

An Investigation into Trust and Reputation Frameworks for Collaborative Teams of Autonomous Underwater Vehicles

Andrew Bolster

University of Liverpool

andrew.bolster@liv.ac.uk



UNIVERSITY OF
LIVERPOOL

July 3, 2014

1 Context

2 Trust in Networks

- What do we mean by trust?
- What are TMFs?
- Reasons for using Communication TMFs
- Pre-existing Research

3 Fusions of Trust Metrics

- Vector Trust
- Multi-Vector Trust
- Challenges for Implementing Multi-vector Trust

4 Development Plan

- Publications
- Thesis Plan

Research Context

- Project launched at QUB ECIT in 2011 under the DSTL/DGA Anglo French Defence Research Group PhD Programme
- What lessons from the Mobile Ad Hoc Network (MANET) space can be transferred to the marine environment?
- Teams of 3 - 16 Autonomous Underwater Vehicles (AUVs) Mine countermeasures, Hydrography, and Patrol Capabilities (MHPC)
- Defence focus, assumption of highly capable enemy attempting to compromise communications / operations
- Primary Simulation/Analysis work done in 12/13
- Moved to UoL Oct 13 after 2 mth placement @ DSTL PDW Naval Systems / Information Systems departments.

Research Collaborations

- DSTL
 - Visits and Placements (Summer '13) at DSTL Porton Down and Portsdown West
 - CDE Exhibition, London, (Spring '12)
 - PhD National Conferences, Oxford and London (12/13)
- DGA/UPMC
 - DGA Conference (Autumn, '12)
 - Visits fo CRIIF (Autumn, '12)
- NATO/CMRE
 - UComms'12
 - Visits & Ongoing data sharing with CMRE(NURC) in La Spezia
- NPL/Plextek
 - CDE Project on Precision Timing for Positioning with NPL/Plextek

Trust in Ad-Hoc Systems and the context of this document

- Particularly interested in the application of Trust in Decentralised (P2P) Autonomous Systems of Systems, Autonomous Underwater Vehicles (AUVs) for example

Trust in Ad-Hoc Systems and the context of this document

- Particularly interested in the application of Trust in Decentralised (P2P) Autonomous Systems of Systems, Autonomous Underwater Vehicles (AUVs) for example
- Trust: *The expectation of an actor performing a certain task or range of tasks within a certain confidence or probability*

Trust in Ad-Hoc Systems and the context of this document

- Particularly interested in the application of Trust in Decentralised (P2P) Autonomous Systems of Systems, Autonomous Underwater Vehicles (AUVs) for example
- Trust: *The expectation of an actor performing a certain task or range of tasks within a certain confidence or probability*
- Full System Views of Trust
 - Design Trust - that a system of systems will perform as spec'd / designed in operation

Trust in Ad-Hoc Systems and the context of this document

- Particularly interested in the application of Trust in Decentralised (P2P) Autonomous Systems of Systems, Autonomous Underwater Vehicles (AUVs) for example
- Trust: *The expectation of an actor performing a certain task or range of tasks within a certain confidence or probability*
- Full System Views of Trust
 - Design Trust - that a system of systems will perform as spec'd / designed in operation
 - Operational Trust - the systems within a larger system will perform as designed in field ✓

Trust Management Frameworks

- Provide information regarding the estimated future states and operations of nodes within networks

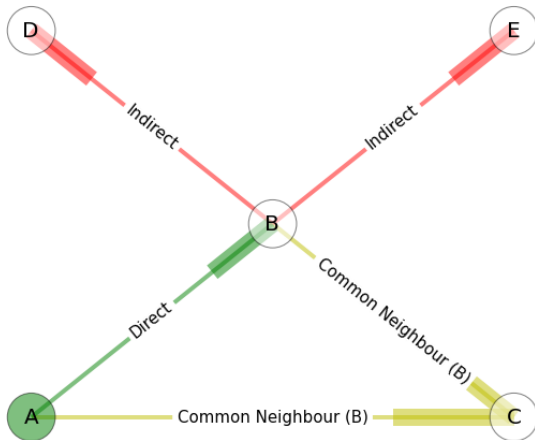
Trust Management Frameworks

- Provide information regarding the estimated future states and operations of nodes within networks
- “[...]collecting the information necessary to establish a trust relationship and dynamically monitoring and adjusting the existing trust relationship” - [4]

Trust Management Frameworks

- Provide information regarding the estimated future states and operations of nodes within networks
- “[...]collecting the information necessary to establish a trust relationship and dynamically monitoring and adjusting the existing trust relationship” - [4]
- Enables nodes to form collaborative *opinions* on their cohort nodes based on
 - Direct Observation of Communications Behaviour (eg Successfully Forwarded Packets)
 - Common-Neighbour Recommendation
 - Indirect Reputation

Transitivity in Trust Networks



TMFs in Ad Hoc Autonomous Systems

- Multiple transitive relationships can be maintained over time, providing trust resilience with dynamic network topology

TMFs in Ad Hoc Autonomous Systems

- Multiple transitive relationships can be maintained over time, providing trust resilience with dynamic network topology
- Enable trust establishment from partial-strangers via indirect trust and direct observation

TMFs in Ad Hoc Autonomous Systems

- Multiple transitive relationships can be maintained over time, providing trust resilience with dynamic network topology
- Enable trust establishment from partial-strangers via indirect trust and direct observation
- Enables nodes to inform internal processes for global efficiency given observed network behaviour / 'wellness', similar to those found in human social networks eg
 - Update routing table based on 'safest' node chains (Phone Tree)
 - Maneuver away from misbehaving nodes (Shunning)
 - Inform as to 'trustworthiness' of forwarded information (Healthy sense of Skepticism)
 - Historic Distrust/Trust decaying over time (Forgiveness/Relationship Decay)

Reason for using TMFs in MANETs

- Provide Risk Mitigation against many classical MANET attacks
 - Black/Grayhole
 - Routing Loop
 - Selective misbehaviour / selfishness
- Generally; to constrain potential malicious behaviour that can operate without detection

Trust in Autonomous Systems

- Public Key Infrastructure - Requires Centralised Control and pre-shared keys
- Resurrecting Duckling - Uses in-action keying with a trusted source
- Evidence Based Trust - Uses shared keys
- Reputation Based Trust - Uses Packet forwarding success rate for prediction of future actions
 - CONFIDANT - Trust-based router implementation using packet forwarding rate
 - OTMF - Trust including transitive information from other nodes
- ... and there are plenty more along the same lines
- Predominantly use single metrics or only communications metrics

Trust in Autonomous Systems

- Public Key Infrastructure - Requires Centralised Control and pre-shared keys
- Resurrecting Duckling - Uses in-action keying with a trusted source
- Evidence Based Trust - Uses shared keys
- Reputation Based Trust - Uses Packet forwarding success rate for prediction of future actions
 - CONFIDANT - Trust-based router implementation using packet forwarding rate
 - OTMF - Trust including transitive information from other nodes
 - MPTM - Relationships and Multiple Metrics combined with Gray Interval assessment
- ... and there are plenty more along the same lines
- Predominantly use single metrics or only communications metrics

Vectorised Trust

- Application of several individual metrics for the construction of a single trust measurement
- For example:
 - $X = \{\textit{packet loss}, \textit{signal strength}, \textit{datarate}, \textit{delay}, \textit{throughput}\}$
- This multi-parameter trust prevents 'smart' attackers; leveraging a known trust metric to subvert a TMF without detection
- Normally expressed as a vector, but can be condensed into an abstracted or weighted form for comparison [3]

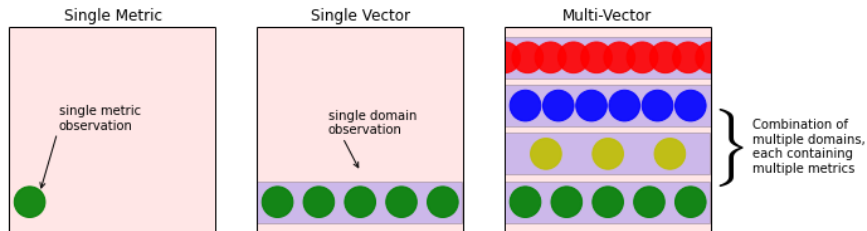
The Need for Multi-Domain Trust Assessment

- Communications not the only target for an attacker (or failure);
 - Following to restricted area
 - Masquerading
 - Hardware Degradation
 - Resource attack via propulsive power
- Physical observation presents opportunity to further reduce the available threat surface while also discriminating between 'True' attacks and mechanical failure.
- Also could provide additional 'handshake' protocols for 'friendly' fleets/teams through reactionary behaviours

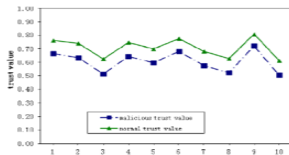
Multi-Vector Trust and the Threat Surface

Potential attacks exist across a multi-domain threat surface

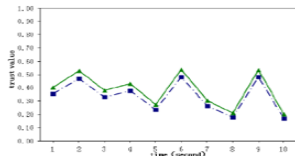
Threat Surface for Trust Management Frameworks



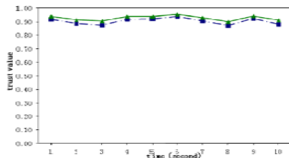
Malicious Behaviour Discrimination



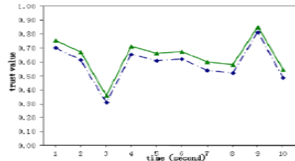
(a) equal weights



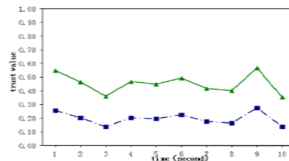
(b) emphasizing PLR



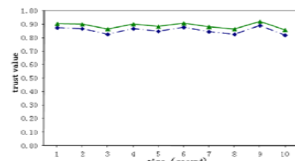
(c) emphasizing signal strength



(d) emphasizing delay



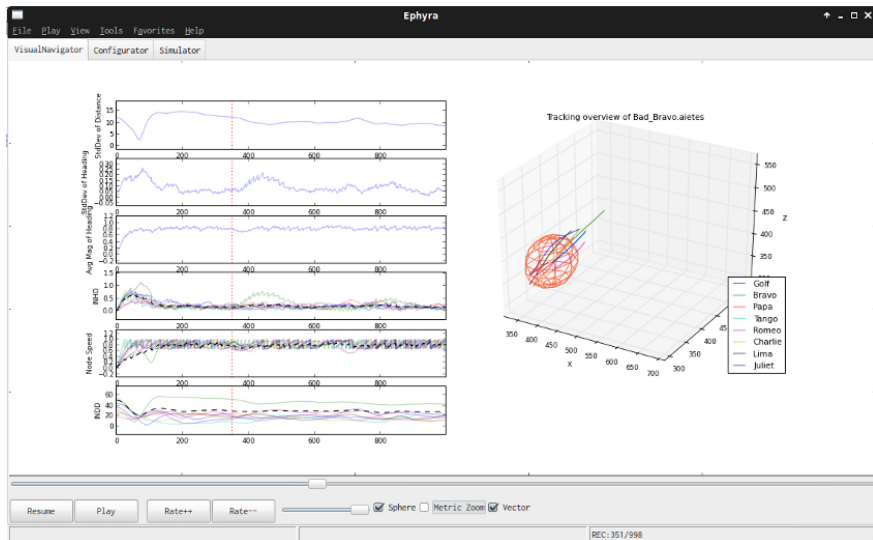
(e) emphasizing throughput



(f) emphasizing data rate

—●— malicious trust values —○— normal trust values

Agent Based Behaviour Simulator



Trust in Mobile Autonomous Underwater Vehicles

- Flocking with Intent: MCM, Port Protection, Survey, Protection Detail, etc.

Trust in Mobile Autonomous Underwater Vehicles

- Flocking with Intent: MCM, Port Protection, Survey, Protection Detail, etc.
- Metric Selection in collaboration CMRE/DSTL
 - Inter Node Heading Deviation
 - Inter Node Distance Deviation
 - Node Speed

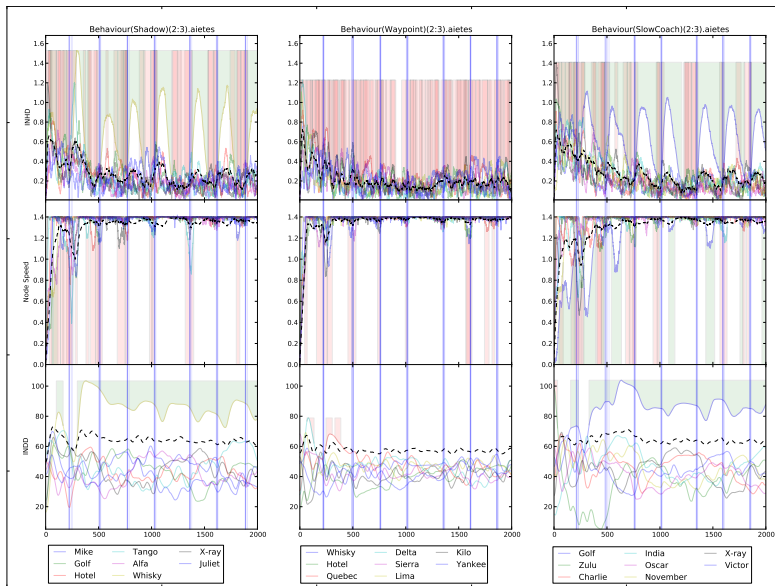
Trust in Mobile Autonomous Underwater Vehicles

- Flocking with Intent: MCM, Port Protection, Survey, Protection Detail, etc.
- Metric Selection in collaboration CMRE/DSTL
 - Inter Node Heading Deviation
 - Inter Node Distance Deviation
 - Node Speed
- Behaviour selection for testing
 - Shadow
 - Spy
 - Sloth
 - Stalker
 - Scoundrel

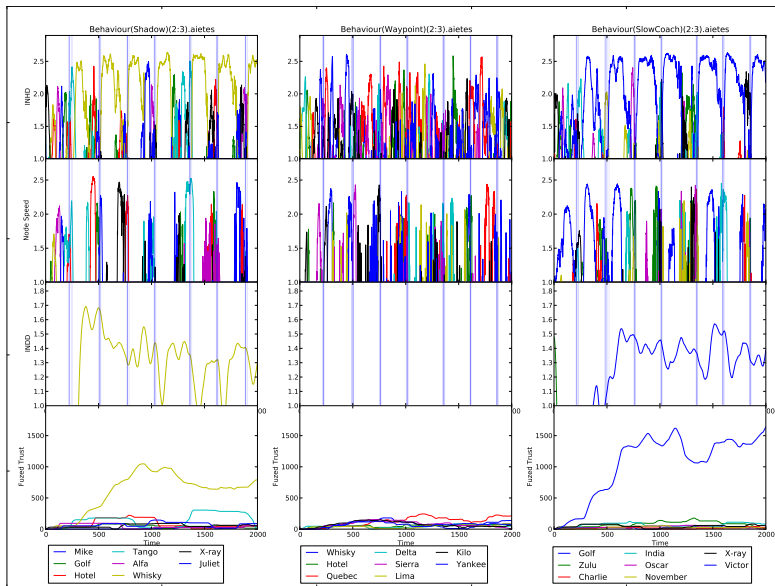
Trust in Mobile Autonomous Underwater Vehicles

- Flocking with Intent: MCM, Port Protection, Survey, Protection Detail, etc.
- Metric Selection in collaboration CMRE/DSTL
 - Inter Node Heading Deviation
 - Inter Node Distance Deviation
 - Node Speed
- Behaviour selection for testing
 - Shadow
 - Spy
 - Sloth
 - Stalker
 - Scoundrel
 - Slow Coach (non-malicious)
 - Spin Doctor (non-malicious)

Raw Behavioural Metric Assessment in AUVs



Behavioural Trust Assessment in AUVs



Behavioural Trust Assessment in AUVs

- Detection and identification based on basic weight-assessment classifier against windowed history of observations, with confidence based on a Grey Theoretic weight
- Currently >96% statistical accuracy of detection and confidence, but this needs much more rigorous analysis

Challenges in Multi-vector Trust

- How to define optimality in trust assessment when dealing with multiple vectors and transitive trust?
- Is there a quantifiable benefit to cross-domain comparison beyond single vector Trust?
- Is there an optimal generic cross-domain comparator?

Current Publications

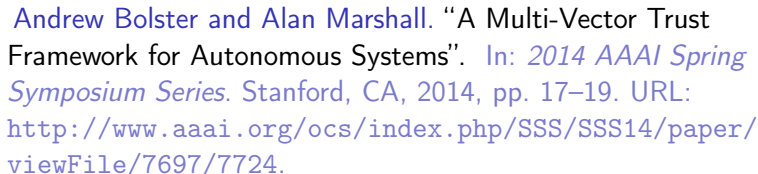
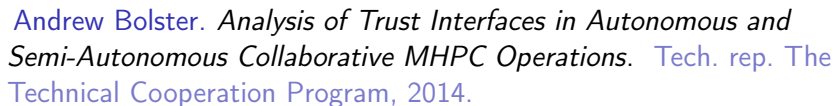
- A Multi-Vector Trust Framework for Autonomous Systems [2]
 - Symposium paper to the Association for the Advancement of Artificial Intelligence on the current state of work, presenting our progress towards multi-vector trust
- Analysis of Trust Interfaces in Autonomous and Semi-Autonomous Collaborative MHPC Operations [1]
 - Part of a Five-Eyes defence strategy programme (TTCP) for assuring C3I capabilities as part of FF2020

Development Plan

- 1 Behaviour Detection (Q3 14) - Formal Analysis of Behavioural Trust Systems
 - ASON 2014 : Seventh Int. WS on Autonomous Self-Organizing Networks (Aug 14)
 - AHUC 2014 : The Fourth Int. WS on Ad Hoc and Ubiquitous Computing (Aug 14)
 - ICCAR 2015 : WASET Int. Conf. on Control, Automation and Robotics (Dec 14)
- 2 MANET/Marine comparison (Q4 14) - Formal Comparison between Terrestrial MANET / Marine contexts
- 3 Multi-Domain Trust Assessment (Q4 14) - Combination of Communicative and Physical Behaviour Trusts
 - IEEE Trans. on Communications / Dependable and Secure Computing / Intelligent Systems
- 4 Reactionary/Perturbative Trust (Q1 15) - Exploration of reactionary behaviours for teams to 'shake down' suspects
 - SASO15: Self-Adaptive and Self-Organizing Systems,
 - SEAMS15: Software Engineering for Adaptive and Self-Managing Systems

Thesis plan

- Abstract, Acknowledgements, Introduction,
- Background Information on Trust and its applications to MANETs
- Background Information on Maritime Uses of Autonomous Systems
- Trust in Autonomous Systems of Systems for Maritime Defence Applications
- Strategies for Multi-Domain Trust Assessment
- Modelling and Analysis of Collaborative Node Kinematic Behaviours in Underwater Acoustic MANETS
- Comparative Analysis of Multi-Domain Trust Assessment in Collaborative Mobile Networks
- Reactionary Behaviours to increase decentralised trust in isolated environments
- Conclusions, Bibliography



References II

-  Ji Guo, Alan Marshall, and Bosheng Zhou. “A New Trust Management Framework for Detecting Malicious and Selfish Behaviour for Mobile Ad Hoc Networks”. In: *2011IEEE 10th International Conference on Trust Security and Privacy in Computing and Communications* (2011), pp. 142–149. DOI: 10.1109/TrustCom.2011.21. URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6120813>.
-  Huaizhi Li and Mukesh Singhal. “Trust Management in Distributed Systems”. In: *Computer* 40.2 (2007), pp. 45–53. ISSN: 00189162. DOI: 10.1109/MC.2007.76. URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4085622>.

The End