Advancing SOTA in Applying Network Science to C2

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Overview

- Goal:
  - To outline recent advances in the state of the art of applying network science to C2
- Overview:
  - Introduction
  - Network science in C2
  - State of the art (SOTA)
  - Recent advances
  - Limitations, conclusions, & future research directions

Introduction: my research

- My research area:
  - Command & Control (C2: military & emergency management)
- My approach:
  - Professional hobby, preferably in collaboration
- My current topics:
  - Information sharing in coalition C2:
    - 2 PhD students (cultural influences; eCommerce to support CMI)
  - Offensive cyber operations:
    - Integrating kinetic & cyber ops
  - Incorporating network science into C2 theory:
    - Editing book (with René Janssen & Herman Monsuur, NLDA)
  - Social media as C2 implementation technology:
    - Analyzing chat from anti-piracy operations (with Oscar Boot, NLDA)

Network science in C2 (1)

- Both disciplines arose in mid 1990s:
  - "Modern" network science:
    - Branch of mathematics & Operations Research (OR)
  - Network-enabled C2 (e.g. NATO NEC):
    - Military science, leadership, & organization theory
- Separate communities:
  - Own journals, conferences, & books
- Yet …
  - NCW / NCO / NEC based on networked concepts
  - All kinds of networks found in C2:
    - Computer networks; command structure; social networks; etc.

Network science in C2 (2)

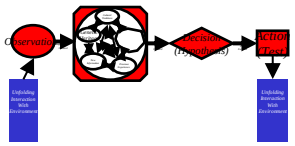
- Network science is theory about:
  - Network representation:
    - Network = set of nodes + set of arcs
  - Real-world phenomena:
    - Biological, technical, information, cognitive, socio-organizational
    - C2 encompasses most of these phenomena
- Network science covers:
  - Network *measures*: degree, centrality, betweenness, clustering
  - Network *topologies*: random, small-world, scale-free
  - Network *processes*: search, navigation, evolution, infection
  - Network *resilience*: failure, random or targeted attack

Network science in C2 (3)

Network:

Agent structure

OODA



node

arc

unit

information (flow)

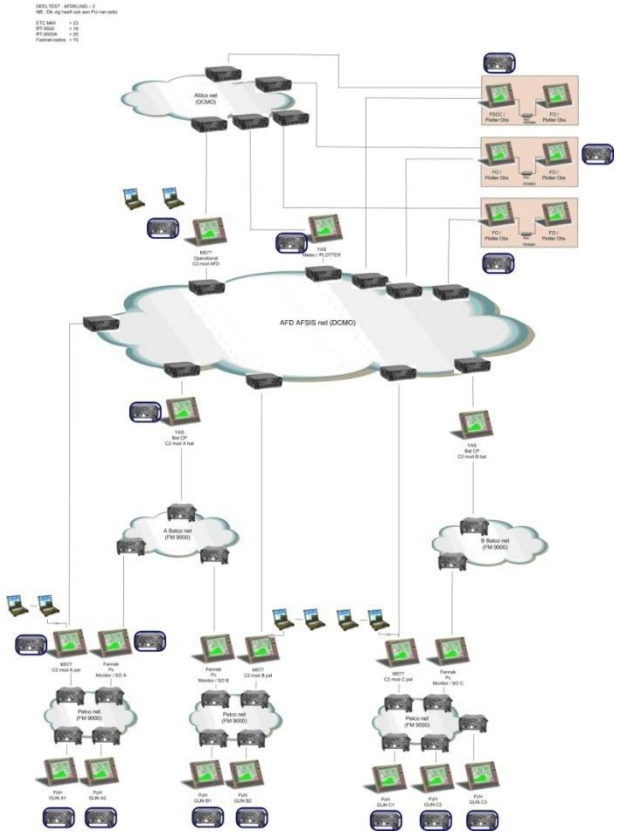
agent

relationship

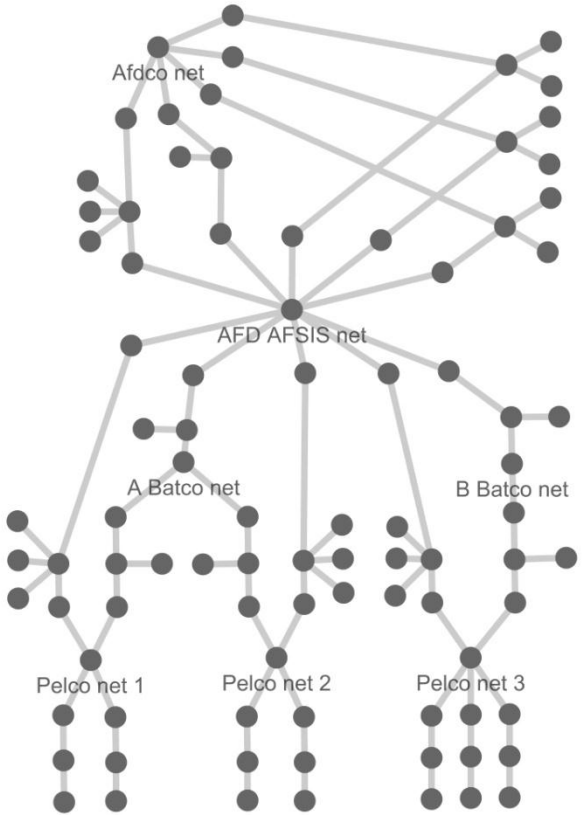
Multi-agent system:

Network science in C2 (4)

(Technical) system



Network model of system

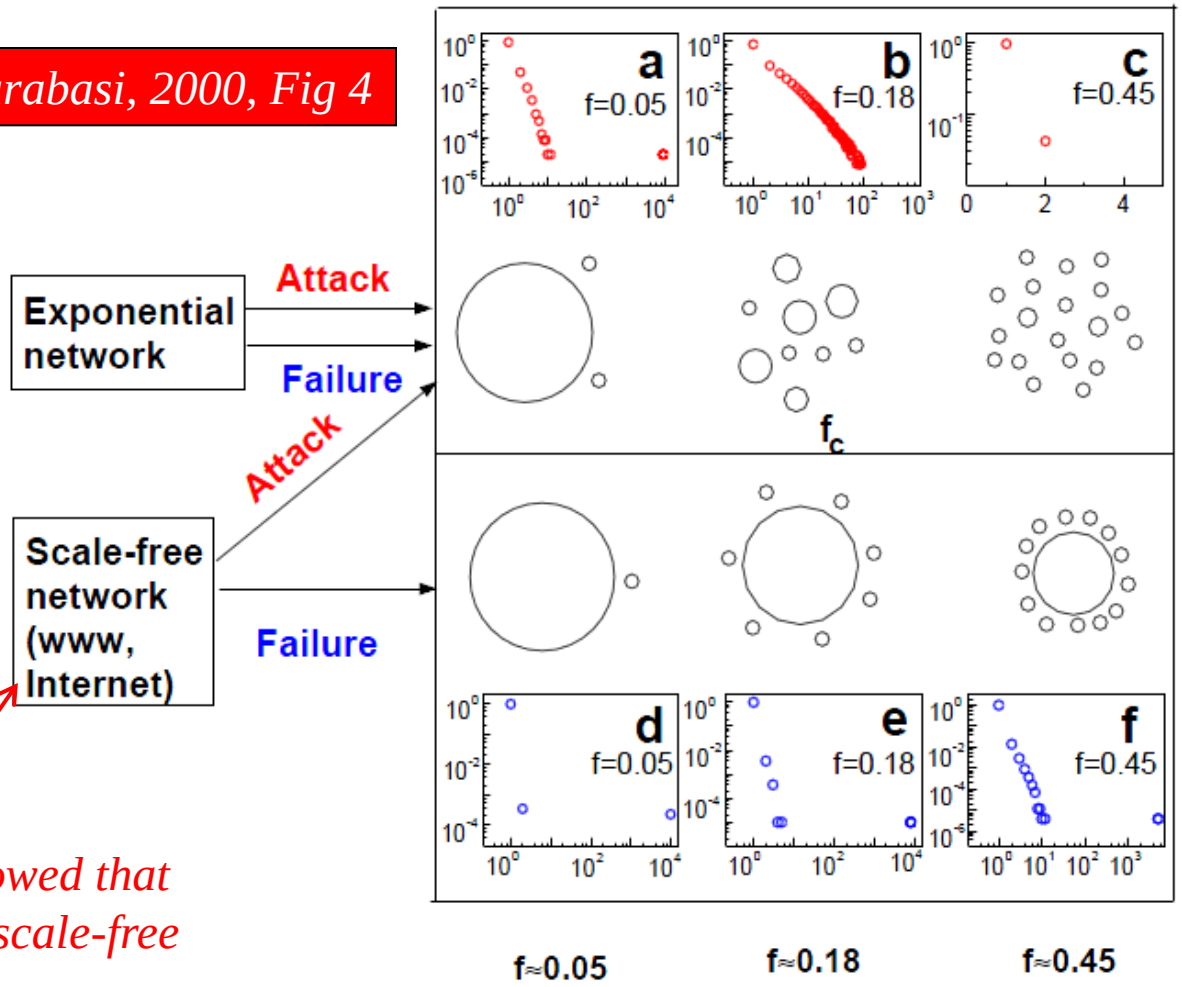


Applying network science to C2

Buizer, 2010

Network science in C2 (5)

Albert, Jeong & Barabasi, 2000, Fig 4

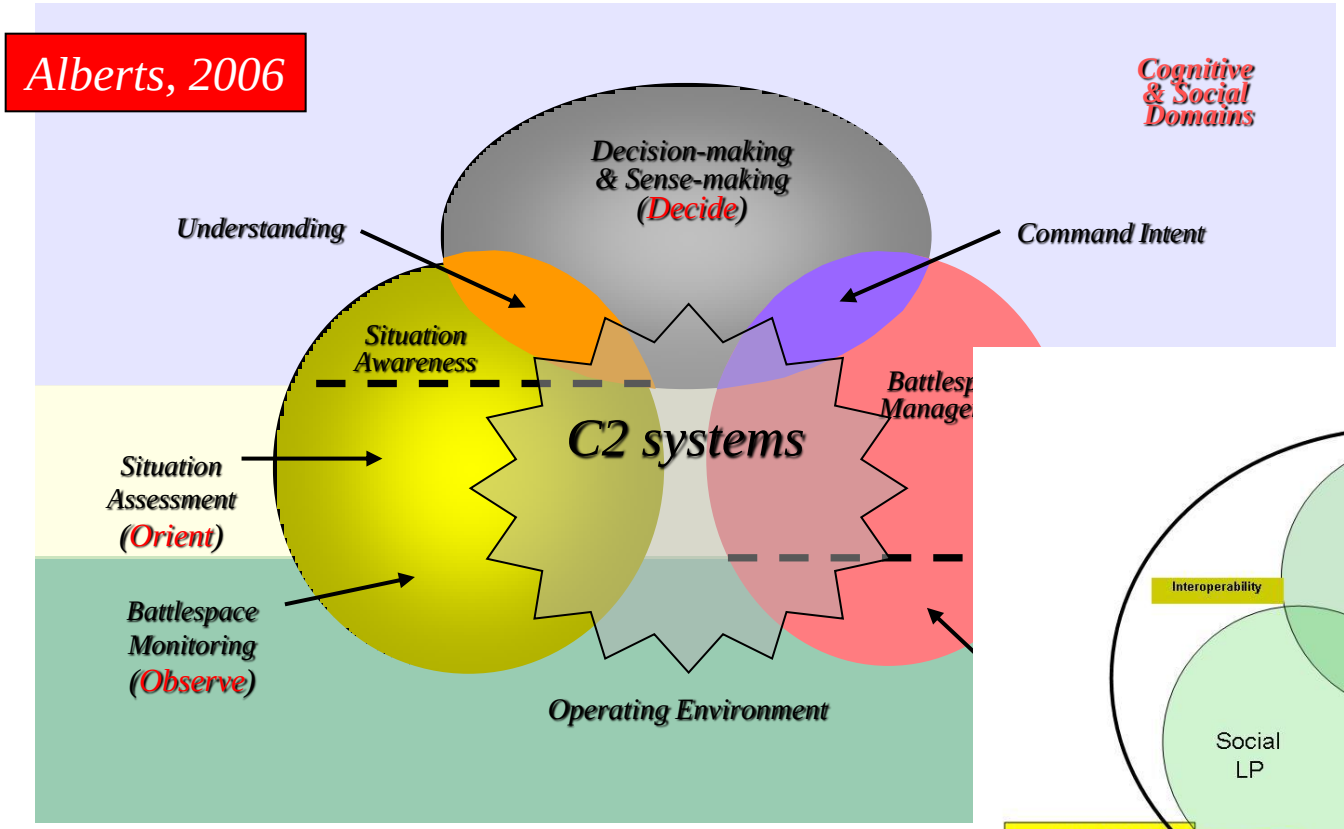


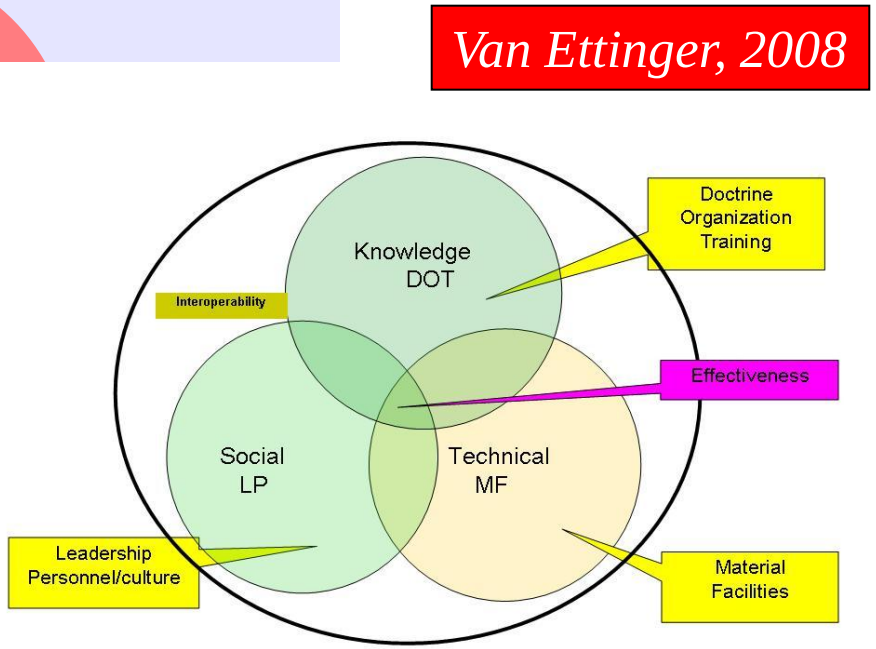
Buizer (2010) *showed that C2 networks also scale-free*

Network science in C2 (6)

- Progressive application in NCW / NEC:
  - (1) Network as *concept*:
    - Network versus hierarchy (implicitly organizational)
    - What nodes and arcs represented was left unspecified
  - (2) Application to computer & telecommunication *hardware*:
    - System of systems
    - Technical / physical network
  - (3) Recognition of *human factors*:
    - Information network = which computer has what information
    - Cognitive network = who shares what knowledge (SSA)
    - Social network = who exchanges messages with whom
  - (4) *Interacting domains* / networks (see next 2 slides)

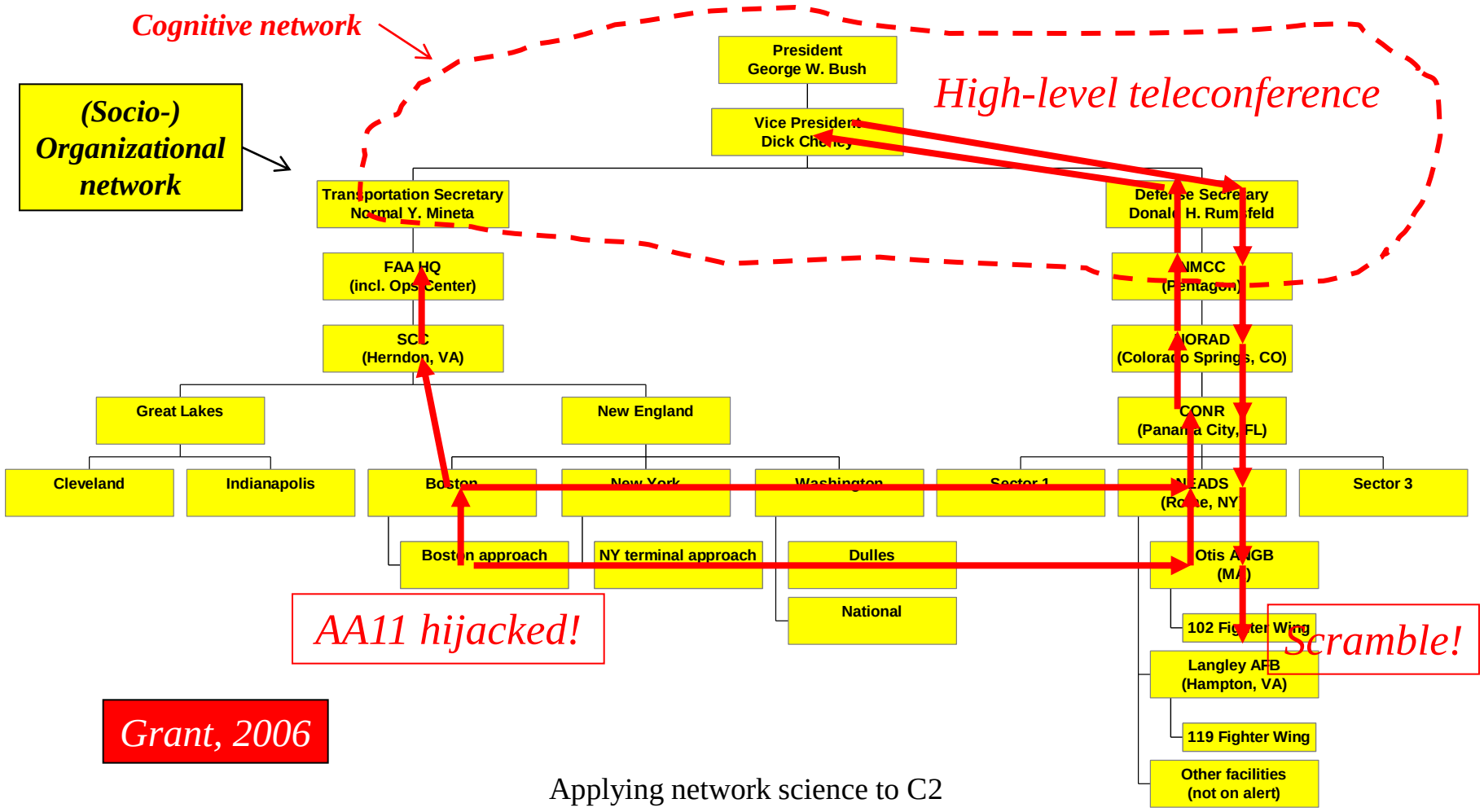
Network science in C2 (7)





Applying network

Network science in C2 (8)

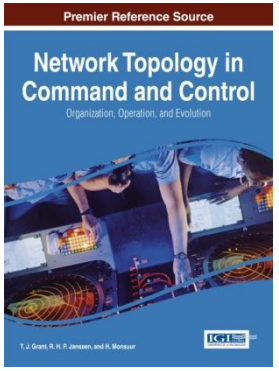


NetSci in C2: state of the art

- Network Science Center, West Point (USMA):
  - Established 2004; part-funded by US DoD CCRP
  - *Undergraduate teaching & research*
  - Representation of physical, biological & social phenomena
- Network Science Collaborative Technical Alliance:
  - Established 2005; US ARL, BBN, + 30 (US) universities
  - To understand commonalities in intertwined networks
  - *Communication, information, & social/cognitive networks*
- US-UK International Technology Alliance:
  - Established in 2006 for ten years; 4 technology areas
  - (1) Network theory focused on *wireless & sensor networks*

Recent advances (1)

- Research history:
  - 2006: My analysis of September 11, 2001:
    - Comms patterns “play” over organizational structure
  - 2008: Van Ettinger’s 3 networks
  - 2010: Student showed C2 networks vulnerable
  - 2011: Monsuur et al provided mathematics
  - 2012: Publisher IGI asked us to compile book
  - 2013-4: Gathered 12 contributions:
    - From US, UK, Australia, Sweden, Netherlands
    - Publication in June 2014

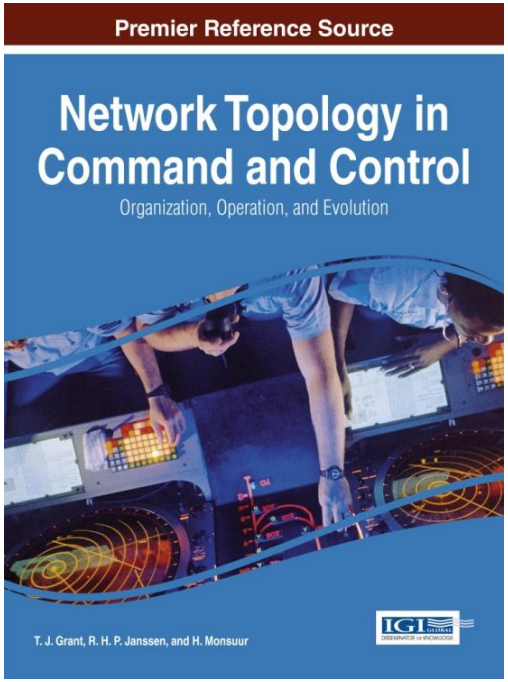


Recent advances (2)

"Network Topology in C2: Organization, operation and evolution"

T.J. Grant, R.H.P. Janssen and H. Monsuur (eds.)

- Due release June 2014
- ISBN-13: 978-1466660588
- US$ 215 (hardcover & eBook)
- Discounts available:
  - 25% library
  - 40-50% individuals
  - Contact editors for online coupon code



Recent advances (3)

- Part 1: Organizational contributions:
  - De-conflicting Civil-Military Networks:
    - Operation Unified Protector as case study
    - Achieving de-confliction between civil & military partners
    - Identify lessons learned: personalities, rotations, agreeing goals
  - Shaping Comprehensive Emergency Response Networks:
    - Multiple Dutch case studies involving local community
    - How professional ER organizations can use community capacity
    - Gain resilience by balance between directive & empathetic governance
  - Networked Operations: Principles of modular organizing:
    - US Army versus Netherlands Army as case study
    - Modular organization theory from Organization & Management science
    - Near-decomposability as organizational design parameter

Recent advances (4)

- Part 2: Modelling contributions:
  - Modelling Command & Control in Networks:
    - Based on Brehmer's (2007; 2013) C2 theory
    - Approach to modelling C2 functions over geographical network
  - Formalized Ontology for C2 Systems as Layered Networks:
    - Geographical, physical, information, cognitive, & socio-organizational
    - Logical ontology, formalized as Entity-Relationship Diagrams
    - 9-11 as example (simulation) application
  - Modeling C2 Networks as Dependencies:
    - C2 modelled as capabilities, dependencies, & vulnerabilities
    - Analyst tool implemented; insurgent scenario as case study
    - Aids in developing plan to alter behaviour of opposing network or increase resilience of own network

Recent advances (5)

- Part 3: Network science contributions:
  - Dynamical Network Structures in Multi-Layered Networks:
    - Theoretical contribution, using stochastic actor-based method
    - Analyzing effect of reciprocity & covering on actors' behaviour
  - Improving C2 Effectiveness based on Robust Connectivity:
    - Developing improved metric for network effectiveness using Cares' (2005) Information Age Combat Model
    - Simulation shows shift in focus from nodes to network as whole
  - Complex Adaptive Information Networks for Defence:
    - Understanding nature of networks that can create self-synchronization
    - Analysis at 3 levels:
      - Node & linkage topology; Local interaction between nodes; Feed through into clustering
    - Complexity theory gives deep insight into self-synchronization

Recent advances (6)

- Part 4: C2 technology contributions:
  - Cyber Security in Tactical Network Infrastructure for C2:
    - Assesses emergent network technologies for C2 using TRLs:
      - Reconfigurable radio systems; emergent topologies; SA technologies; security metrics; information asset protection systems; autonomous network monitoring & control
    - Long-term commitment needed in procurement, standardization, training, doctrinal & legal development
  - Smart Surveillance Systems:
    - Heterogeneous multi-modal data from automated sensor networks beyond human capacity to fuse, aggregate, & filter
    - Prototype developed using distributed smart agents:
      - Demonstrates reduction in role of human operators
    - Surveillance around Den Helder harbour using AIS as case study

Recent advances (7)

		Network science									
		Theory:				***Application:***					
		Node	Measure	Topology	Process	Geog	Phys	Information	Cognitive	Socio- org	Coalition
C2	***Theory:***										
	Infrastructure	(graph)		*"white space" (2)*			11	11			
	1 node	*"white space" (1)*									
	Organization									2	2, 3
	M nodes	10	9	7, 9, 10			ITA, NSC, 10	ITA, NSC, 1, 7	NSC, CTA	NSC, CTA, 7	1, 2
	Effectiveness		8	8				7		7	
	Application:										
	Model	5, 6	6	*"white space" (2)*		5	5	5	5	4, 5	5
	Observe	6	6				ITA, 12	ITA, 12		4	
	Orient	6	6						NSC, CTA	NSC, CTA, 4	
	Plan	6	6							4	
	Decide	*"white space" (3)*								4	*"white space" (3)*
	Act									4	
	Learn									4	

Limitations

- State of the art:
  - Based on mission statements on websites
  - Not based on literature survey
- International C2 Journal:
  - Surveyed:
    - Walker et al (vol 3 no 2) apply SNA to C2 approach space
    - Phister (vol 4 no 2) proposes use of NetSci technology
- ICCRTS proceedings:
  - Not surveyed exhaustively, but …
  - Attended since 2005 & no papers from NSC / CTA / ITA seen
- May be other journals or conferences

Conclusions

- Existing state of the art limited to:
  - Interoperability & communications in physical & information networks
  - Information sharing, collaboration, & self-synchronization in cognitive & social (but not organizational) networks
  - Observe & Orient (i.e. INTEL) processes
- Contributions have advanced state of the art in:
  - Integrating real (kinetic) & virtual (cyber) geographies
  - Organizational issues:
    - De-conflicting civil & military partners
    - Involving community in emergency response
    - Applying modular organizations
  - Modelling C2 in theory & application of network science
  - Self-synchronization at node, network, & topology levels

Future research

- 3 “white spaces” where research needed:
  - Application of network science to C2 nodes:
    - C2 infrastructure, SA, quality of information, agility
    - Organization / command structure
  - Application of network topology & processes to:
    - C2 theory (infra, single nodes, organization, multi nodes)
    - C2 applications (modelling & OODA loop)
  - Application of network science to C2 processes:
    - Decision-making, acting, & learning
    - Theory & applications of network science

Resources

- Newman. 2003. *Structure and Function of Complex Networks*. SIAM Review, 45, 2, 167-256.
  - Reviews SOTA (N.B. 2003). Warning: mathematical formulae!
- Barabási. 2003. *Linked: How everything is connected to everything else*. Plume, New York.
  - Easy read.
- Lewis. 2009. *Network Science: Theory and applications*. John Wiley, Hoboken, NJ.
  - Comprehensive textbook. Warning: mathematical formulae!
- Grant, Janssen & Monsuur (eds). 2014. *Network Topology in Command & Control: Organization, operation & evolution*. IGI Global, Hershey, PA.
  - http://www.igi-global.com/book/network-topology-command-control/99488

Any questions?

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