of overarching visions and concepts with pragmatic outlooks, will be pivotal for the correct solution to materialize.

This paper explores the benefits of developing and executing architectural products. Relevant use cases are utilized to articulate constraints and problems associated with the needs of the user and the builder. Discussions will center on those Complex System architectural products that provide the Cognitive/Cognitive Radio community with solutions from a "set of solutions" – e.g., equipment upgrades or new purchases; changes in leadership, doctrine, organization or policies; updated training; improvements in/to facilities.

The discussion will be bounded by heuristics that Systems Architects and Engineers must employ. Additional System Architecting embellishment and emphasis will be provided through real-life examples of bottom-up and top-down architecting successes.

1. **Introduction**

Mainstream customers and users of wireless radio communications systems, most notably First Responders and the War Fighter, are searching for solutions to the growing list of problems and constraints associated with the multi-layered complexity of the current and future wireless communications space.

For a small user community's First Responder system the resources required to "do the job" -its organization and management, and training requirements - are, typically, easier to fulfill and/or meet. However, when the user community is expanded 20 to 100 times or more across a mega-community (i.e., large city U.S.A.) the management of it all to ensure interoperability across the many users from many participating agencies and departments is a challenge. The list of constraints and problems is formidable and growing; a high level operational view - an architectural rendition - of the Wireless Communications system for the City of New York's First Responder capability could easily take on the intricacy and complexity of a similar view of a complex system such as the Global Information Grid. (see Figure 1.)

Figure 1

The First Responder System (FRS) for a "large town, U.S.A" entity such as New York City is a complex system. The component systems were chosen from myriad manufacturers (a "buffet" of choices commonly referred to as a Family of Systems) and funded by agencies that may or not be working closely together. The individual groupings of communication systems were acquired separately (Fire Department, Police, supporting Federal agencies, etc.) and maintain a continuing operational, yet independent existence; e.g., the FD communication system works well before and after it was deployed to a natural disaster where myriad agencies responded. A large FRS does not appear fully formed – its development and existence is evolutionary with functions and purposes added, removed, and modified as new "challenges" or scenarios are identified and planned for. The FRS performs functions, i.e., provides capabilities, that do not reside in any component system or singular participating groups and the loss of any component will significantly degrade the performance or capabilities of the entire FRS. Finally, the FRS encompasses a wide/large geographic extent as information, not energy or mass, is exchanged between component systems.[1]

2. Architecting Complex Systems

Complex Systems cannot be developed without architectural products; its very name -"complex" - signals the need for more than core or traditional S.E. methods and practices. One of the 'new' engineering methodologies and processes associated with Systems of Systems Engineering is Systems Architecting. For one of the user groups of interest for the SDR Forum, the War Fighter, architectural product development, based on the DoD Capability Based Assessment (CBA) methodologies, is now the "order of the day" and interoperability measurements for Department of Defense (DoD) Systems of Systems (i.e., complex systems) loom large on any systems engineering team's radar screen. The resulting architectures are utilized to integrate myriad, diverse systems selected from many Family of Systems (FoS) components resident amongst varied agencies – sound familiar? These architectures are used to evaluate the "as is" state – the current state for the complex system - for gaps and develop the "to be" state – what the complex system will look like when the gaps are filled and/or new technologies, organizational changes, etc. have been incorporated. The specific analyses are grouped into what's called a Capability Based Assessments (CBA). For an FRS the capability (in short, what a complex system is expected to do) could read "respond successfully to an emergency with full-up local, state and federal agency involvement."

3. The Total Solution Space/Set

Developing the architecture for these complex systems requires an awareness of complex systems engineering *considerations* or *factors*, e.g. *organizational, political, societal, physics and technological,* that may not have been considered during the development of the current complex system's individual component systems or equipment (particularly legacy equipment); i.e., the solution does not or may not necessarily be a materiel one. In order for a capability development effort to be successful – assure the customer and user that it is interoperable and reliable - members of a CBA team must consider or weigh all factors before the final decision on what the final solution is made. The total solution set – considered and reviewed at all points along the architectural product development path and in the context of architectural development and complex system constraints and variables - includes:

- The **D**octrine under which the complex system operates (***organizational and political***)
- The **O**rganizational construct or hierarchy for the complex system (*organizational, political, and societal*)
- Missing, ineffective or new **T**raining requirements for operators and maintainers (***organizational, technological, political***)
- Improved or a total new development of **M**ateriel components – e.g., the actual Cognitive Radio (***physics, technology, improved legacy systems***)
- With myriad agencies, some of whom can be viewed as "in competition" with other agencies contributing people and equipment to the response, and not prone to respond rapidly simply because an on-scene commander from a competing agency said something needed to be done, one often sees the need for an emphasis on **L**eadership (***organizational, political, societal***)
- Diverse **P**ersonnel requirements; with myriad agency participation, homogeneity (e.g., one group of many synchronized into what one could call a "one service" perhaps?) will give way to a heterogeneous environment (***organizational, political and societal***)
- The numerous **F**acilities or infrastructure support requirements; with multiple agencies participating comes varied facility needs (***organizational, political, physics, and technological***).

Whether one looks at the domain of a First Responder or the War Fighter one can be assured that a plethora of legacy communication systems will continue to "hang around" for the foreseeable future (e.g., the result of shrinking or stagnant budgets) and competing or non-cooperative agencies within either domain will continue to oversee and influence/direct the heterogeneous group of users required to make it all work while saddled with legacy systems. This is an example of one of many intersections of the diverse solution space – **M**ateriel (the communications systems), **O**rganizational (diverse, competitive agency participants and stakeholders) and **L**eadership demands (extracting working relationships out of those competitive groups). When those intersections are coupled to a significant increase in the numbers of users competing for the same wireless "space" – the solution space has expanded to include **P**ersonnel, **O**rganization, **D**octrine, and **T**echnology considerations. Thus, for the aforementioned as well as other intersection scenarios, a dynamic and tenuous environment exists and the need to employ architected solutions is absolute.

Given the complexity of these systems (myriad users, agencies, physical separation, the politics, societal differences of the agencies, the multiple, non-interoperable systems, etc.) and the desired end state - an efficacious system - every architecture attribute, complex system engineering consideration and factor must be traced directly to and adjudicated via a complex engineering mapping - requirements definition, analysis of alternatives, and synthesis - to the total solution space, **D**, **O**, **T**, **M, L**, **P**, and **F** (DOTMLPF)[2]. That is a challenge and the contributions of a Systems Architecting team – developing architectural products that demonstrate, from an interoperability perspective, the reliability and efficacy of a complex system such as FRS - is essential for that challenge to be met.

4. **Complex systems and Capability Based Assessments (CBA) or Capability Base Planning (CBP)**

What is the purpose and advantage of a CBA or CBP? One of the major frustrations of previous efforts and processes employed to understand the requirements has been that solutions are introduced to "the system" without any higher-level rationalization. The intent of introducing the concepts of a CBA or CBP is to replace statements such as "we need a more advanced fighter," or "we need a more advanced radio" with "we need the capability to defeat enemy air defenses" or "we need the capability to streamline our communications and improve interoperability with all user communication devices." The latter "statements" provide the rationalization for needs based on requirements while promoting competition among solutions. Note: In the context of this paper, CBAs and CBPs are similar enough that one can be likened to the other.

In the context of complex systems, which an FRS certainly falls under, the architectural development process associated with CBAs relies on two sets of architectures, the "as-is"and "to-be" products.

The "as-is" architecture defines and portrays the state of the complex system today. Knowing how it looks today allows architects and systems engineering to evaluate where solutions are needed AND affords opportunity for effective measurements of efficiency, efficacy and success when a new architecture is developed. Note: The selected solution(s) for "the need" required in order for the "as is" architecture to function better or faster will come from the total solution set mentioned earlier.

The "to-be" architecture defines and portrays the future state of the complex system – how it will look when the needed solution(s) to the problem are implemented. Additionally, the to-be architecture is the focus for the follow-on M&S effort – where the measures of efficiency and performance are acquired.

The fundamental tenet or process for any CBA and the associated architectural development effort is (see Figure 2, page 5):

- Define the desired mission or "capability"; in the case of an FRS it could read: respond rapidly to a catastrophic incident and effectively suppress the catastrophe through effective management of, and communications with, available resources.

- Develop scenario(s) that showcase the capability; often, in complex system analysis, > 1 scenario will be required to faithfully replicate the many arrangements of the myriad systems and users. Note: Scenarios must be articulated in enough detail to allow for the identification of every activity associated with the users or actors associated with the scenarios; anything less will result in a less than accurate depiction of all user activities.

- Identify and document all system functions required by the user to complete the activities successfully. This emphasizes the need for a complete and accurate depiction or description of the user activities – without knowing all activities one won't know all of the system function required.

- Identify and document the systems available for use by the user.

- Identify and document the functions each available system offers.

- Map all system functions to user activities.

At this point, with the required DoDAF architectural products in hand, the system architect and engineer can perform a static assessment to identify gaps – i.e., specific locations in the function to activities mapping matrix where no function is available for the user; most often, there is no system available for purchase that provides that function.

With a list of gaps – system functions required by not available – the system architect and engineer can begin searching for other systems available today that can provide those functions. If current systems are not available the search for future systems has to be initiated. Finding THE system(s) that will provide the needed functions, is reputed to be interoperable with the legacy systems (today's complex systems contain legacy systems – totally new system development is simply too costly) and will be available when required is a daunting task. Additionally, future systems generally await new technologies to be developed thus there myriad constraints on any expectations that the new system is "right around the corner." In short, the search can be daunting.

When the search is complete and the required new system(s) have been identified a new set of architectural products are required – the "to-be" architecture. Here is where the architect redraws those architectural products that reflect the new system functions and their mapping to the user activities. Additionally, some proof of their efficacy along with the validation that the "new complex system" will work as predicted; here is where the Modeling and Simulation (M&S) support appears. M&S support teams are required as they will construct a computer model of the complex system, work their magic and run the million of excursions/iterations, and assist the architecting teams at those points in the architecture where M&S results highlight where "what ifs" changes are required; e.g., choke points or bottle necks appear during the M&S computer runs.

And, when the M&S efforts are complete and the re-drawn "to-be" architectural products are finished, a roadmap architectural product is required. The systems architect and engineer, via the roadmap product, communicates, to the user, the time frame(s) when the solution or its incremental build schedule will be available. The DoDAF has an excellent set of roadmap products - a system evolution description and system technology forecast. With these two products the systems architect and engineer can track development, delivery and integration of specific system functions as well as the arrival of new technological developments required before the new system can even begin to be designed and developed.

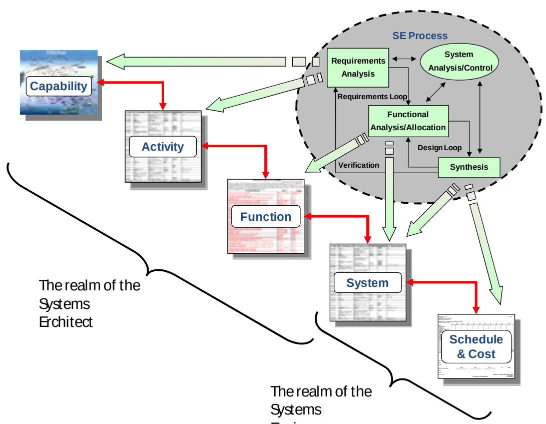

Figure 2

Assessing complex systems competently is a "full contact sport." The range of architectural products required to accurately assess the required capability can be broad and complex systems architecting is not something a couple of people go about doing. A fairly large team of people is the norm as few architects/engineers offer the breadth of experience required and the amount of work accomplished can be substantial.

Note: Albeit in its infancy stage, the development of a complex systems architecture that highlights the need for a Cognitive Radio is underway as the Public Safety SIG's Cognitive Use Case Group completes its scenario development efforts. Most importantly, the tenets and methodologies associated with Capability Based Assessments (CBA) are being discussed AND several architectural products have been developed and the vetting process regarding their efficacy and need is underway.

5. **Complex system architects, engineers, user and builders**

The architecting of complex systems, or Systems of Systems (SoS), leads to solutions. However these solutions can't be initiated, designed, or implemented without total cooperation between the user and the builder. The "glue" that encourages and sustains that cooperation can be found in the relationship between the Systems Architect (who works for the user/customer) and Systems Engineer (who works for the builder). The tightest coupling imaginable is required these two entities to work together towards the delivery of the solution – an effective yet as simple an architecture as possible that drives successful initiation and completion of the Systems Engineering phases – requirements understanding, the solution's design, the building and integration of the solution into the rest of the complex system, along with successful testing and final sell-off to the customer.

An aside note: understand that the user is not just one user but a mix of users with varying requirements, resources, and competing territory – thus, a Complex System with all the attributes and characteristics annotated above!!! In addition, let us not forget that "the builder" will not be just one but a complex, evolving and contrasting mix of manufacturers/builders and, in its own right, a Complex System!!!!

The much hoped for synergy of a complimentary mixing amongst those complex systems – the solution, the user of that solution and the builder/solution provider – will require the builder's overarching visions and concepts to be melded with the pragmatic outlook one expects from a customer – all achievable via rigorous complex systems architecting and engineering and the singular reason why advocacy groups such as the SDR Forum need to embrace and promote the accompanying concepts and practices. Not promoting complex systems engineering thinking will engender or sustain short sighted thinking such as what was espoused at an earlier SDR Forum setting - "software defined radio technology will force the user to operate completely differently." In a positive disruptive technology sort of vein that may be true but only sound architecting efforts and the resultant products will lead the user and customer to embrace and demand a material solution – the "M" solution – amongst other solutions from the total solution set that includes a Cognitive Radio. Without the "buy in" that architectural products can and will elicit from the users the customer base will continue to wrestle with their continuing dilemma – how to spend the few communication system upgrade dollars judiciously under a burgeoning and ever changing organizational and political landscape!

6. **Summary**

Users of complex wireless systems, the potential builders of Cognitive Radios and the SDR Forum face a new and complex system environment today. Considerations or factors that can influence that system's capability and reliability map directly to the types of architectural efforts underway within DoD. The authors state unequivocally that a reliable, interoperable complex system that's populated with Cognitive Radios cannot be realized without the inculcation of rigorous System of System engineering and architecting processes and methodologies. This inculcation of architectures, CBA processes and methodologies cannot be realized unless the SDR Forum promotes an environment where users, customers and builders plan, collectively, the development and employment of a system of systems, via robust scenarios, for the "as-is" and the "to-be" complex system architecture. From that architecture and analysis a viable Cognitive Radio solution will be the result.

Suggested preparatory or on-going activities for promotion by the Forum include:

1) Gaining insight into the CBA processes and the methodologies associated with SoS development and understanding the process associated with the development of architectural products under architectural frameworks such as DoDAF.

   An aside note: Some insights into the CBA process and some preparatory work have begun in working groups like the SDR's Public Safety SIG. No one should infer that the Forum or its groups are promoting DoDAF-specific products. However, the concepts are critical to ensuring the Forum's success at gaining buy-in from the user that a Cognitive Radio meets their needs. If the architectural products are developed correctly in a partnership-like manner with the user communities the SDR Forum can trumpet loudly that it influenced the decision process positively – isn't that what it's all about?

Suggested preparatory activities (continued)

2) Factors and considerations mentioned previously - political, societal, organizational and technological - will influence the cultural environment that SoS engineering and architecting teams work in. Gaining a deeper understanding of how those influencers play into that culture will facilitate the interaction between SDR forum members and the users, stakeholders and customers of the future Cognitive Radio.

[1] Maier, M.W. (1996) "Architecting Principles for Systems-of-systems." Proceedings of the 6th International Symposium, INCOSE 1996.

[2] Extracted, in part, from the Defense Acqusition Guidebook; Version 4.5 9p99). Retrieved from the following URL: http://akss.dau.mil/DAG/Guidebook/ IG_c4.2.6.asp