Battlespace Communications Network-of-Networks Interface Modelling

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Abstract— **This work focuses on the proposed Network-of-Networks Interface Model (NIM) at the center of the Battlespace Communication System Land (BCS(L)) being developed for Australian Defence Force. The NIM seeks to resolve network interfaces in a Network-of-Networks construct through the application of Systems Engineering. The notion of Network-of-Networks (NoN) is analogous to System-of-Systems (SoS), but with additional challenges to incorporate Information Exchange as well as application of Open Systems Interconnection (OSI) model in the identification, specifications and design of interfaces. Simulation and data modelling techniques are employed to capture network interfaces for the proposed BCS(L) NoN with executable results reported.**

Keywords—System-of-Systems, Network-of-Networks, IER, OSI Model, Interfaces, Requirements

I. Introduction

The Australian Defence Force (ADF) is fast moving towards digitised Command, Control, Communications, Computer and Information (C4I) warfare environment. A pre-requisite enabler for the C41 dominated warfare is a reliable communications infrastructure manifested in the form of Network-of-Networks, analogous but engineering-wise different from System-of-Systems concepts employed in large scale Air / Maritime weapon systems [1]. A key Systems Engineering problem in the realization of Network-of-Networks is defining the self-contained network constructs (Configuration Items or Network Nodes) and resolving the interfaces between them. The Systems Engineering problem is further complicated when the Information Exchange Requirements (IER), a key consideration in the design of military communication systems, are required to be incorporated in the Network-of-Networks system integration issues.

The ADF Battlespace Communication System – Land (BCS(L)), composed of multiple acquisition projects, represents an ensemble of networks that interact to achieve one or more Land communications capabilities, such as voice, data and/or video services. From an operational architecture perspective, these services are delivered to Operational Node(s), essentially a varying operational construct, satisfying the IER for each User. From a network architecture perspective, the services are materialised through Service Delivery Points (SDP) [4] to the Network Node(s), essentially a network construct, satisfying network functionalities through a set of infrastructure elements.

Instead of working to an Operational Node connectivity pattern that typically addresses the IER between the operational entities, the BCS(L) nominates Network Node interface patterns as the constituent construct of the Network-of-Networks concept. This construct is an abstraction to represent the operational entity (*Performer* in a modelling language) that shares a collection of ICT infrastructures forming the Network-of-Networks. Network-of-Networks are, holistically, a collection of network interfaces between the Network Nodes. The NIM is different to several works reported previously [2] [3], because it focuses on delivering operational information to Users associated with the Network Nodes across a multitude of networks. There are several technical advantages to employ a NIM approach, but most importantly it provides flexibility in acquiring communications capabilities to ADF future [5] force structures.

II. Battlespace communicaiton System (land)

BCS(L) is the pivotal communications network infrastructure for conduct of ADF's Land warfare within the Joint Combat environment. The network infrastructure enables the information services required by military commanders to make timely decisions. The BCS(L) together with User Applications forms the Land Network, a key component in the modernisation of the Australian Army. To that effect, the BCS(L), provides, among others, communications and network services required for effective Command and Control (C2), connectivity between deployed and tactical forces, and extending the strategic communications services into deployed and tactical area of operations. The BSC(L) is also required to maintain interoperability with legacy systems and to support Army's interoperability within ADF and Coalition operations.

The Australian Army, though, view the Land Network as a single logical capability, the communications network infrastructure is actually comprised of physical components with specific mobility characteristics being fixed, deployed, and mobile, segmented by Defence Terrestrial Communication Network (DTCN), Battlespace Telecommunication Network (BTN), and Tactical Communication Network (TCN) respectively. Operationally [5], the deployed and mobile networks are seen as Core, Edge, and Backbone elements of the holistic network system, as shown in Figure II-1.

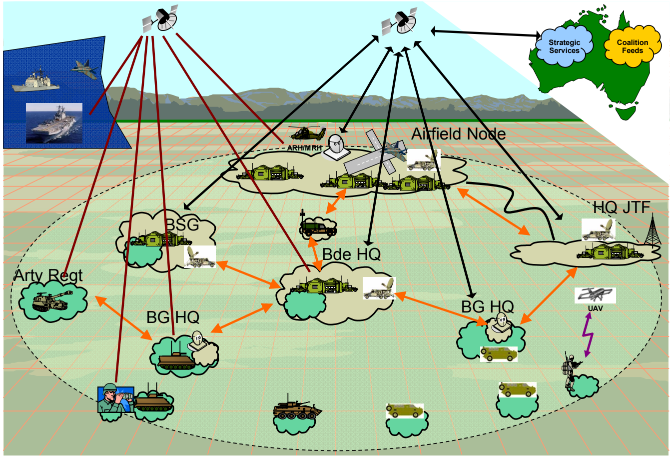

Figure II-1 Land Network Topology

III. Network of Network Interface Model

The NIM is built upon:

- Providing repeatable constructs for identification, specification, and verification of interfaces in Network-of-Networks operating with TCP/IP and custom protocols in support of multiple User Applications.
- Identifying and specifying Network / System - External Interface (EIF) in a vertical construct between the User Applications and Communication Systems within a Network Node (NN).
- Identifying and specifying Network / System - Internal Interface (IIF) in a horizontal construct between the Communication Systems among the Network Nodes.
- Attributing each Interface Requirements Specification with the causal Information Item in IER.
- Tying, in a parent child relationship, the Information Item provided by external User Application.
- Quantifying and measuring the performance of Network / System interfaces with the size and frequency of the Information Item and in turn the messages exchanged between Users via User Applications.

The Network-of-Networks interface model, illustrated in Figure III-1, caters for horizontal sharing of the network infrastructure by external applications (User Applications) such that the infrastructure is not vertically tied to a particular User Application. The User Applications represents External Interfaces (EIF) to the Network infrastructure. The communications between the User Applications characterise the operational information exchange between the User(s) associated with the Network Nodes in a Network-of-Networks. Internal Interface (IIF) in the network infrastructure includes all interfaces between elements of the infrastructure, typically housed in the Network Nodes (NN) but operating in various layers of the OSI model. The interface pattern from the Network-of-Networks interface model provides BCS(L) with a means to specify network interfaces (internal and external) in a consistent manner from the perspective of Systems Engineering.

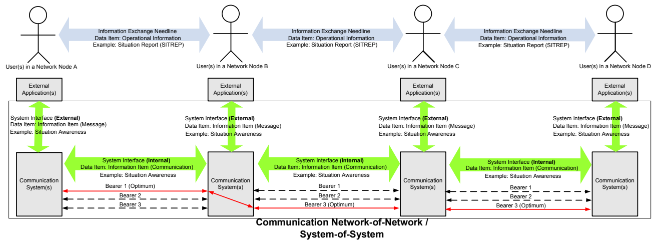

Figure III-1 BCS(L) Network of Network Interface Model

Implementation of NIM for specifying BCS(L) interfaces with external User Applications requires harmonisation of Information Definition and alignment of Information Items.

A. Harmonisation of Information Definition (IDF)

A hurdle in an universal implementation of NIM for is harmonization of Information Definition nomenclature and content used in developing IER for military communications. The NIM employs Information Definition (IDF) [6] as the reference Index Scheme, such that an Information Item defined by any organization/ project is indexed to the reference IDF scheme. The results can be presented in a nomenclature and content preferred by the project. The process is illustrated in Figure III-2, where the Information Items employed by external User Applications are owned by two fictitious projects: JP XYZ, and LAND ABC. These Information Items are indexed to the reference IDF Scheme for specifying external interfaces between BCS(L) and the external User Applications. Other Information Definition schemes with a hierarchical structure and unambiguous descriptions are equally suitable. An Information Definition scheme with semantic definitions describing the data structure will be an added advantage, though not necessary, to support the NIM.

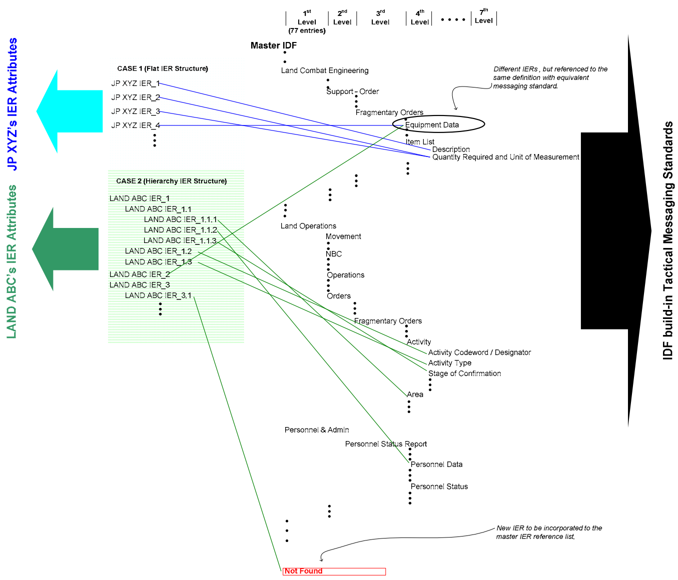

Figure III-2 Harmonization of Information Definition

B. *Alignment of Information Item Attributes*

No two Information Definition schemes have an identical hierarchy. Alignment of Information Item attributes between any two IDF schemes is essential to specify the BCS(L) external interfaces with User Applications. The NIM first seeks to align another IDF with the common highest corresponding entity in the BCS(L) IDF Scheme, and then work downward to capture the required attributes for an Information Item. The alignment process terminates when the attributes of an Information Item from the external User Application are mapped to a message item in the corresponding hierarchy of BCS(L) IDF Scheme. The alignment process is depicted in Figure III-3.

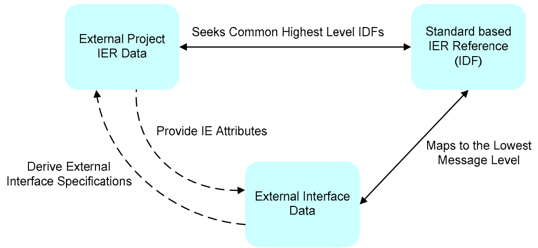

Figure III-3 Alignment of Information Items Attributes

Implementation of NIM for specifying BCS(L) internal interfaces requires first obtaining applicable Network Nodes and then implementing OSI Model for peer to peer interfaces between Communication Systems within a NoN construct.

C. *Obtaining Applicable Network Nodes for Internal Interfaces*

ADF Land Force operates in a nodal structure, currently reflected by 15 unique BCS(L) Network Nodes, conveniently represented as A - O in this paper. Each BCS(L) Network Node supports one or many Users out of 19 types of Network Users, defined by Land Network Concept [5], though represented as I - XIX in this paper. Applicable Network Nodes for BCS(L) internal interfaces are obtained in two stages. First, with the help of ADF operational community, a pair is established between Network Nodes and Users, illustrated in Table III-1, such that no User is missing from the BCS(L) internal interfaces.

Table III-1 Network Nodes and User Pairs

		BCS(L) Network Nodes														
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
BCS(L) User Types	I	1														
	II		2				9									
	III			3			10									
	IV				4	6										
	V				5											
	VI					7										
	VII					8										
	VIII							11	14							
	IX							12	15		18					
	X							13	16	17						
	XI										19					
	XII											20				
	XIII											21				
	XIV											22				
	XV												23			
	XVI												24			
	XVII													25		
	XVIII													26		
	XIX														27	28

A total of 28 pairs were found in Table III-1. Each of these pair (*N*) represents a string of Network Node and User Type in the form of (*NN_User*). Second, the pairs are extrapolated to obtain an N^2 Matrix shown in Table III-2, such that no Network Node is missing from the BCS(L) internal interfaces. Based on the N^2 Matrix, potentially 784 Internal Interfaces (IIF) are to be managed by BCS(L). However, limited by the military command structure, and the ADF's operational environment, not all constructs within the N^2 Matrix in Table III-2 are applicable for obtaining a valid set of Network Nodes for BCS(L) internal interfaces. The legitimate IIF are derived by considering information need (*Needline*) between the pair of *NN_Users*, resulting (x) in an applicable subset of the N^2 Matrix in Table III-2. This subset represents the most generic information exchange pattern between the Users associated with the Network Nodes subjected to internal interfaces of the BCS(L).

Table III-2 N^2 Interface Matrix for BCS(L) Network Nodes

	NN_User 1	NN_User 2	NN_User 3	NN_User 4	NN_User 5	NN_User 6	NN_User 7	NN_User 8	NN_User 9	NN_User 10	NN_User 11	NN_User 12	NN_User 13	NN_User 14	NN_User 15	NN_User 16	NN_User 17	NN_User 18	NN_User 19	NN_User 20	NN_User 21	NN_User 22	NN_User 23	NN_User 24	NN_User 25	NN_User 26	NN_User 27	NN_User 28
NN_User 1	X	X	X		X	X	X	X	X	X	X																	x
NN_User 2	X	X	X						X	X	X	X		X	X													x
NN_User 3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	
NN_User 4			X	X	X	X				X	X					X	X	X	X	X	X	X	X					
NN_User 5																												
NN_User 6			X																									
NN_User 7	x	x																										
NN_User 8																												
NN_User 9	X	X	X	X	X				X	X	X	X	X	X	X	X	X	X										
NN_User 10		X	X	X					X	X	X	X	X	X	X	X	X	X										
NN_User 11		X	X	X					X					X	X													
NN_User 12		X	X	X		X			X	X	x	x	X	x	X	X	X	X										
NN_User 13			X	X	X	X				X		X	x		X	X	X	X	X				X					
NN_User 14		X	X	X	X				X	X	X	X		x	x	x	X											
NN_User 15		X	X	X					X	X	X	X	X	x	x	X	X	X										
NN_User 16			X	X	X	X				X		X	X		X	x	X	X	X									
NN_User 17			X	X	X					X		X	X		X	X	X	X	X				X					
NN_User 18			X	X	X					X		X	X		X	X	X	x	X				X					
NN_User 19				X				x		x			x			X	X	X	x					X	X			
NN_User 20			X	X						X		X	X		X	X	X	X	X	X	X	X	X			X		
NN_User 21			X	X												X	X	X	X	X	X		X	X			X	
NN_User 22				X																		x						
NN_User 23				X	X								X			X	X	X	x	X	x			X				
NN_User 24																			X		X		X		X	X		
NN_User 25																								x				
NN_User 26																								X	X	X		
NN_User 27																										x		
NN_User 28																												

D. *Implementing OSI Model for Peer to Peer Interfaces*

Like any other system integration, the internal interfaces are required to ensure a seamless integration of the networks in a Network-of-Networks. As a general rule, BCS(L) internal interfaces are peer-to-peer interfaces, typically under the OSI Model, that enable the networks to operate to a common protocol stacks, such as TCP/IP. However, BCS(L) is a unique communications system comprised of networks which operate different protocol stacks. Networks operating different protocol stacks do not natively integrate into a network-of-networks given their incompatible peer-to-peer interfaces. The BCS(L) Network-of-Networks design has introduced an overarching networking mechanisms, called Tactical Gateway, to enable inter-operation of individual networks. From the perspectives of the BCS(L) NIM, Tactical Gateways are the interface break points. Such that boundaries for peer-to-peer internal interfaces are determined considering the applicable common protocol stacks. A new internal interface is introduced where a different protocol stack is employed. The breaking of the internal interface is essential to realistically model: a) self-contained networks within BCS(L) and their inter-operation, b) performance of the interfaces, and c) performance of the integrated BCS(L). The example in Figure III-4 illustrates the concept of modelling Tactical Gateway within the BCS(L).

Within the Tactical Gateway subsystem, the vertical interfaces are characterised by a cascade of state-transition diagrams, such as the RFC 793 Transmission Control Protocol [7], shown in Figure III-4. Protocol translation is executed in the Application layer, where the execution behavior is captured as the top layer of state-transition diagram. This modelling construct allows the NIM to adequately capture the Tactical Gateway characteristics, and in parallel to serve as the breaking-point of the BCS(L) internal interface.

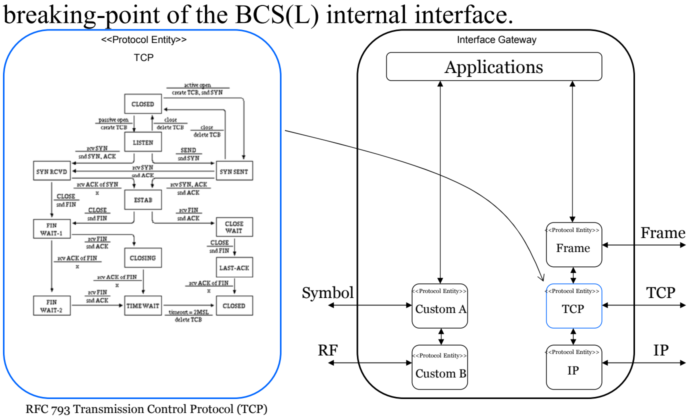

Figure III-4 Tactical Interface Gateway Subsystem

IV. NIM Data Model

BCS(L) NIM is a subset of larger BCS(L) System Architecture Model with a complete data model implemented in Vitech CORE® data repository tool. Figure IV-1 depicts elements of the data model applicable to BCS(L) NIM. A different data repository tool can also be used as long as the data structure described in Figure IV-1 is preserved. The data model for BCS(L) NIM is described in three specific data structures namely: User-to-User, Network-of-Network, and System-of-System.

A. *User-to-User Data Structure*

The purpose of User-to-User data structure within the NIM Model is to capture the needs of information exchange between the Users associated with Network Nodes. The User-to-User data structure contains five data classes, namely: *Performer, Needline, Interface, ExchangeCharacteristic, and InformationItem.* Network Nodes are modelled as *Performer*, logical interface as *Needline*, and physical interface as *Interface*.

The relationship between *InformationItem*, and *Performer* is established via the *Needline*. Each *Needline* is modelled simultaneous as *Interface*, such that traceability between logical interface (modeled as *Needline*) and physical interface (modelled as *Interface*) is maintained.

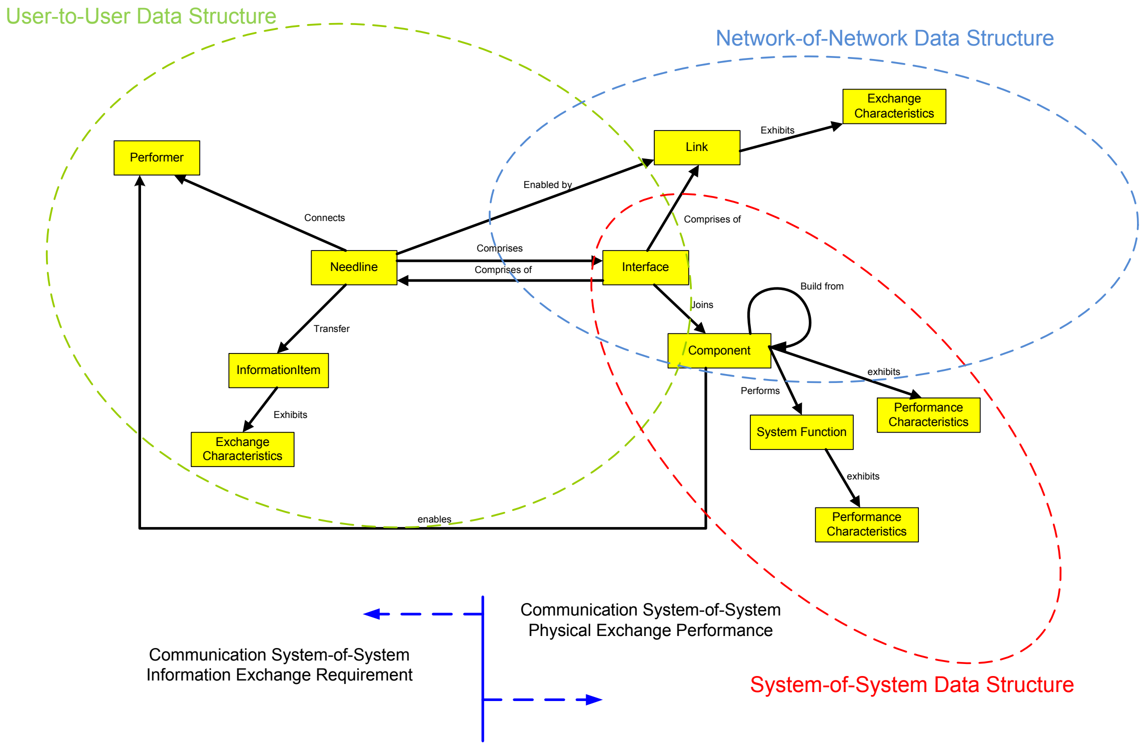

Figure IV-1 BCS(L) NIM Data Model and Data Structure

The *InformationItem* is nominated as per the BCS(L) IDF Scheme. The quantitative aspects of *InformationItem* are captured by *ExchangeCharacteristic*. These characteristics essentially derive the BCS(L) Interface Requirement Specifications (IRS).

B. *Network-of-Networks Data Structure*

The purpose of Network-of-Networks data structure within NIM Model is to model the self-contained BCS(L) network constructs in a consistent manner. The Network-of-Networks data structure contains four data classes, namely: *Component*. *Interface, Link*, and *ExchangeCharacteristic*.

In addition to *Performer*, all BCS(L) Network Nodes are also represented as *Component* to cater for the logical, and physical characteristics, of the Network Node. An *Interface* is established between each *component*, where their embedded BCS(L) Transmission System is modelled as *Link*. The BCS(L) operational concept is shaped by the ADF Land command hierarchy, which means not all interfaces are required to be support by a Transmission System. Where a Transmission System is required, it will be modelled as *Link* with *ExchangeCharacteristic* to capture their communication attributes.

C. *System-of-System Data Structure*

The purpose of System-of-System data structure within NIM Model is to represent the remaining BCS(L), that cannot be represented by the Network-of-Network data structure. The System-of-System data structure contains four data classes, namely: *Component*, *Function*, *PerformanceCharacteristic*, and *Interface*.

The System-of-Systems data structure captures the classical System Engineering data include physical interfaces specifications, functional decomposition, system breakdown structure, etc. The BCS(L) Network Node is modelled as the top-level *Component* hierarchy. The level-2/level-3 *Component* hierarchy captures non-Transmission System specific physical entities such as, Network Planning and Management System (NPMS), Equipment Mounting Hardware, Power Generation System etc. This data construct allows the unification of BCS(L) "Network" and "System" in a single model.

The *Function* data class captures end-to-end BCS(L) functional decomposition. The functionality of subsystems, including those provided by external agencies, is "stitched back" to complete the end-to-end functional decomposition of the BCS(L). The Measurement of Effectiveness (MOE) and Measurement of Performance (MOP) data are modelled as *PerformanceCharacteristic*.

V. BCS(L) NIM EXECUTION EXAMPLE

The example depicted in Figure V-1 represents the Information Exchange Requirement (IER) that is required to be satisfied for operational communications between the *Network Node L* and the *Network Node B*. Three Network-of-Networks internal interfaces, including, *L-to-D*, *D-to-C*, and *C-to-B*, are required to be specified, designed and verified to objectively assess the performance of the communications between these nodes. The network interfaces are represented as, *IIF 629*, *IIF 339* and *IIF 58*. Single, or multiple Transmission Systems between each interface, can be leveraged to support such Information Exchange Requirement. The end-state interface design will have to cater for the trade-off between Transmission System performances, and verify against the information item attributes.

IER are represented as $IER_n\{a, b, c, d\}$, where n is the type of information. a, b, c and d are the information attributes that characterise the IERs. While the IER are standardized using IDF, the attributes are driven by the Network Node Users' operational requirement.

Each BCS(L) Transmission System is represented by $TransmissionSystem_m\ \{w, x, y, z\}$, where w, x, y, and z are the attributes that characterise the network/ communication performance of the Transmission Systems. The function $TransmissionSystem_m$ is the overall characteristic function to characterise the BCS(L) Transmission System, which is subject to w, x, y and z attributes.

In addition, each BCS(L) subsystem within the Network Node is represented by $Subsystem_p\ \{h, i, j, k\}$, where h, i, j and k are the attributes that characterise the performances of the BCS(L) subsystems. Similarly, the function $Subsystem_p$ is the overall characteristics function to characterise each BCS(L) subsystem, that is subject to h, i, j and k attributes.

The performances of $TransmissionSystem_m$ and $Subsystem_p$ to support IER_n are given by the following relationships.

IER_n Performance Parameters on $TransmissionSystem_m$ (PPT) = $PerformanceFunction_{PPT}\ (IER_n\{a, b, c, d\} \mid TransmissionSystem_m\ \{w, x, y, z\})$

IER_n Performance Parameters on $Subsystem_p$ (PPS)= $PerformanceFunction_{PPS}\ (IER_n\{a, b, c\ d\} \mid Subsystem_p\{h, i, j, k\})$

The combined IER_n Performance Parameter (PPC) is subject to $TransmissionSystem_m$ (PPT) and $Subsystem_p$ (PPS). The relationship is expressed as *CombinedPerformance* (PPC) = $PerformanceFunction_{\mathrm{PPC}}$ (*PPT, PPS*).

The exact performance functions, $PerformanceFunction_{PPT}$ and $PerformanceFunction_{PPS}$*, and* $PerformanceFunction_{\mathrm{PPC}}$ have not been defined at this stage. An ongoing data capture effort is undertaken to quantify *PPC*, *PPS*, and *PPT* for performance assessment of BCS(L) Network-of-Network interfaces. Parallel efforts are also being invested by the operational community to collect IERs attributes logged during operational exercises. The BCSL NIM provides a much required mechanism for BCS(L) network-of-network performance evaluation, through the performance assessment of its interfaces.

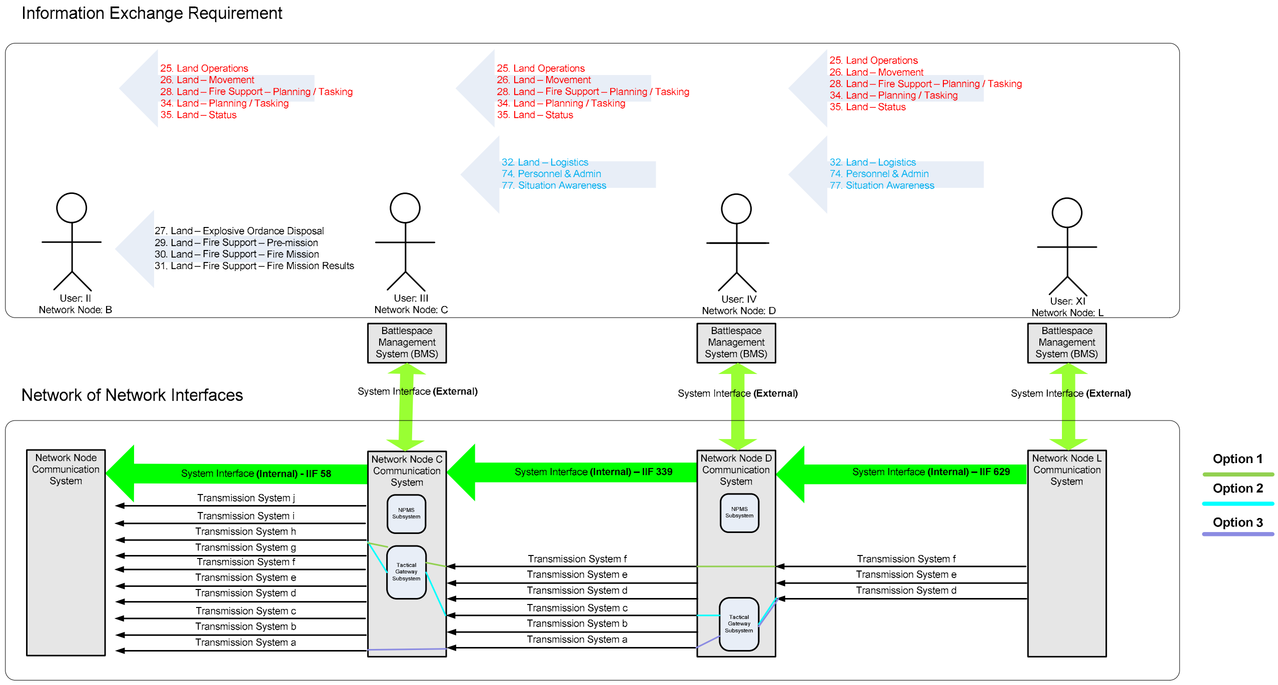

Figure V-1 BCS(L) NIM Execution Example

VI. Summary and Future Works

An approach to model Network-of-Networks interfaces is presented in this work. The proposed Network Interface Model is driven by the needs to establish ADF's Land operation using Network Node construct, as the pivotal building block of networks. The Model captures external and internal interfaces across the Network-of-Networks and System-of-System in a consistent and repeatable manner. Whilst capturing interfaces, the Model incorporates Information Exchange Requirements (IERs), System/ Subsystem Breakdown Structures, Logical/ Physical Interfaces, Functional Decompositions, and Network/ System Performance Parameters. In order to capitalise the proposed Model, the BCS(L) system engineering data needs to be managed in a customised repository. This paper also proposes a data-structure that could meet this challenge. An example was presented to illustrate how the interfaces of a real-world Battlespace Communications System / Network, of type Network-of-Networks, are modelled. An empirical method to evaluate performance of the interface performance is also provided. Further enhancement to the Network Interface Model are envisaged for incorporating network Quality of Service (QoS) as the performance attributes of network interfaces. From modelling language perspectives, future improvement will include transition to industry best practice such as SysML. This enhancement will be formed as part of second generation of the Network Interface Model.

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Disclaimers

The views and conclusions expressed in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Department of Defence, Australia.

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