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Hyper-Nodes for Emerging Command and Control Networks: The 8th Layer

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COALITION COMMAND AND CONTROL IN THE NETWORKED ERA

C2 Architecture, C2 Experimentation

Hyper-Nodes for Emerging Command and Control Networks: The 8th Layer

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ABSTRACT

In this paper we introduce the architecture and functionality of a new *8th layer* that extends the well known 7-layer OSI model to implement adaptive networking by giving every critical node of a C4I network its own specialized Network Operation Center (NOC) capability. Emerging network-centric concepts such as FORCEnet and ubiquitous networking services such as the Global Information Grid will need to incorporate self-organizing network clusters including semi-autonomous sensors, unmanned vehicles, and human decision-makers. In these predominantly mesh networking architectures the behavior of every node, its capability to form or to heal the network, depends on the node's awareness about networking status and capabilities of its neighbors. This trend toward meshing of more capable nodes will eventually evolve into a qualitatively new architecture, in which every significant node also acts as a small-scale NOC. We illustrate this trend by observations of recent SOCOM-NPS Tactical Network Topology experiments. We show how this can be thought of as the 8th level of the OSI stack, where the new layer adds intelligent adaptive self-control. The new layer requires a new protocol, which would include a new type of message, its semantics and syntax, as well as a new type of interpreter describing the behavior of the 8th layer state machine.

The 8th layer interpreter must exhibit empirical adaptivity, improving with experience. It achieves goal-seeking behavior by choosing how to satisfy or modify Service Layer Agreement (SLA) constraints; it achieves sensing by way of polling higher-level SNMP MIB data describing overall NOC status; and it captures experience through a memory mechanism for learned network management actions.

We call these intelligent modular subnetworks that adapt their behavior and organization through incorporation of this 8th layer *hyper-nodes*. We believe hyper-nodes are a fundamental building block of the kinds of open, extensible mesh networks required in many military operations. A network of hyper-nodes is scalable, adaptive, and robust, thus a required kind of infrastructure for enabling extensible growth and information Superiority (Hayes-Roth, 2006a).

1. Adaptive C2 Networking with Unmanned Vehicles

Since 2003 a team of Naval Postgraduate School researchers together with their SOCOM sponsors has been operating a plug-and-play testbed, which enables discovery, integration, and demonstration experiments for a broad range of solutions employing networks of sensors, unmanned vehicles, and human decision makers.

The testbed contains a tactical, OFDM 802.16 backbone, terminating in various locations within the 200 mi length in Northern California, which provides for the ad hoc plug-in of UAVs, boats, ships, small SOF and Marine units, including airborne and ground self-forming mesh communications. It contains an expanding set of domestic and overseas remote command and tactical centers with global reach back capabilities and rapidly deployable self-forming wireless clusters (including student network operation services 24/7). The Maritime component being developed jointly with the Lawrence Livermore National Laboratory extends the testbed capabilities to ship-to-shore, ship-to-ship, ship-UAV (Unmanned Aerial Vehicle)-ship, ship-USV (Unmanned Surface Vehicle)-ship, and ship-AUV (Autonomous Underwater Vehicle), sensor mesh mobile networks.

The testbed enables real-time collaboration of ISR, UAV control, Boarding Party, and Tactical Operation Center crews with the remote experts around the globe, including such sites as Lawrence Livermore National Laboratory, Biometrics Fusion Center, Defence Threat Reduction Agency, and Mission Support Centers.

Figure 1 illustrates the network management view of the testbed backbone, the long-haul wireless network between NPS and Camp Roberts, located 100 mi south of NPS, providing the two-way global reach to the unmanned assets and tactical units practicing self-forming command and control networking at Camp Roberts.

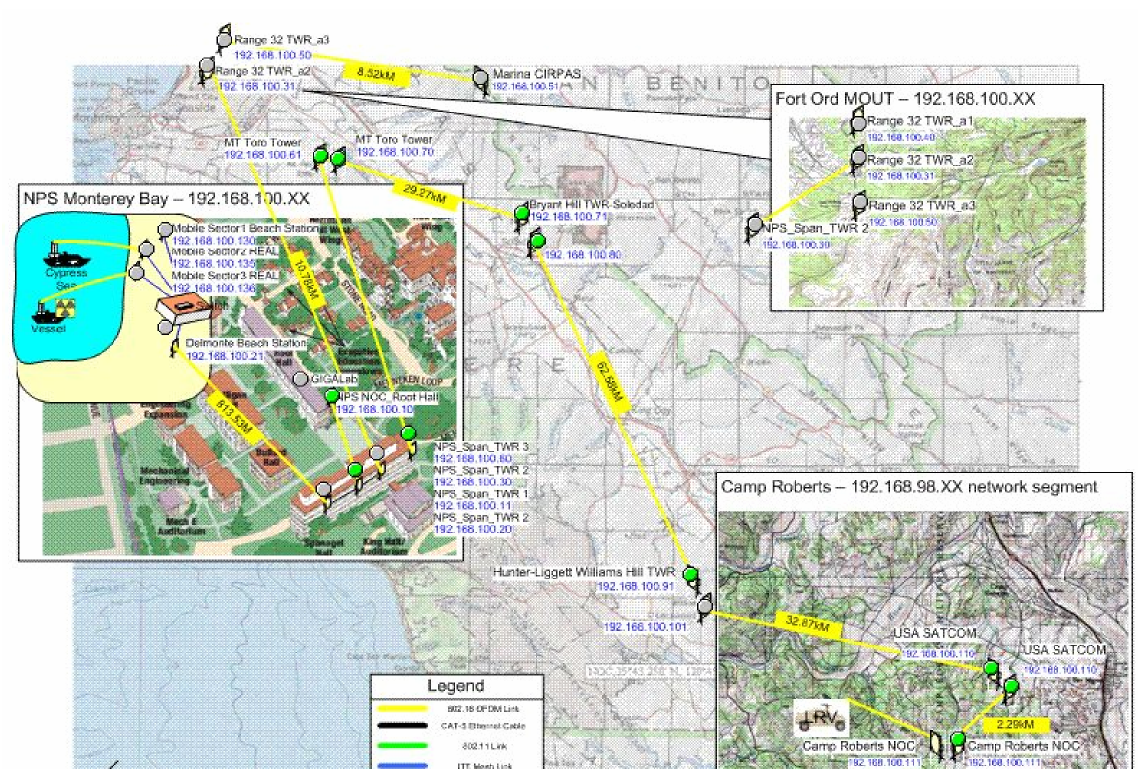


Figure 1. Tactical network testbed with self-forming clusters of small units and unmanned vehicles

An example of self-forming networking cluster with unmanned vehicles, which could be plugged into the testbed different remote location is described by Figure 2 (courtesy of Dr. Dave Netzer)

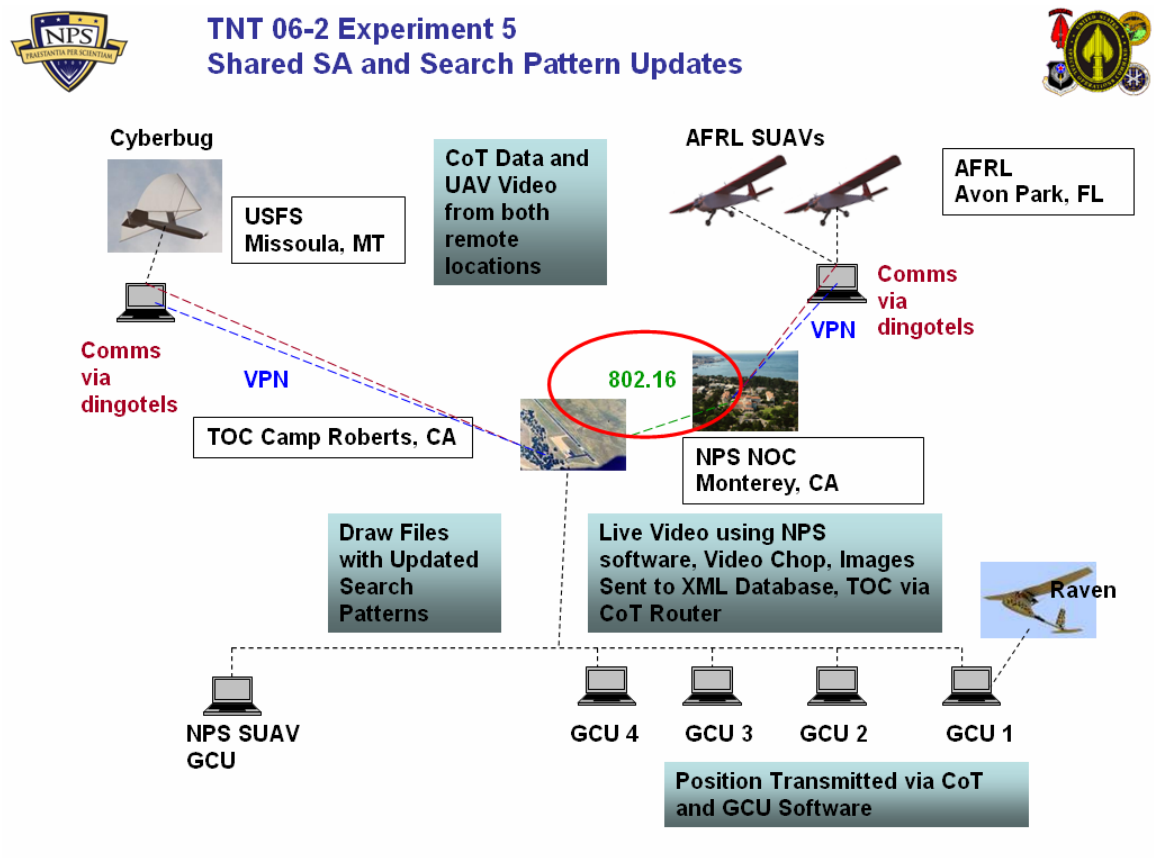


Figure 2. Self-forming networking with UAVs for tracking the high-value targets

In the live environment of High-Value Target (HVT) tracking experiment, depicted in Fig. 2, the UAV ground (or mobile) station operators at CGU1, CGU2, CGU3, CGU 4, Cyberburg, AFRL, and NPS SUAVs nodes , constantly require Network Operations Center feedback on the assessment and prediction of their ability to deliver video and situational awareness data. The NOC crew is using heavily populated views as in Figure 1, or more detailed presentations of network configuration, fault, and performance management (Figures 3-5), to quickly assist UAV and field operators in changing location for their mobile air-ground nodes as well adapting, primarily by switching, an applications load.

Figure 3. Four UAVs are streaming video, but one video flow is lost.

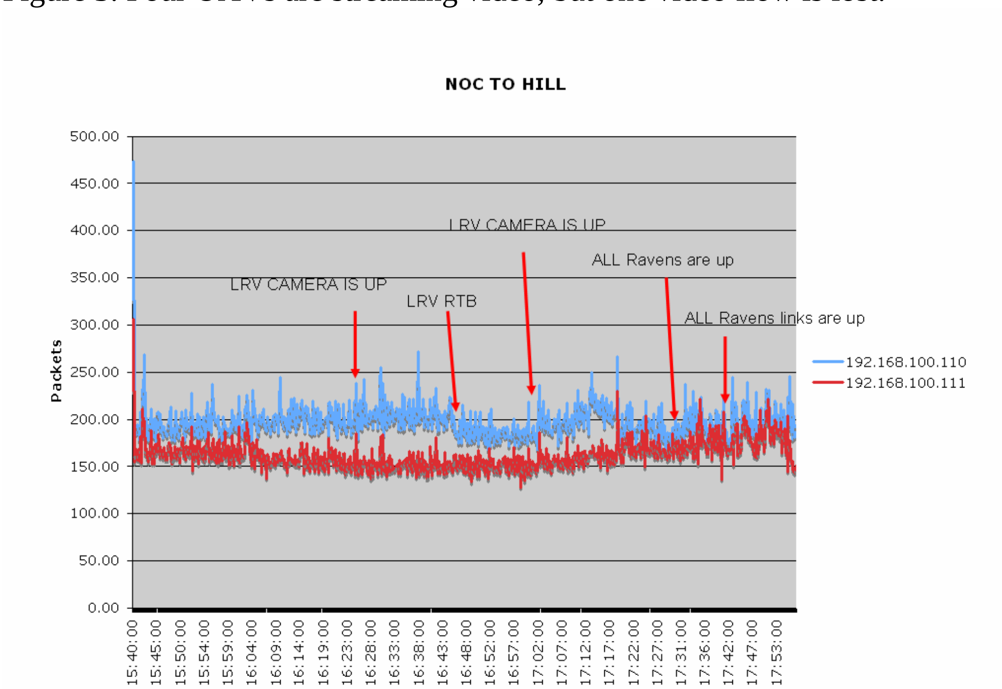
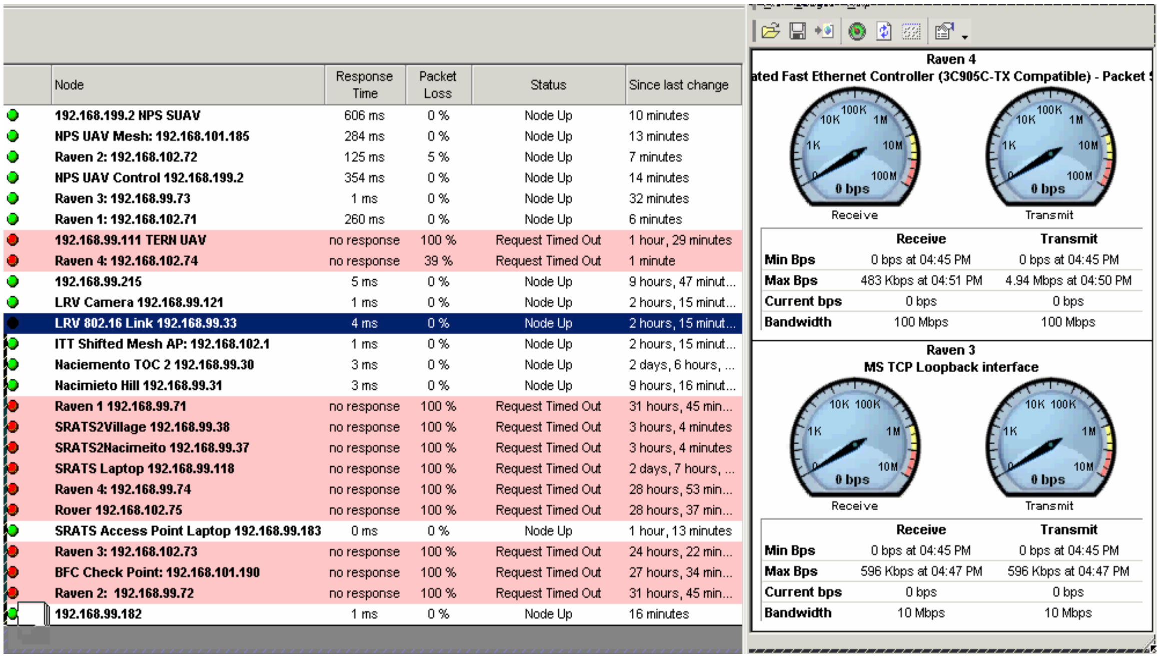


Figure 4. The tactical wireless OFDM 802.16 link behavior during Light Reconnaissance Vehicle (LRV) video feed integration .



Node	Response Time	Packet Loss	Status	Since last change
192.168.199.2 NPS SUAV	606 ms	0 %	Node Up	10 minutes
NPS UAV Mesh: 192.168.101.185	284 ms	0 %	Node Up	13 minutes
Raven 2: 192.168.102.72	125 ms	5 %	Node Up	7 minutes
NPS UAV Control 192.168.199.2	354 ms	0 %	Node Up	14 minutes
Raven 3: 192.168.99.73	1 ms	0 %	Node Up	32 minutes
Raven 1: 192.168.102.71	260 ms	0 %	Node Up	6 minutes
192.168.99.111 TERN UAV	no response	100 %	Request Timed Out	1 hour, 29 minutes
Raven 4: 192.168.102.74	no response	39 %	Request Timed Out	1 minute
192.168.99.215	5 ms	0 %	Node Up	9 hours, 47 minut...
LRV Camera 192.168.99.121	1 ms	0 %	Node Up	2 hours, 15 minut...
LRV 802.16 Link 192.168.99.33	4 ms	0 %	Node Up	2 hours, 15 minut...
ITT Shifted Mesh AP: 192.168.102.1	1 ms	0 %	Node Up	2 hours, 15 minut...
Naciemento TOC 2 192.168.99.30	3 ms	0 %	Node Up	2 days, 6 hours, ...
Nacimieto Hill 192.168.99.31	3 ms	0 %	Node Up	9 hours, 16 minut...
Raven 1 192.168.99.71	no response	100 %	Request Timed Out	31 hours, 45 min...
SRATS2Village 192.168.99.38	no response	100 %	Request Timed Out	3 hours, 4 minutes
SRATS2Nacimeito 192.168.99.37	no response	100 %	Request Timed Out	3 hours, 4 minutes
SRATS Laptop 192.168.99.118	no response	100 %	Request Timed Out	2 days, 7 hours, ...
Raven 4: 192.168.99.74	no response	100 %	Request Timed Out	28 hours, 53 min...
Rover 192.168.102.75	no response	100 %	Request Timed Out	28 hours, 37 min...
SRATS Access Point Laptop 192.168.99.183	0 ms	0 %	Node Up	1 hour, 13 minutes
Raven 3: 192.168.102.73	no response	100 %	Request Timed Out	24 hours, 22 min...
BFC Check Point: 192.168.101.190	no response	100 %	Request Timed Out	27 hours, 34 min...
Raven 2: 192.168.99.72	no response	100 %	Request Timed Out	31 hours, 45 min...
192.168.99.182	1 ms	0 %	Node Up	16 minutes

Figure 5. Performance and Fault Management Views at the NOC during multiple UAV video feeds.

The NOC Facilitator provides such a feedback by consulting with NOC crews at different locations. In the TNT experiment we have a minimum of two fixed NOCs, 100 mi apart from each other, and two or three mobile NOCs. By doing so, the Facilitator quickly filters and interprets numerous details related to the node behavior and advises the field operator on the course of networking action (Figure 6). This may take 30 sec to several minutes including the communication delays between NOC and operators. With UAVs moving quickly following the convoy or tracking the vehicle going 60 mi/hr on the ground, by the time configuration/performance managing advice is received, the network performance has already changed and several links have broken.

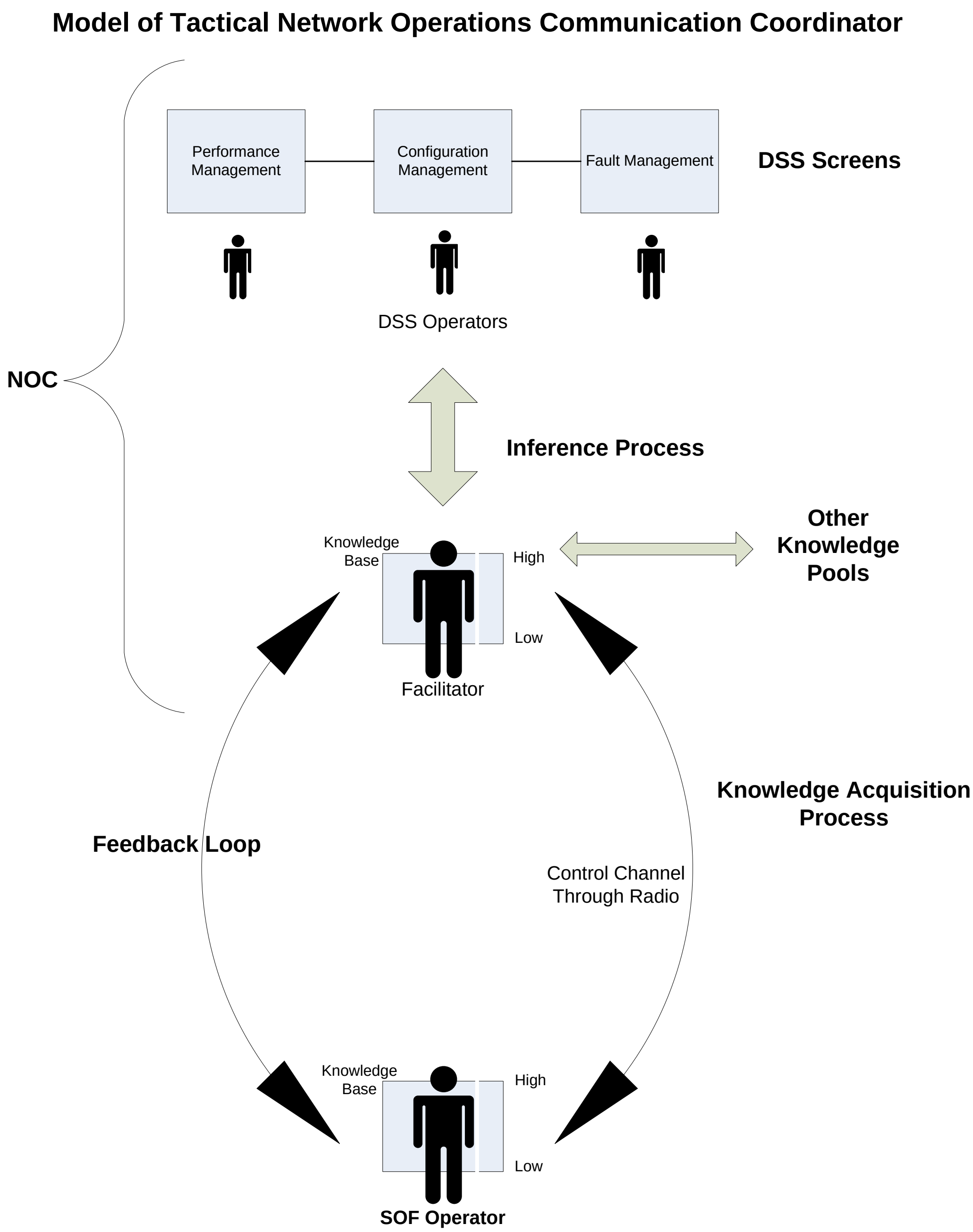


Figure 6. Tactical Network performance/configuration via the NOC Facilitator feedback.

The hyper-node would short-cut the described feedback loop by adding to the top of the OSI reference model the 8^{th} layer, which we envision as a platform for bringing simplified NOC functionality onto the hyper-node communication protocol stack. How can we simplify and structure the NOC business process, so that it could transfer into the NOC protocol for the 8^{th} layer? What would be the building blocks of such a protocol architecture? What do we have to acknowledge in the 8^{th} layer handshake and what key data fields should be present in 8^{th} layer header? The rest of our paper is devoted to these questions.

2. The 8th Layer and Hyper-Node Concept

The idea of extending the OSI Reference Model beyond layer 7 has started to gain momentum recently. Interestingly enough, most of the proposed extension ideas clearly target a need to add human interface or decision support functionality to the OSI layers "chain of command."

Dr. Sarah Stein, North Carolina State University, in her paper on 8th Layer Initiative writes: "There are seven layers in the networking architecture that define how systems communicate. This architecture is the foundation on which all information technology (IT) is built. Insiders frequently refer to the human factor in IT as the eighth layer. The title is the message; our greatest challenge is not the technology." (Stein, 2004, p. 3).

With a different focus, Russel Ormond, presents the concept of Layer 8, which he tags as financial, and Layer 9, referred to as political, extensions to the OSI stack (Ormond, 2004).

Bauer and Patrick directly refer to the new layers as human factor extension to the OSI seven layers (Bauer and Patrick, 2004).

In this paper we argue that mapping NOC capabilities in Layer 8 functionality is critical for emerging Command and Control network-centric environments based on unmanned vehicle-decision maker adaptive self-forming networks. Our orientation doesn't exclude the above mentioned approaches. Accounting and billing, which is in the focus of Stein's paper, are recognized functional components of the network management life cycle. Efficiency of NOC crew response to network operation problems depends heavily on the quality of decision support interfaces (see Figure 7 as an example), i.e. the quality of human interface development. However, enabling ad hoc application services (video, data sharing, voice, etc) combined with real-time performance and configuration management feedback requires much more elaborate structure for the 8th Layer.

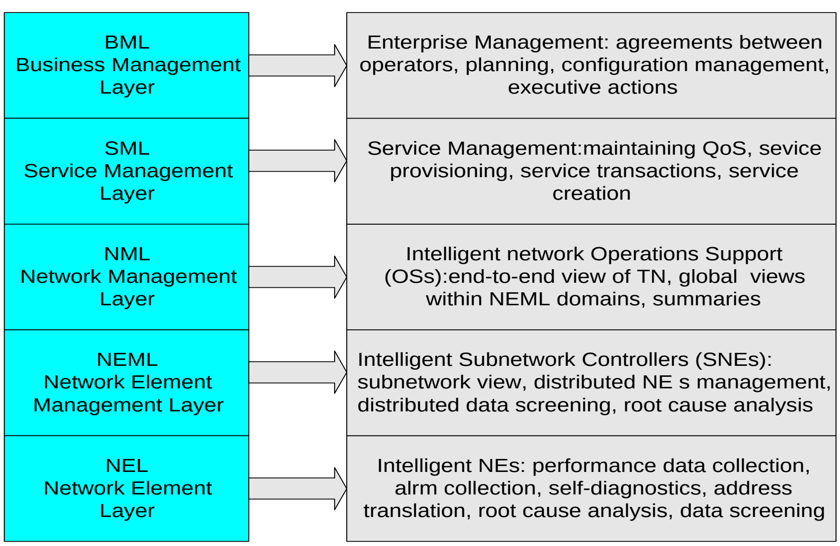


Figure 7. TMN architecture of network operation layers

Ideally, we'd like to have the 8th layer mapping the network management hierarchy of services. The TMN (Telecommunications Management Network) network management architecture (Lewis, 2000) gives us a good hint on management layers to be nested in the 8th OSI layer functionality (Figure 7). The 8th layer protocol should provide individual nodes with the capabilities of self-diagnosis (NEL), subnetwork view (NEML), end-to-end performance (NML), QoS requirements response (SML), and Service Level Agreements negotiation (BML)

In the next section we describe configurable management components that would allow engineers to create a robust small-scale replica of a NOC that would be a candidate for the 8th Layer protocol.

3. The 8th Layer Interpreters and Building Blocks

During the last three years, the NPS research team has successfully introduced and solutions for network-aware C2 and tactical adaptive collaborative environments (Bordetsky, *et al.*, 2004; Bordetsky and Bourakov, 2006). Figure 8 illustrates one of the most recent results in introducing network-aware tactical nodes in the environment of UAV-based High-Value Target tracking operations.

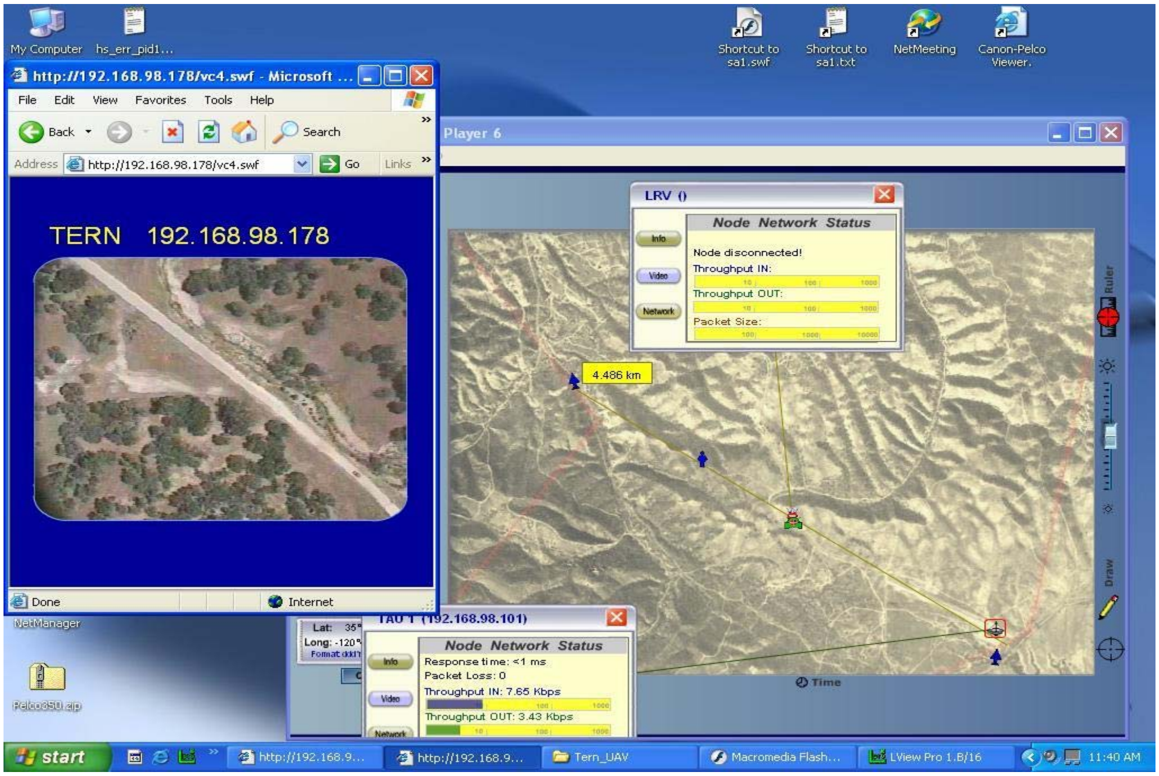


Figure 8. Operator view of mesh wireless networking with UAV at the distance of 4.3 km between neighboring nodes with good video feed and network awareness data on neighbor performance

Notice that in comparison with rather populated NOC network performance view (Figure 1), the gauges in the operator SA interface reflect only throughput, packet loss, and response time constraints associated with the neighboring nodes. This layer 3-4 performance data, can be retrieved by means of Simple Network Management Protocol (SNMP) agents (Subramanian, 2000). Such performance data should be employed by the Layer 8 protocol as one of the key monitoring processes.

However, the network awareness view, illustrated by Figure 8 could easily become very busy, as the number of manned-unmanned hyper-nodes scales up to several dozen. The complexity of OSI layers 3-4 performance constraints increases with the number of interacting nodes. This clutters the view for humans and also for unmanned nodes that need to monitor and control flows. To reduce the complexity and make the problem manageable, hyper-nodes should associate observed performance with higher level Quality-of-Service (QoS) requirements (constraints). Further, when hyper-nodes are faced with multiple competing constraints, they will achieve best results if they can establish and assure Service Level Agreements (SLAs) that allow them to trade-off competing constraints to optimize the overall network's performance.

3.1 The 8th Layer Monitors

In accordance with TMN architecture we can describe the event-constraint space of a typical NOC by the following categories.

-NEL, NEML, and NML events and constraints, primarily captured by means of the SNMP protocol
-SML, primarily reflected in the situational awareness interface requirements (video of certain quality, shared files, response time, distance to the node, etc)
-BML, primarily reflected in SLA negotiation (availability, reliable connectivity) events.

Correspondingly the hyper-node 8th layer should include several Monitors with the associated polling and event interpretation protocols:

-SNMP events Monitor (OSI layers 2-4, TMN NEL, NEML, NML),
-SA constraints Monitor (TMN SML),
-SLA constraints Monitor (TMN BML).

In such an architecture the SNMP event-constraints monitor is simply a commonly used SNMP agent manager, relocated from the Network Management System suite at the NOC to the hyper-node 8th layer suite. Unlike it, the monitors for SA constraints and SLA requirements negotiation do not have a common standard, and these need to be developed.

Given the fact that of all three types of monitors, the SNMP is the only one well standardized, we can consider a different approach. This approach would be to unify the 8th Layer monitoring process by using the SNMP Monitor exclusively, but extending the SNMP MIBs (Management Information Basis) to the new layer of service and business management variables, including the facilitator decision space. This task is doable (Bordetsky and Dolk, 2003), but would require development of a new RFC (Request for Comments) addressing such SML-BML control variables as:

Application switching,
Node physical mobility initiation,
Receiver Context and Requirements Modeling,
Sender Dynamic Information Context and Transmission Requirements Modeling,
Recipient context determination,
SLA generation,
SLA negotiation,
QoS monitoring and SLA assurance, etc.

We envision that coordination of different monitoring processes within the 8th Layer would be driven by the **network productivity SLA requirements**. Each hyper-node would evaluate its own 8th Layer controllable variables. Each hyper-node would attempt to optimize its own sub-network. Figure 9 illustrates the basic adaptive process.

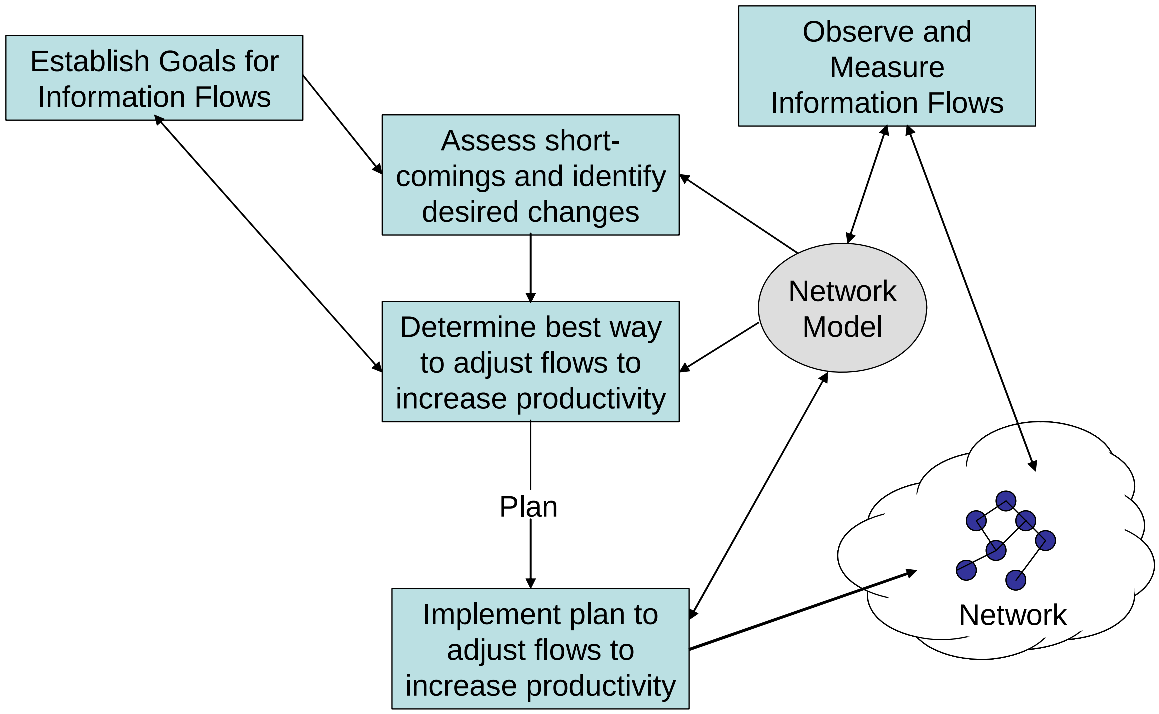


Figure 9. Intelligent adaptation required to maximize network productivity.

3. 2 The 8th Layer Memory

In addition to key monitoring processes, the 8th Layer protocol, which enables adaptive network management by the hyper-node itself, should also include a memory mechanism. Such memory mechanism would record and apply a small-scale knowledge base reflecting configuration, performance, security, and application management experiences of NOC crews (Fig. 6). Cabletron Spectrum Network Management System provides a good example of using Case-Based Reasoning (CBR) techniques (Lewis, 2000) for maintaining fault management memory at the SLM level. The CBR memory could be an efficient solution for NML adaptation when applied as part of a multi-agent network management architecture (Bordetsky, Brown, and Christianson, 2004). Based on those considerations we envision the 8th layer memory mechanism to be built using such a CBR technique.

3.3 The 8th Layer Solvers

If we were to define the 8th layer ontology, the most straightforward way would be to represent it through a concatenation of quantitative and context-based constraints reflecting the NEML, NML, SML, and SLA requirements, with SLA constraints defining the goal-seeking intelligence of the 8th Layer. Adapting different resources of physical, link, network, transport, and application layers of hyper-nodes functionality would require a multiple criteria solver, which would enable the hyper-node to perform feasibility analysis and then compromise on a large number of heterogeneous constraints. The PSI multiple criteria technique, developed by Dr. R. Statnikov, provides a robust constraint satisfying solver for self-forming network adaptive management (Bordetsky, *et al.*, 2005). Using the PSI Multiple Criteria technique as a constraint solver for 8th Layer protocol would allow hyper-nodes to develop holistic patterns of network behavior in the form of Pareto boundaries. One very interesting feature of PSI technique is the ability of balancing large number of constraints by allocating the constraint sets to other hyper-nodes, especially those whose processors are idling, for rapid parallel consolidation of the instantaneous Pareto boundary for the overall network(Statnikov, Bordetsky, and Statnikov, 2006).

Approaches like those described above have traditionally focused on relatively simple notions of network "performance." In our recent studies of network-centric operations, we've focused increasingly on the importance of focusing network performance on the delivery of high-value information. Our aim is to optimize the delivery of valuable information at the right time, a concept we call VIRT (Hayes-Roth 2005, 2006b). Complex networks of the sort we've been considering have two limiting factors in most cases: (1) human decision makers have limited time to process information and (2) communication bandwidth among mobile entities is highly limited. As a result, it can make an enormous difference to assure that only timely and significant information is delivered to each recipient. This means the network should become aware of the dynamic information requirements of each recipient. Then the network can assure its limited resources are allocated first to assuring such valuable information reaches its intended recipients.

VIRT focuses the entire network on the recipient's perception of valued information and it causes the network to filter and prioritize appropriately. We've shown a five orders of magnitude reduction in information volume in one example, and this will be typical. Hyper-nodes are an obvious way to implement VIRT in dynamic mesh networks, because the resources are constrained, the operations dynamic, and the bandwidth limited. To incorporate VIRT into the 8th Layer solvers will require recipients to specify their dynamic information requirements and will require publishers and senders of information to tag their information with corresponding semantics. The 8th Layer would then incorporate agents to match information suppliers with information consumers, giving top priority to SLAs that move high value information in a timely way.

4. 8th Layer Command Set Composition

Based on the above described 8th Layer protocol, including Monitors and Solvers, we'd like to draft an example of possible commands structure for the 8th Layer protocol. At this point of the hyper-nodes concept development we do not pretend this set of commands is mature enough to be used as a solution. We consider it only as a sample set to seed the discussion for a future 8th Layer Protocol RFC.

We propose as a first approach the use of three different event-constraint monitors:

-SNMP events Monitor (OSI layers 2-4, TMN NEL, NEML, NML),
-SA constraints Monitor (TMN SML),l
-SLA constraints Monitor (TMN BML

We'll use SNMP V1. This protocol would be a good foundation for 8th layer management of OSI Layer 2-4 events. Each hyper-node would have an SNMP Manager for monitoring and an SNMP agent for responding to the other hyper-node polls.

For the Situational Awareness Monitor example we'll adopt the Cursor-on-Target (CoT) Protocol, recently devised at MITRE (Miller, 2004). This protocol provides the high-level command schema of

> What, When, Where, and Details commands with broad range of requirements to the situational awareness application flow (CoT Overview, 2005):
>
> -Tactical Imagery (Raider, Adocs, IPL)
> -Real-time ground blue force positions (FBCB2)
> -Weapon target pairing solutions (DLARS)
> -Real-time tactical air picture (Link16, CT-II, ACARS)
> -Strike engagement orders (ADOCS, Raider, Link16)
> -ISR collection requests (Raider, AFATDS, DLARS)
> -Weather data (GATM)
> -SIGINT information (SIRS, NCCT, ISRW)
> -Mensurated target locations (DPSS, Gridlock)
> -UAV sensor point of interest (Predator)
> -Platform cross cueing data (Predator, Link16)
> -Air Support Requests (AFATDS)
> . . .

For the SLA constraints monitoring and negotiation we'll us the following principal messages as a foundation. Each incorporates a specified service-level agreement (SLA), which is a parameterized specification of a type of communication service, at an assured level of quality, serving particular suppliers and consumers, throughout a particular temporal interval. For example, one SLA would ask for video, in 640x640 pixels, 32 bits of color, 10 frames per sec, with maximum latency of 1 sec, from UAV 21, to Bravo Company BC3, from 1001 through 1100 Zulu. The SLA represents a desired level of information the hyper-node believes will help it achieve a maximum bang for the buck (VIRT vs. bandwidth consumption). In terms of such a goal SLA, the principal 8th Level messages include:

- Request for bid for given SLA
- Offer of bid for SLA in response to a request for bid
- Acceptance of offer of bid for SLA
- Confirmation of offer in response to acceptance of offer of bid for SLA
- Report of predicted violation of SLA by the provider
- Offer of revised bid for SLA in response to predicted violation
- Cancellation of SLA by requestor

The consolidated set of monitoring commands would look as follows:

The hyper-node 8^{th} Layer SNMP **manager** issues requests such as:
Get: A request for information of a specific variable.
GetNext: A request for the *next* specific variable.
Set: A request to change the value of a specific variable.

The hyper-node 8^{th} Layer SNMP **agent** responds with:
Get-Response: A response to the manager's Get and GetNext commands.
Trap: An asynchronous message to the recipient about an error or event.

CoT Situational Awareness commands:

What: *Tasking*
When: *Task Validity Period*
Where: *Search Location*
Details: *Target Description*

Another example:

What: *Chat*
When: *Now*
Where: *Everywhere*
Details: *Message Text*

Two examples of SLA contracting:

What: *Request bid for <SLA>*
When: *Task Validity Period*
Where: *From supplier to consumer*
Details: *Dynamic information content, quality, timeliness*

What: *Offer bid for <SLA>*
When: *Task Validity Period*
Where: *From supplier to consumer*
Who/how: *Network service provider making bid*
Details: *Dynamic information content, quality, timeliness*

Further more, we can expand the Situational Awareness command schema of What, When, Where, and Details commands down to the SNMP Monitors, i.e. the level of network performance and configuration awareness. For example:

What: *A request for information of a UAV throughput*

When: *End of SNMP Polling Period*
Where: *UGV Hyper Node, GPS Location*
Who/how: *UGV Hyper Node SNMP Manager, Polling the UAV MIB*
Details: *Sending the SNMP **get** packet via the UDP port*

What: *A request for information on route to Tactical Operation Center node*

When: UAV Ground Station *Situational Awareness Alert*
Where: *UAV Hyper Node, GPS Location*
Who/how: *UAV Hyper Node SNMP Agent, Reading the UAV MIB*
Details: *Sending the SNMP **trap** packet via the UDP port*

All together the described examples demonstrate that the 8th Layer Protocol could be designed on the basis of the Situational Awareness command expanded down to network element behavior awareness, and up Service Level Agreements negotiation.

Additionally we'll have to define the Facilitator Commands and Pareto boundary identification commands, which we leave for the next step of our research.

5. Conclusion

In the paper we presented the vision for a new *8th layer* that extends the well known 7-layer OSI model to implement adaptive networking by giving every critical node of a C4I network its own specialized Network Operation Center (NOC) capability.
We introduced the concept of hyper-nodes, which adapt their behavior and organization through incorporation of this 8th layer *hyper-nodes.* We described a possible architecture of the 8th layer interpreters, but left several critical issues still unstructured. We left for the next step of our research the Facilitator and Pareto boundary identification commands. One of the most important questions left unanswered in the paper is the format and headers for 8th Layer "packets" as well as routing techniques. These have a much different meaning than in OSI Layer 3. Defining those concepts is a subject of our ongoing research, which we hope to publish in the next paper.

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