An Investigation into Trust and Reputation Frameworks for Autonomous Underwater Vehicles

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Structure of this presentation

Structure

- Statement of Research Purpose
- Summary of Contributions
- Errata
- Discussion of new research that has entered the field since submission
- Chapter Summaries
- Open for Discussion

Summary of Contributions

Primary

- Trust in UANs
- Trust assessment based on Physical Behaviours
- Multi-domain Trust

Secondary

- Automatic weighting of MTFM
- Agent based UAN Sim
- Synthetic Domains from metrics over multiple domains
- Review of Trust in the marine defence context

Publications

- Analytical Metric Weight Generation for Multi-Domain Trust in Autonomous Underwater MANETs. IEEE UComms 2016
- Single & Multi-metric Trust Management Frameworks for Use in Underwater Autonomous Networks. IEEE TrustCom 2015
- Analysis of Trust Interfaces in Autonomous & Semi-Autonomous Collaborative MHPC Operations, The Technical Cooperation Program, Portsmouth, UK 2014.
- A Multi-Vector Trust Framework for Autonomous Systems, AAAI 2014.

Erratta

Erratta

- Many small typographic issues corrected
- Missing Citation in 3.1.1,5-7[a]
- Out-of-order paragraphs in 4.2.5 (Top should be bottom)

[a] R J Urick (1983). *Principles of underwater sound*. NewYork.423pages. ISBN: 0070660867.

Recent Research Trends

Trust

- Interesting general move towards decentralised trust[a]
- Ditto cohort based relative trust assessment[b]
- Increasing use of ML techniques to assess contextual trust dynamically[c]
- Human Factors emerging as a increasingly vital area of research[d]
- Novel/Updated techniques for generalised TMF assessment are emerging[e]

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[a] Korzun et al., 2015.
[b] Singh and Sidhu, 2016.
[c] Rishwaraj, Ponnambalam, and Loo, 2017.
[d] Saeidi, 2009; Matthews et al., 2016; Lahijanian and Kwiatkowska, 2016.
[e] Janiszewski, 2016.

Recent Research Trends

Acomms

- Assumptions of Gaussian noise naive for real applications[a]
- The Beaufort Sea has fundamentally changed it's characteristics in 20 years and highlights fundamental flaws in channel modelling assumptions[b]
- Higher-Stack level functionality problems remain open(i.e. MAC+Route+ID+Interop)[c]
- Assumptions on increasing accuracy and timeliness of passive localisation proving accurate[d]

[a] Mahmood and Chitre, 2016; Deane and Preisig, 2016.

[b] Schmidt and Schneider, 2016.

[c] Diamant, Francescon, and Zorzi, 2016; Petroccia, 2016; Petroccia, Alves, and Zappa, 2016; Anjangi and Chitre, 2016.

[d] Vio, Cristi, and Smith, 2016; Ferreira et al., 2016; Das and Thampi, 2016.

Focus On

- Trust
- Autonomy
- Decentralised networks
- Harsh Environments

Stated deficiencies in

- Single Metric Trust
- Threats from Capable actors
- Systemic Trust
- Lack of modelling of Trust in Harsh environments

Focus On

- Network/Graph concepts
- Routing
- Trust Perspectives and Models
- Trust Relationships
- Multi-Party Trust
- Trusted Threats
- Autonomy and Design constraints of Autonomous Systems
- Current Trust Management Frameworks

Key Outcomes

- Definition of Trust
- Levels & Constraints of Autonomy
- Lack Specification and Validation for Autonomous Systems
- Threats to Trust
- Threats to MANETs
- Need for Trust in Autonomous Systems

Focus On

- Marine Acoustics
- AComms Modelling
- AUV Operations
- Need for Trust in AUV AComms

Key Outcomes

- Channel Emulation Models
- Selection of characteristic constraints
- Threat Surface
- Operational / Kinematic constraints and Scenario selection

Chapter 4: Assessment of TMF Performance in Marine Environments

Focus On

- Comparative factors between UAN/WLAN
- Relevant Metric Selection re AComms
- Comparison of Single & Multi Metric TMFs in UAN
- MTFM weight variation assessment and regression

Key Findings

- Modelled optimal performance range @ ≈0.015-0.025pps/100-300m node separations ▸ Details
- MTFM outperforms single metric TMFs for selected misbehaviours ▸ Details
- MTFM vector weighting further improves performance and tolerance ▸ Details
- Long collection times due to sparsity can impact trust assessment relevance

Focus On

- Physical Misbehaviours and Metrics
- "Failure" vs "Selfish" vs "Malice"
- AUV Kinematics
- Metric variability in collaborative collision avoidance (flocking)
- Metric based classifier

Key Findings

- First physical misbehaviour detection system in UAN
- Demonstrated that different misbehaviours impact different physical metrics differently

  Details 1 Details 2
- Highly accurate, manually configured, blind behaviour classifier ($\approx$ 0% FP, $\gtrsim$ 90 % TP)

Chapter 6: Multi-Domain Trust Assessment in Collaborative Marine MANETs

Focus On

- Combination of comms. & phys. metrics
- Random Forest based metric significance correlation to build H weighting vector for MTFM
- Domain specific behaviour effects across domain space
- Relative vector weight measurement across cohort ($\Delta T, \Delta T^{-}$)
- Generation and Appraisal of alternate/targeted "domains"

Key Findings

- Misbehaviours impact across domains (not obvious) ▸ Details
- Inherent redundancy (eg INDD/P_{RX}) allows differential behaviours to be detected ▸ Details
- Application level selfishness (STS) very difficult to automatically
- Extended Ch4 behaviour based optimisation of MTFM to dynamically select most significant metrics

Summary of Contributions to the Field

Σ

- UWA Multi Metric/Domain Trust
- UWA Trust is Hard & it's mostly the channels' fault
- Discrimination of non-comms misbehaviours/failures even just using comms metrics
- Methodology for exploring / training / metric relevance
- Single-Metric Trust is unstable in such an environments
- Multi-Metric Trust works & can discriminate behaviours
- Not all metrics are equally useful
- Simple classifiers can be very good in some behaviours (MPC)
- - can be not so good for others (STS)

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Outstanding Research Challenges

$\notin$

- Smarter Detection Classifier
- Cooperative / Periodic / Variable attack profiles
- Further assessment of impact and tolerance of misbehaviours in the network
- Commonality of detection filters across Multiple-base scenarios
- Real experiments and Cross validation implementations
- Heterogenous Node capabilities / Mixed-mission characteristics
- Extension to logical routing domain
- Application of mixed-domain trust assessment to non-physical systems
- Reflective Trust (i.e. systems trust of the operator)

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Fig 1.1 Multi-Domain Threat Surface

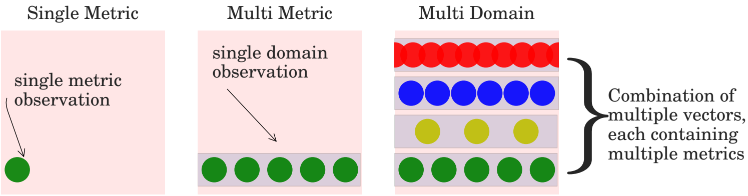

Fig. 1: Multi-Domain Threat Surface

Tab 2.3 Definitions of Trust

Definition	Source
Assured reliance on the character, ability, strength, or truth of someone or something.	Merriam-Webster
Firm belief in the reliability, truth, or ability of someone or something	OED
The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a articular action important to the trustor, irrespective of the ability to monitor or control that other party	Mayer, Davis, and Schoorman, (1995)
An expectancy held by and individual or a group that the word, promise, verbal or written statement of another individual or group can be relied upon	Rotter, (1967)

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Fig 2.5 Model of Trust

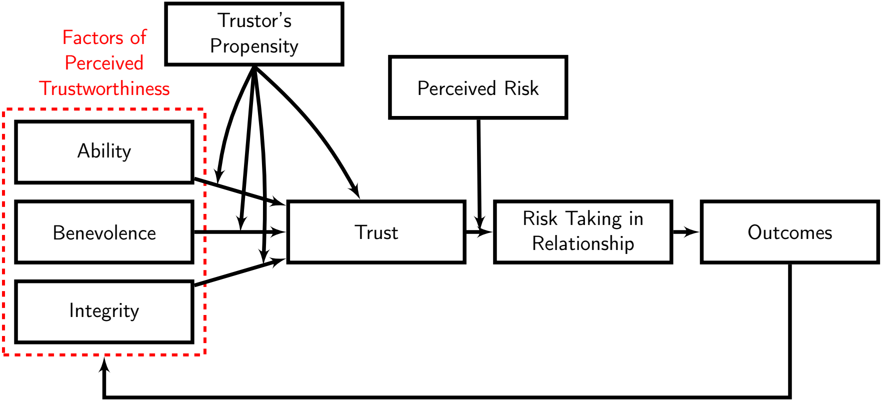

Fig. 2: Model of Trust (from Mayer, Davis, and Schoorman, (1995))

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Fig 2.6 Trust Construct Relationships

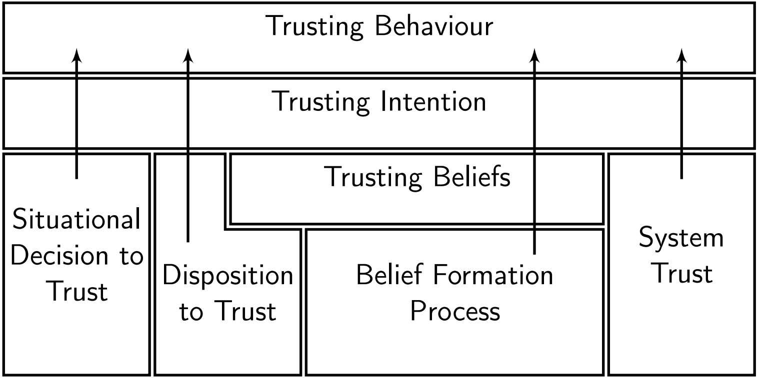


Fig. 3: Trust Construct Relationships (from Liu and Wang, (2010))

Fig 2.10 Trust Topologies

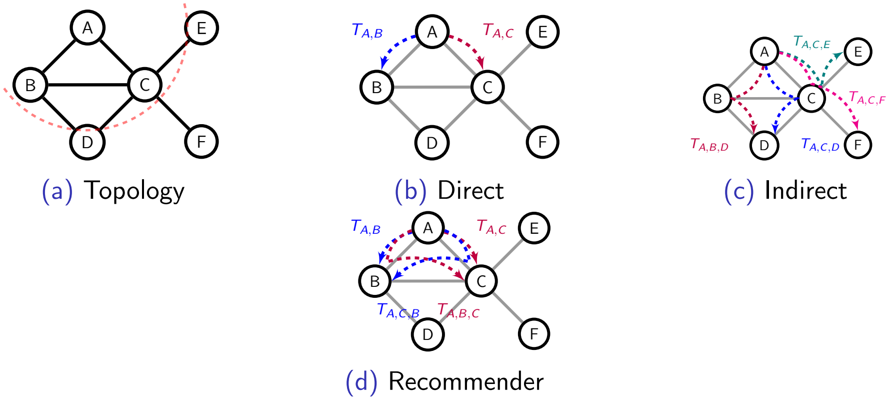
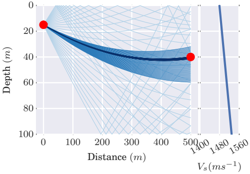
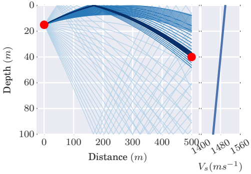


Fig. 4: Trust Topologies; Direct, Indirect, Recommender, etc. from the perspective of Node A

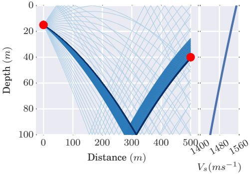
Fig 3.3: Bellhop Model



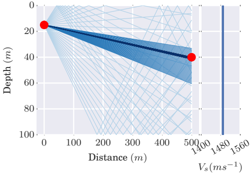
(a) Linear Increasing



(b) Linear Decreasing



(c) Quadratic



(d) Isovelocity

Fig. 5: Bellhop Model of Non-Linear Marine Shortest-Path Propagation in various Speed of Sound Profiles

Communications Channel Considerations

Key Characteristics of the Marine Acoustic Channel Urick, 1983; Partan, Kurose, and Levine, 2006; Stojanovic, 2007; Stefanov and Stojanovic, 2011:

- Slow propagation ($1400ms^{-1}$) incurring long delays
- Inter-symbol interference
- Doppler Spreading
- Non-Linear propagation due to refraction
- Fast & Slow fades from environmental factors (flora/fauna/surface and seabed conditions)
- Freq. dependant attenuation
- Significant destructive multipath effects

Attenuation in the Marine Acoustic Channel

The attenuation that occurs in an underwater acoustic channel over distance d about frequency f is given as $A_{aco}(d, f) = A_0 d^k a(f)^d$ or

$$10 \log A_{aco}(d, f)/A_0 = k \cdot 10 \log d + d \cdot 10 \log a(f) \qquad (1)$$

where A_0 is a normalising constant, k is a spreading factor, and $a(f)$ is the absorption coefficientStefanov and Stojanovic, 2011;

$$10 \log a(f) = \frac{0.11 \cdot f^2}{1 + f^2} + \frac{44 \cdot f^2}{4100 + f^2} + 2.75 \times 10^{-4} f^2 + 0.003 \qquad (2)$$

Attenuation in the Marine Acoustic Channel

The attenuation that occurs in an underwater acoustic channel over distance d about frequency f is given as $A_{\mathrm{aco}}(d,f) = A_0 d^k a(f)^d$ or

$$10 \log A_{\mathrm{aco}}(d,f)/A_0 = k \cdot 10 \log d + d \cdot 10 \log a(f) \tag{1}$$

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Compared to RF Free space PL: $(A_{\mathrm{RF}}(d,f) \approx \left(\frac{4\pi df}{c}\right)^2)$

- Exponential in d: $A_{\mathrm{aco}} \propto f^d$ vs $A_{\mathrm{RF}} \propto (df)^2$
- f factor four orders higher in $f \propto A_{\mathrm{aco}}$ vs $f \propto A_{\mathrm{RF}}$

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Multi-Metric TMF - Grey Grading

$$\theta^t_{k,j} = \frac{\min_k |a^t_{k,j} - g^t_j| + \rho \max_k |a^t_{k,j} - g^t_j|}{|a^t_{k,j} - g^t_j| + \rho \max_k |a^t_{k,j} - g^t_j|} \tag{3}$$

$$\phi^t_{k,j} = \frac{\min_k |a^t_{k,j} - b^t_j| + \rho \max_k |a^t_{k,j} - b^t_j|}{|a^t_{k,j} - b^t_j| + \rho \max_k |a^t_{k,j} - b^t_j|} \tag{4}$$

$$[\theta^t_k, \phi^t_k] = \left[\sum_{j=0}^{M} h_j \theta^t_{k,j}, \sum_{j=0}^{M} h_j \phi^t_{k,j} \right] \tag{5}$$

$$T^t_k = (1 + (\phi^t_k)^2 / (\theta^t_k)^2)^{-1} \tag{6}$$

Where $a^t_{k,j}$ is the value of an observed metric x_j for a given node k at time t, g and b are respectively the "good" and "bad" reference metric sequences from $\{a^t_{k,j} k = 1, 2 \ldots K\}$, $H = [h_0 \ldots h_M]$ is a metric weighting vector such that $\sum h_j = 1$

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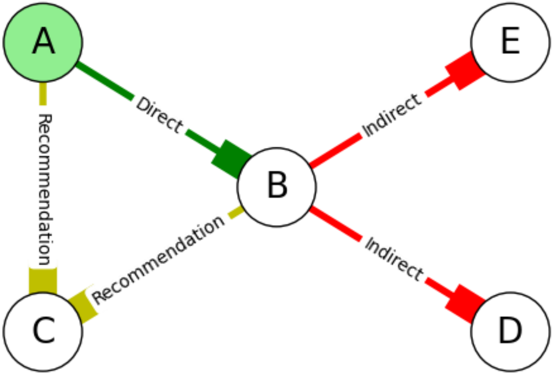
Multi-Metric TMF - Topological Relationships

Includes shared assessments from other nodes weighted based on their relative topology to provide a final value[1]

$$T_{i,j}^{MTFM}$$



$$
\begin{aligned}
T_{i,j}^{MTFM} =& \frac{1}{2} \cdot \max_s \{ f_s(T_{i,j}) \} T_{i,j} \\
&+ \frac{1}{2} \frac{2|N_R|}{2|N_R| + |N_I|} \sum_{n \in N_R} \max_s \{ f_s(T_{i,n}) \} T_{i,n} \\
&+ \frac{1}{2} \frac{|N_I|}{2|N_R| + |N_I|} \sum_{n \in N_I} \max_s \{ f_s(T_{i,n}) \} T_{i,n}
\end{aligned} \tag{7}
$$

Where $T_{i,n}$ is the subjective trust assessment of n_i by n_n, and $f_s = [f_1, f_2, f_3]$ given as...

Grey Trust Equs II

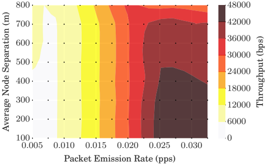
$$
\begin{aligned}
f_1(x) &= -x + 1 \\
f_2(x) &= \begin{cases} 2x & \text{if } x \leq 0.5 \\ -2x + 2 & \text{if } x > 0.5 \end{cases} \\
f_3(x) &= x
\end{aligned}
\tag{8}
$$

Back

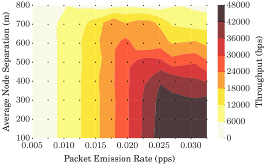
Tab 4.1: System Model Constraints

Parameter	Unit	Terrestrial	Marine
Simulated Duration	s	300	18000
Trust Sampling Period	s	1	600
Simulated Area	km^2	0.7	0.7-4
Transmission Range	km	0.25	1.5
Physical Layer		RF(802.11)	Acoustic
Propagation Speed	m/s	3×10^8	1490
Center Frequency	Hz	2.6×10^9	2×10^4
Bandwidth	Hz	22×10^6	1×10^4
MAC Type		CSMA/DCF	CSMA/CA
Routing Protocol		DSDV	FBR
Max Speed	ms^{-1}	5	1.5
Max Data Rate	bps	5×10^6	≈ 240
Packet Size	bits	4096	9600
Single Transmission Duration	s	10	32
Single Transmission Size	bits	10^7	9600

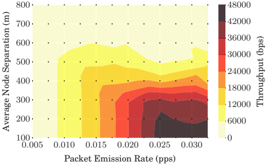
Throughput



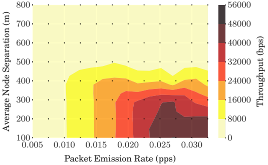
(a) Static



(b) Single Mobile

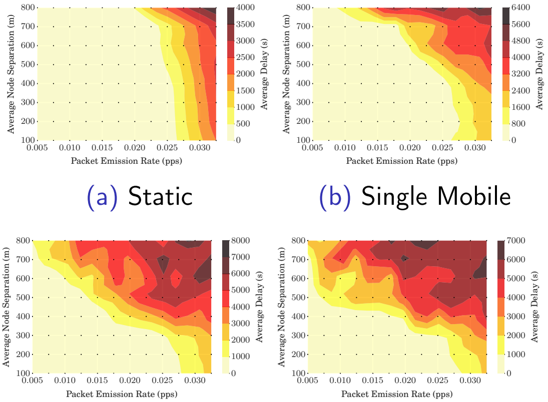


(c) All-but-one Mobile



(d) All Mobile

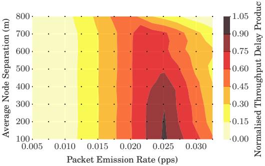
Delay



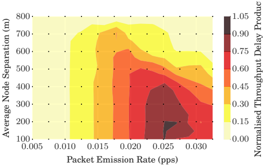
(a) Static (b) Single Mobile

(c) All-but-one Mobile (d) All Mobile

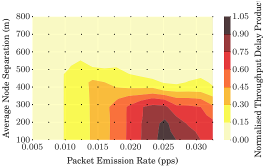
Fig 4.12: Normalised Throughput-Delay Product



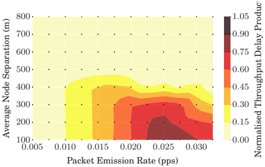
(a) Static



(b) Single Mobile

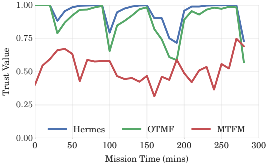


(c) All-but-one Mobile

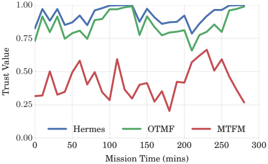


(d) All Mobile

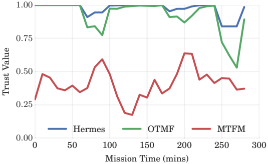
Fig 4.14: Hermes, OTMF, MTFM Trust assessments



(a) Fair Scenario



(b) Malicious Power Control (MPC) Scenario



(c) Selfish Target Selection (STS) Scenario

Fig. 9: $T_{0,1}$ for Hermes, OTMF, MTFM assessment values for fair and malicious behaviours in the fully mobile scenario

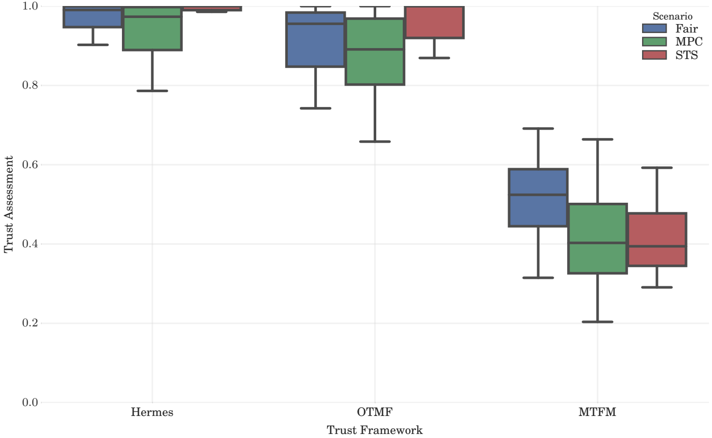
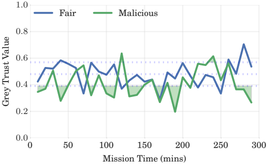
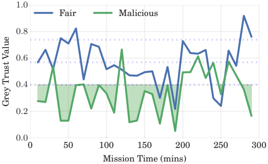


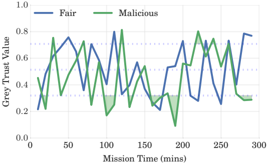
Fig. 10: Visualisation of TMF performance comparison across Fair, MPC and STS scenarios



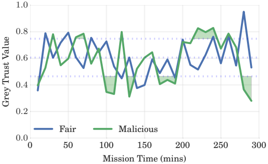
(a) Delay Emphasised



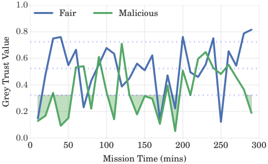
(b) *PLR* Emphasised



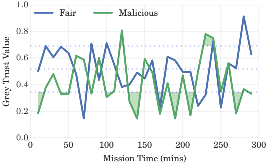
(c) Received Power (P_{RX}) Emphasised



(d) Transmit Power (P_{TX}) Emphasised



(e) Throughput (S) Emphasised



(f) Offered Load (G) Emphasised

Fig. 11: $T^{\mathrm{MTFM}}_{1,0}$ in the All Mobile case for the Malicious Power Control behaviour

Fig 4.18: Factor Analysis

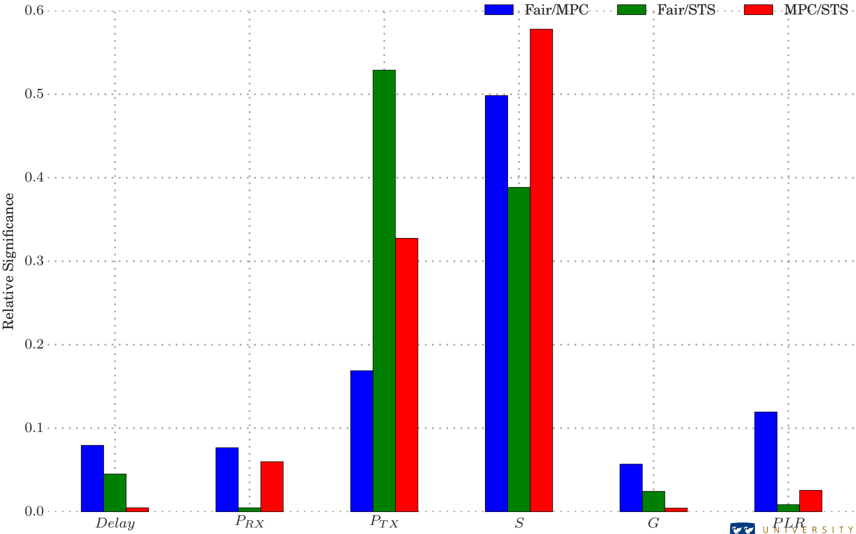


Fig. 12: Random Forest Factor Analysis of Malicious, Selfish and Fair behaviours compared against each-other

Fig 5.3: Observed Metric Values

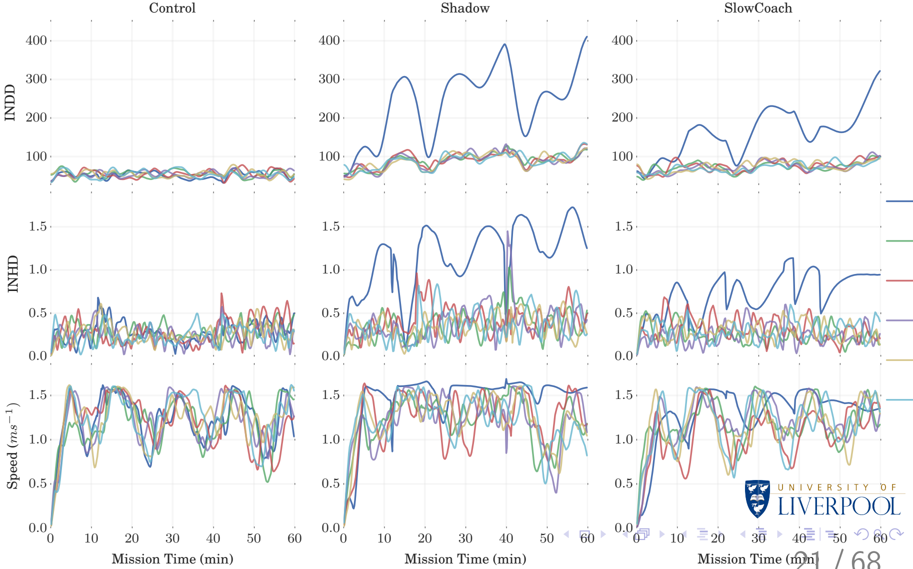


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Fig 5.4: Relative Node Deviance

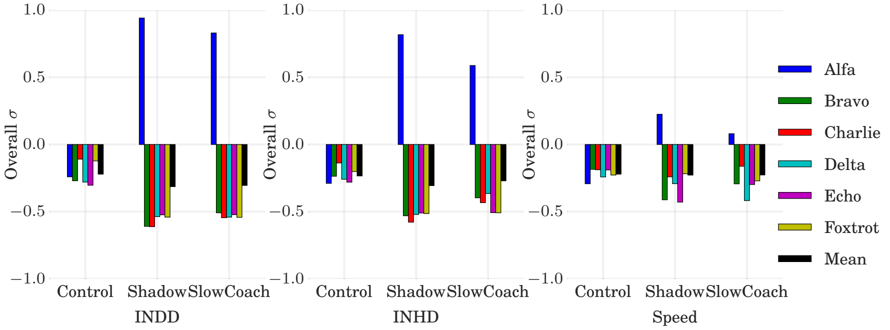

Fig. 13: Per-Node-Per-Run deviance for each metric, normalised in time $(\sum \alpha / T)$

Fig 6.1: Alternate Domain Construction

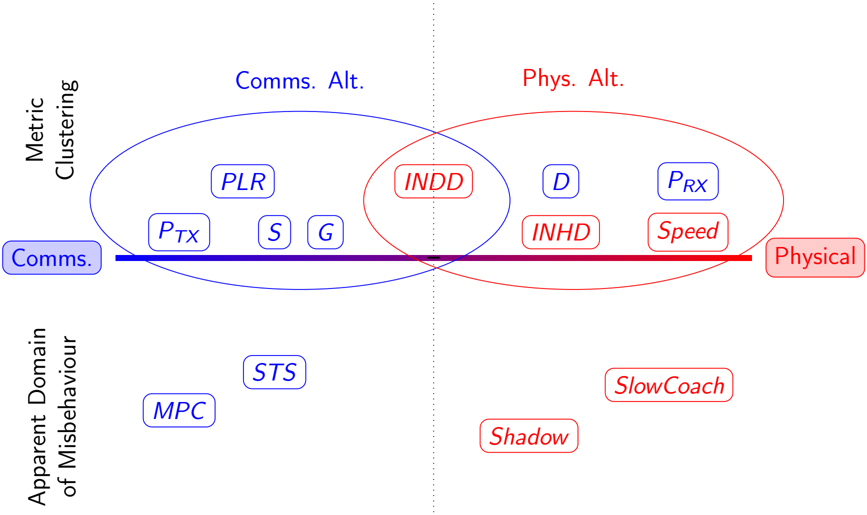

Fig. 14: Assumptions made about the relevant domains of impact / detectability of misbehaviours, and domain relevance of metrics, may not be optimal

Fig 6.2: Communications Metric Features

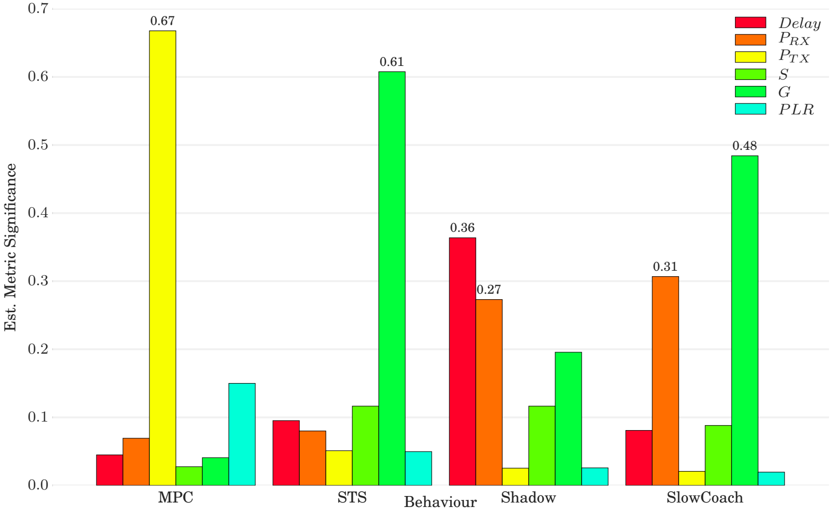

Fig. 15: Communications Metric Features (X_{comms})

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Fig 6.3: Physical Metric Features

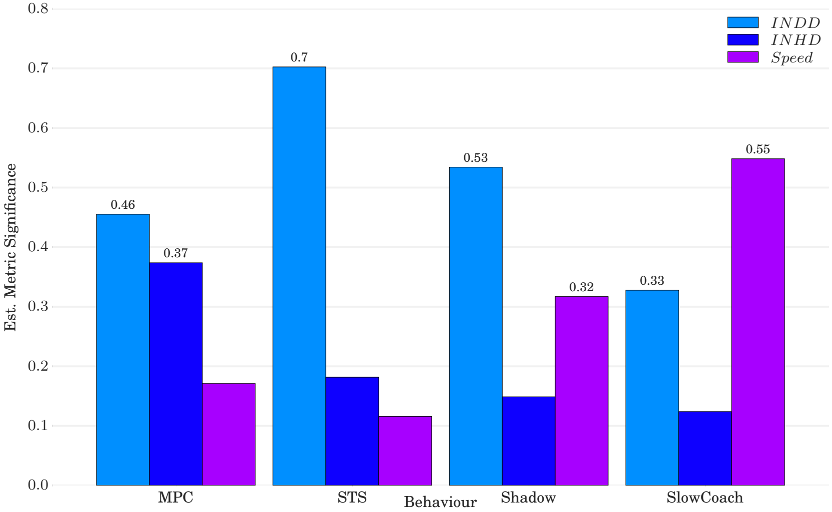


Fig. 16: Physical Metric Features (X_{phys})

Fig 6.4: Multi Domain Metric Features

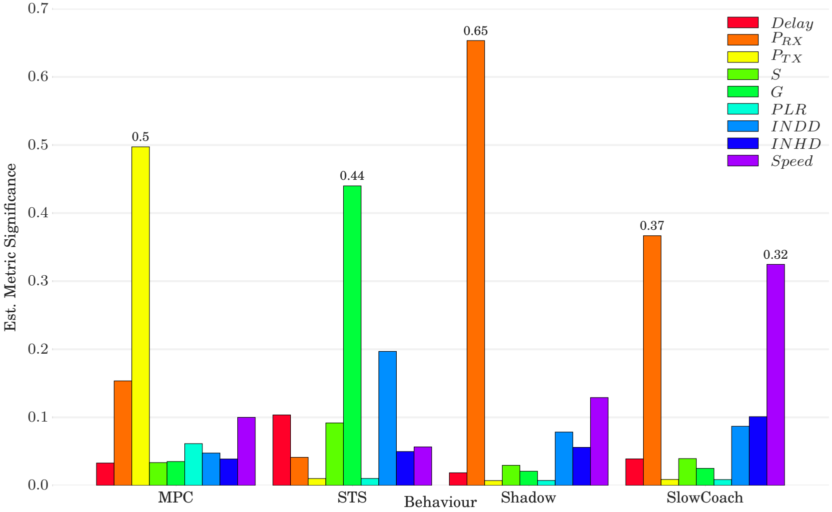


Fig. 17: Multi Domain Metric Features (X_{merge})

Table 1: Multi Domain Metric Feature Correlation (X_{merge})

Misbehaviour	*Delay*	P_{RX}	P_{TX}	*S*	*PLR*	*G*	*INDD*	*INHD*	*Speed*
MPC	-0.187	0.129	0.579	0.006	0.069	-0.146	0.040	-0.190	-0.297
STS	-0.195	-0.035	0.019	-0.100	0.019	0.381	-0.209	0.057	0.062
Shadow	0.004	-0.654	0.030	-0.016	0.030	0.063	0.120	0.158	0.266
SlowCoach	-0.157	-0.533	0.013	-0.132	0.013	-0.028	0.159	0.206	0.460

Fig 6.10: Accuracy Characteristics

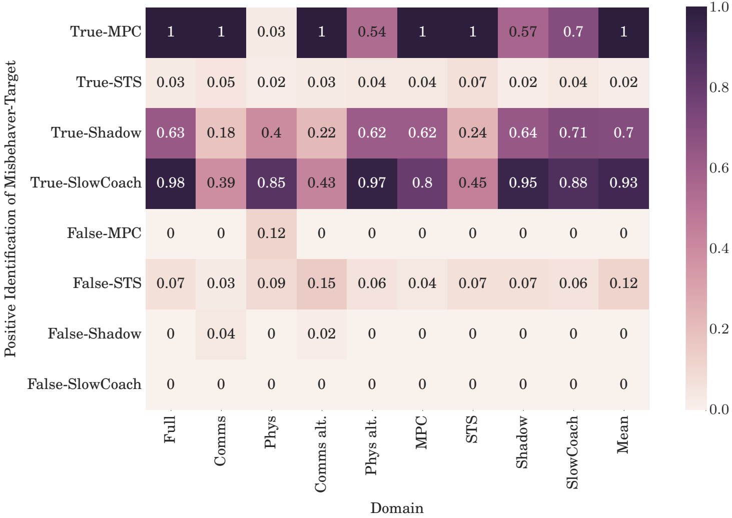
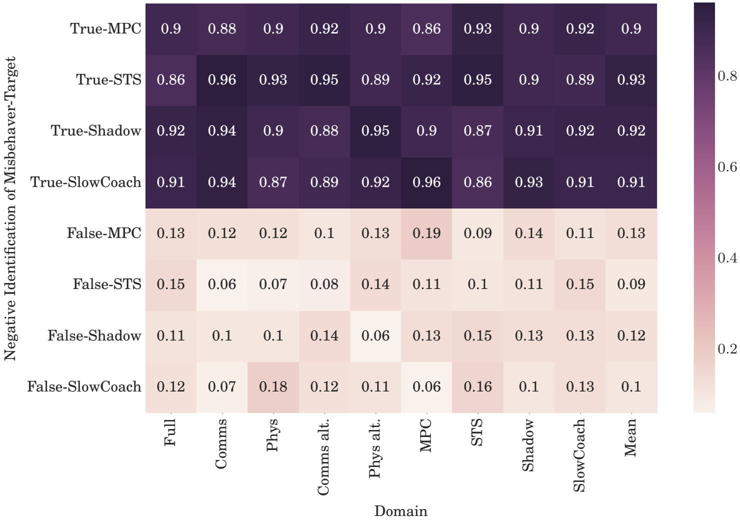


Fig 6.11: Selectivity Characteristics



Tab 6.11: Metric Selection/Weighting

Table 2: ΔT_{ix} behaviour detection performance across meta-domains, including selected metrics

Domain		Behaviour ΔT_{ix} MPC	STS	Shadow	SlowCoach	Mean	Metrics in Domain *Delay*	P_{RX}	P_{TX}	S	G	*PLR*	*INDD*	*INHD*	*Speed*
Basic	Full	0.81	-0.03	0.42	0.60	0.45	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Comms	0.85	0.04	0.19	0.26	0.34	✓	✓	✓	✓	✓	✓			
	Phys	0.04	0.00	0.39	0.69	0.28							✓	✓	✓
Alternate	Comms alt.	0.85	0.03	0.38	0.45	0.43				✓	✓	✓	✓		
	Phys alt.	0.48	0.03	0.42	0.63	0.39	✓	✓					✓	✓	✓
Synthetic	MPC	0.89	0.01	0.35	0.54	0.45	✓	✓	✓					✓	
	STS	0.86	0.06	0.37	0.49	0.45	✓		✓	✓		✓	✓		
	Shadow	0.49	-0.00	0.44	0.66	0.40		✓					✓	✓	✓
	SlowCoach	0.47	0.00	0.37	0.72	0.39	✓	✓		✓					✓
	Mean	0.88	0.03	0.42	0.69	0.50		✓	✓		✓		✓		✓

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Fig 6.9. Metric-Target Correlations

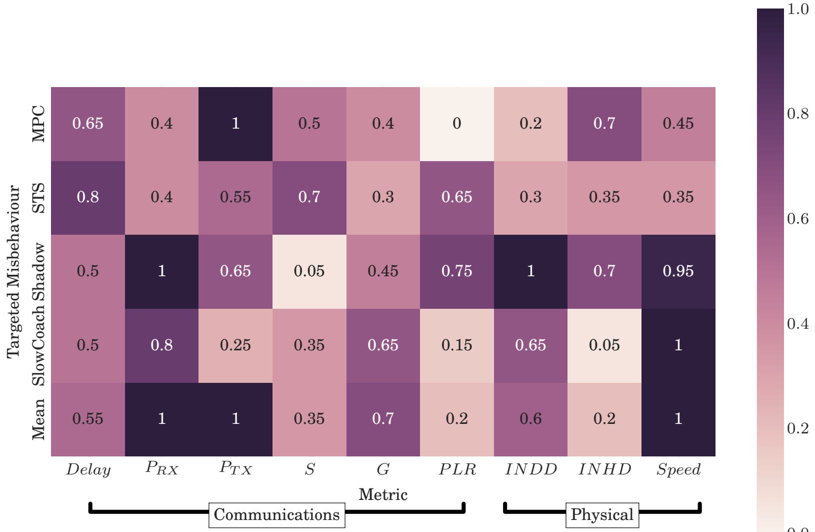
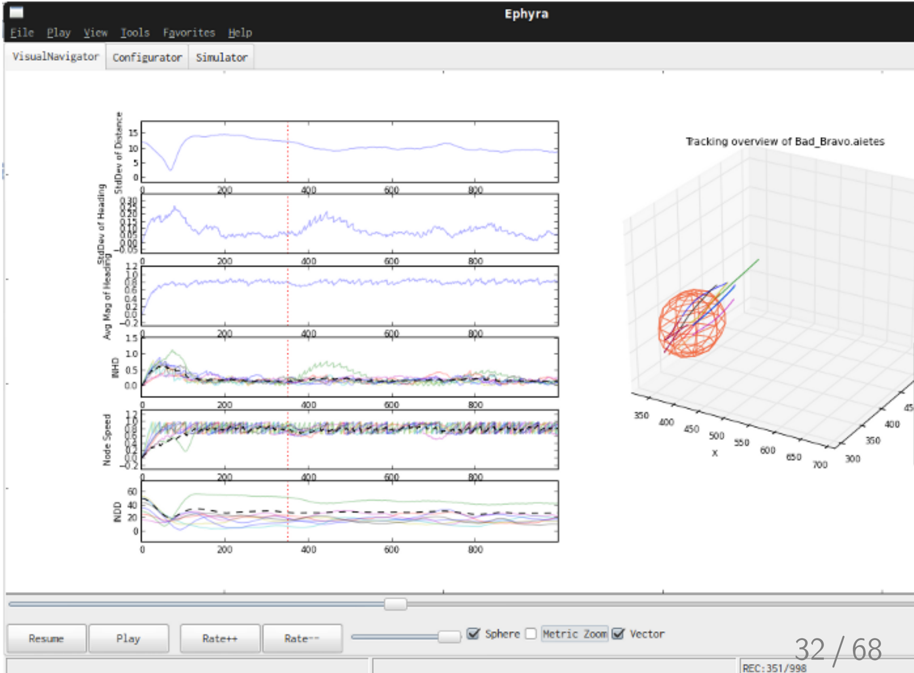


Fig. 18: Correlations between highest performing synthetic domain metrics with respect to Targeted misbehaviours


Ephyra
File Play View Tools Favorites Help
VisualNavigator Configurator Simulator
StdDev of Distance
StdDev of Heading
Avg Mag of Heading
INHD
Node Speed
NDD
Tracking overview of Bad_Bravo.aietes
Resume
Play
Rate++
Rate--
Sphere
Metric Zoom
Vector
REC: 351/998

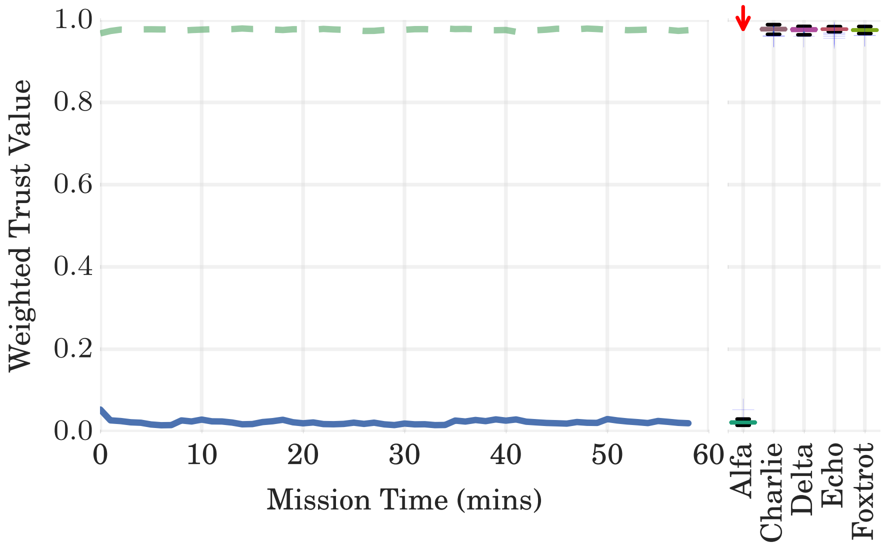


Fig. 19: MPC Comms Metric Shadow (showing mean of non-misbehaving nodes)

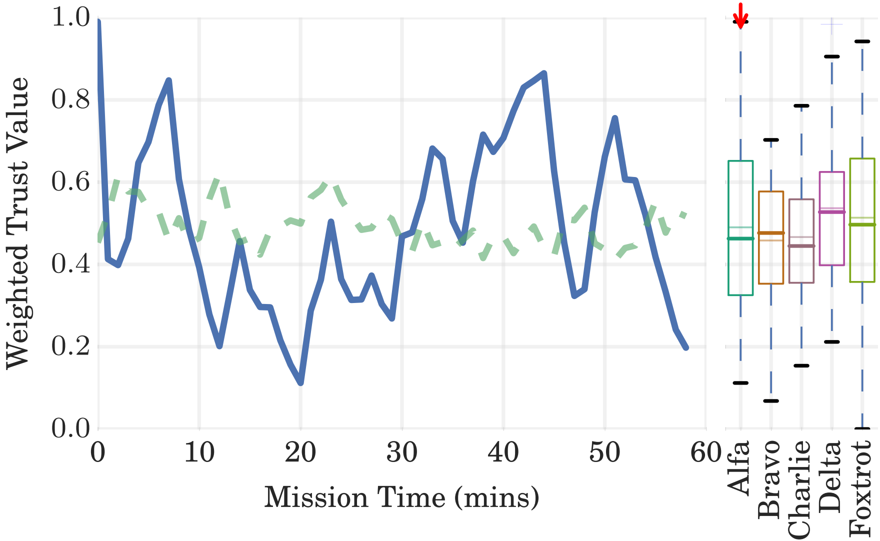


Fig. 20: MPC Physical Metric Shadow (showing mean of non-misbehaving nodes)

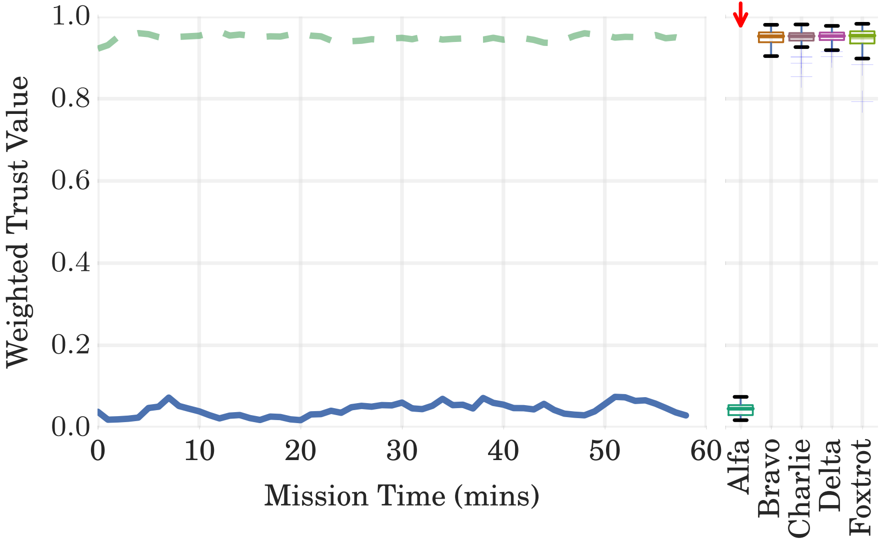


Fig. 21: MPC Full Metric Shadow (showing mean of non-misbehaving nodes)

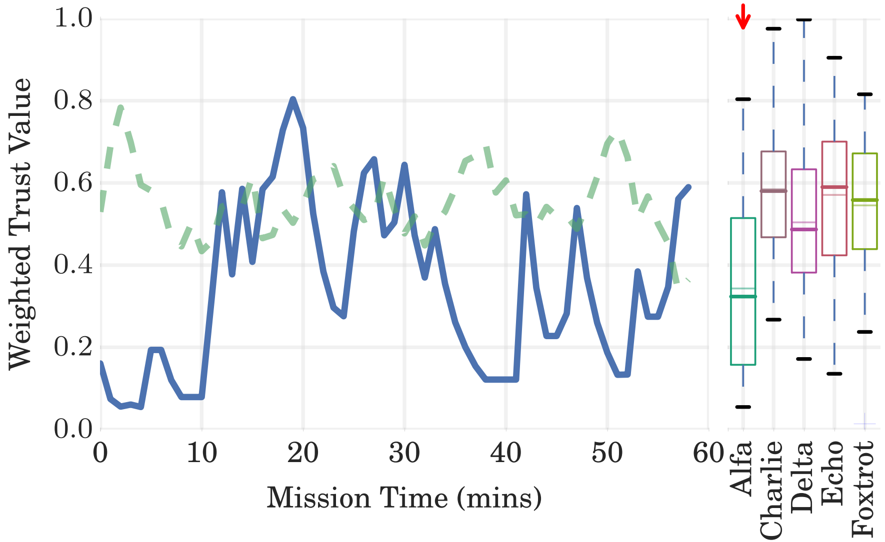


Fig. 22: STS Comms Metric Shadow (showing mean of non-misbehaving nodes)

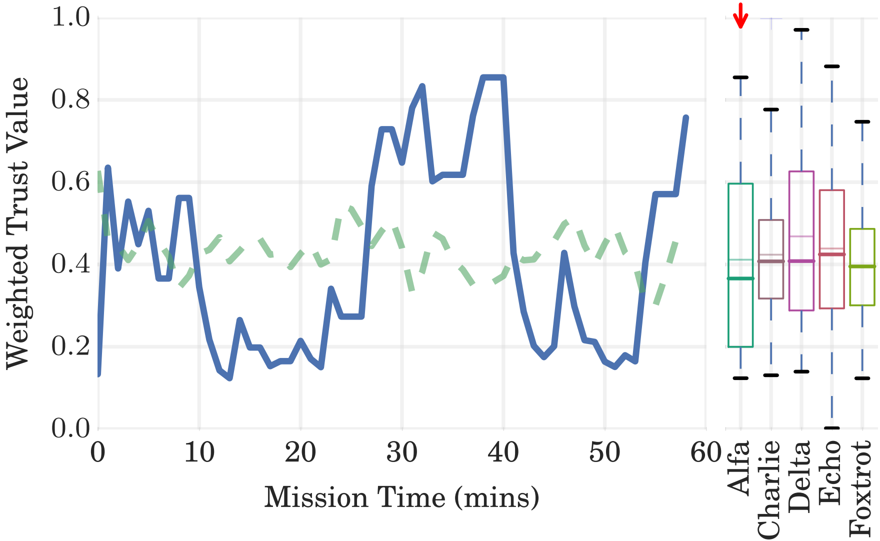


Fig. 23: STS Physical Metric Shadow (showing mean of non-misbehaving nodes)

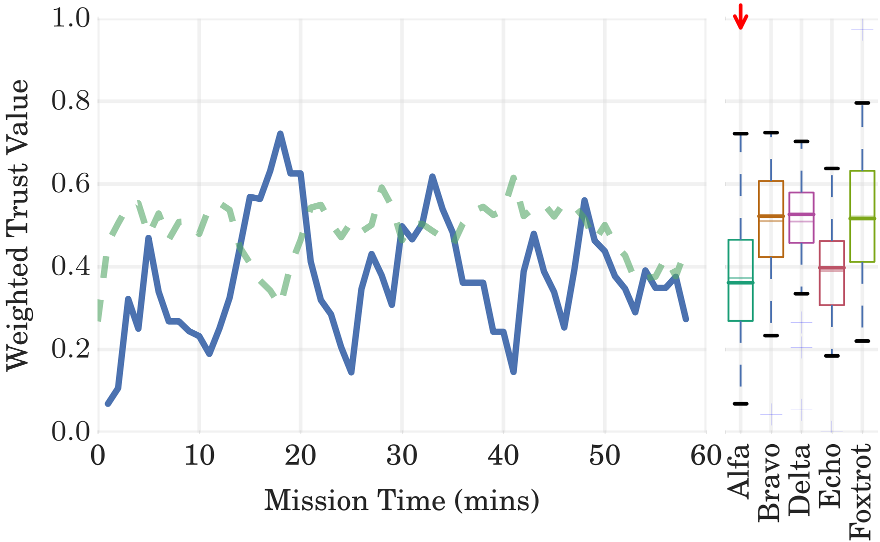


Fig. 24: STS Full Metric Shadow (showing mean of non-misbehaving nodes)

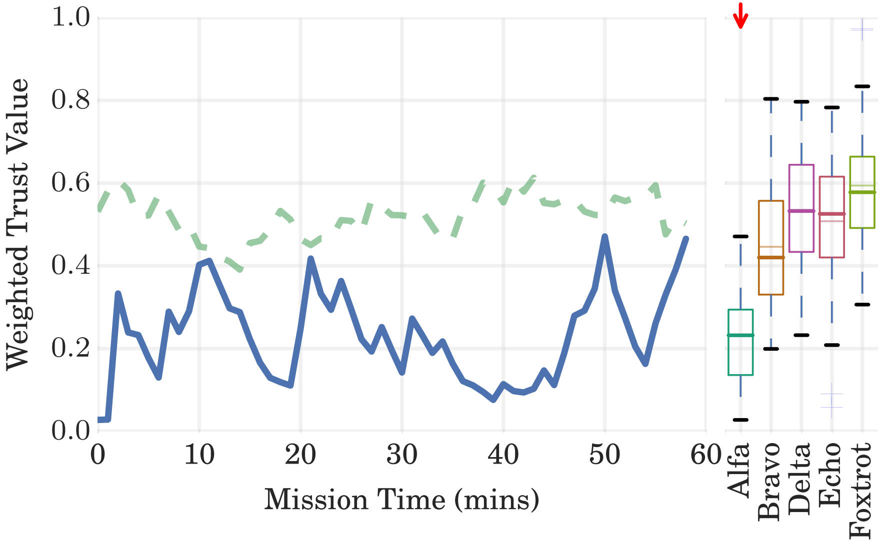


Fig. 25: Shadow Comms Metric Shadow (showing mean of non-misbehaving nodes)

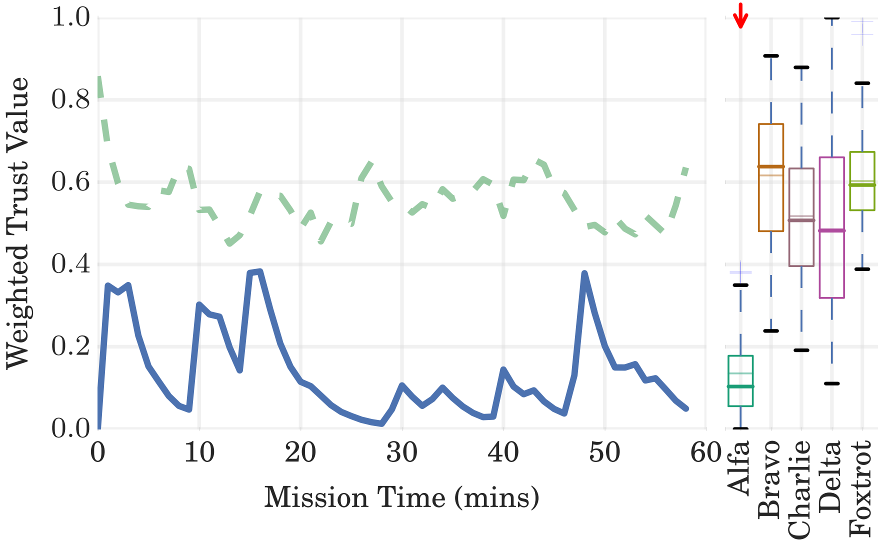


Fig. 26: Shadow Physical Metric Shadow (showing mean of non-misbehaving nodes)

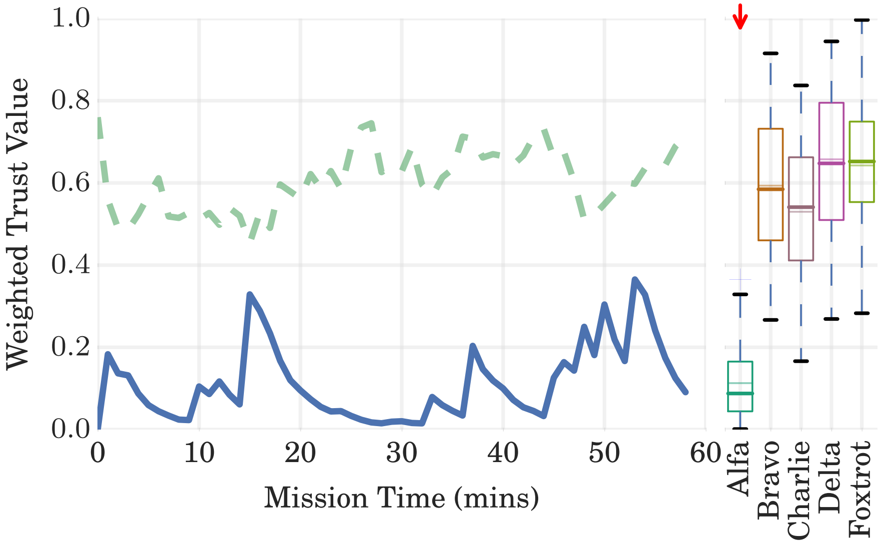


Fig. 27: Shadow Full Metric Shadow (showing mean of non-misbehaving nodes)

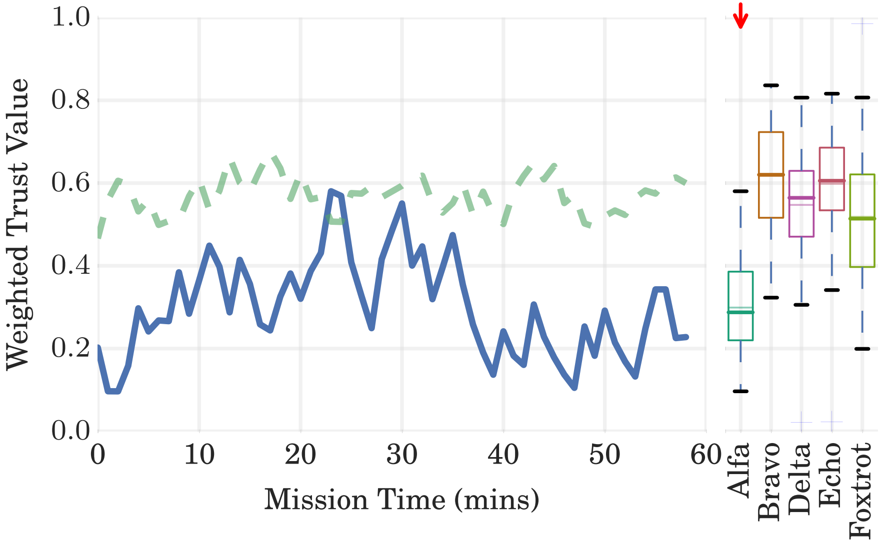


Fig. 28: SlowCoach Comms Metric Shadow (showing mean of non-misbehaving nodes)

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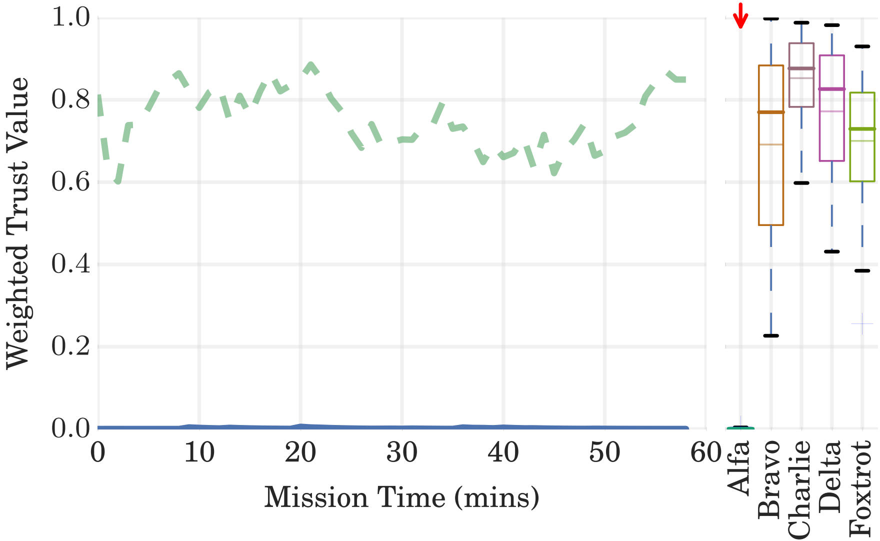

Fig. 29: SlowCoach Physical Metric Shadow (showing mean of non-misbehaving nodes)

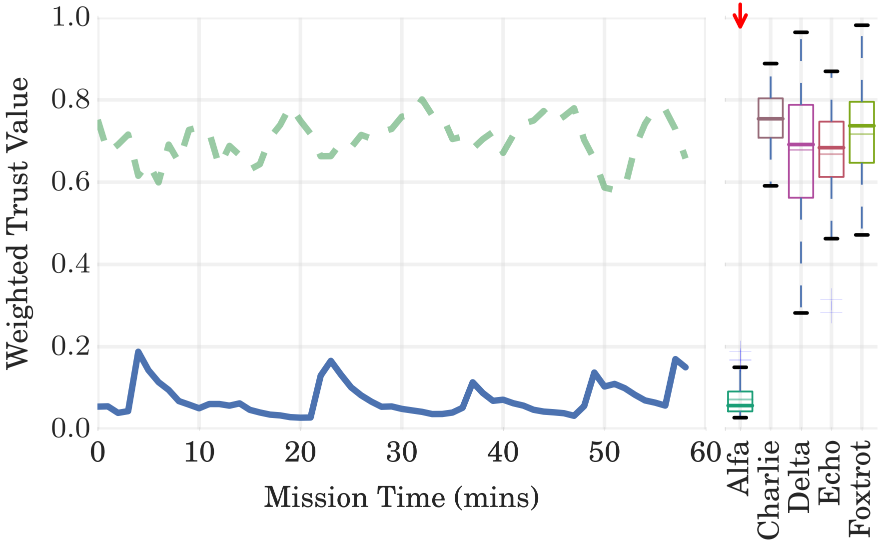

Fig. 30: SlowCoach Full Metric Shadow (showing mean of non-misbehaving nodes)

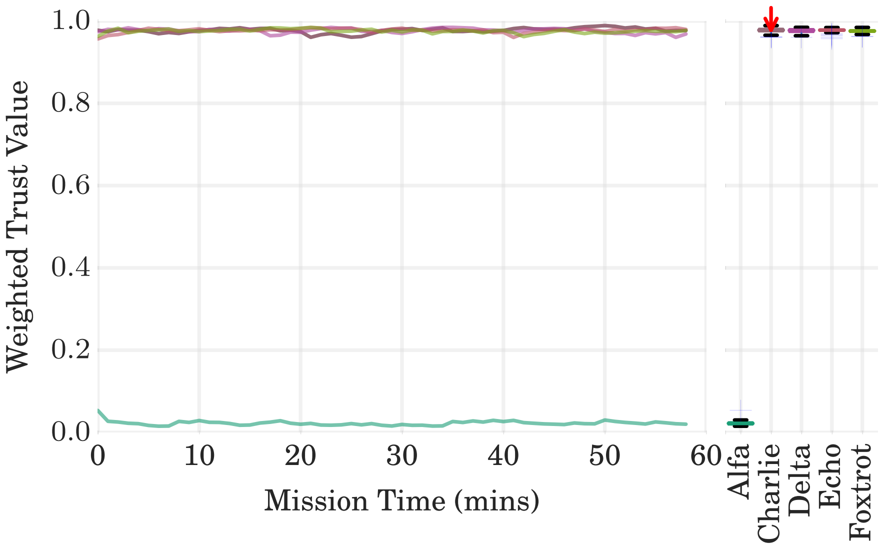

Fig. 31: MPC Comms Metric Shadow (targeting non-malicious node)

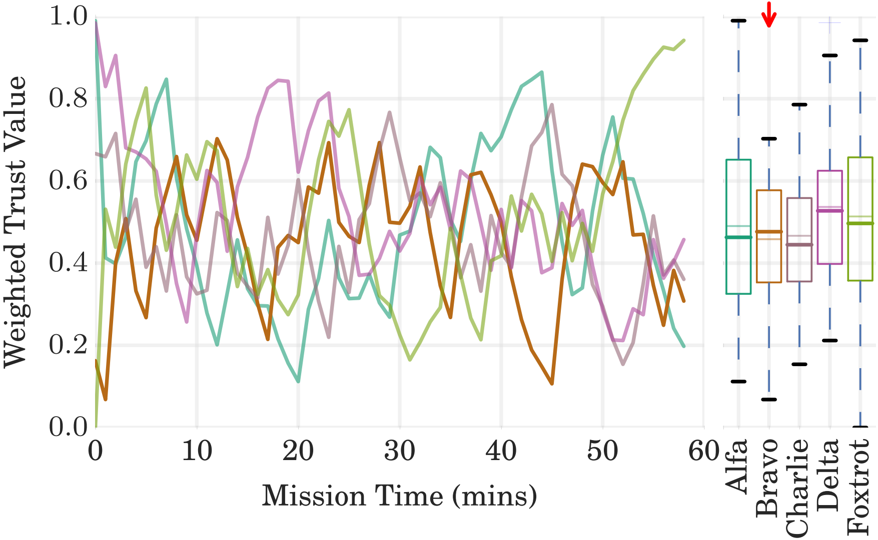

Fig. 32: MPC Physical Metric Shadow (targeting non-malicious node)

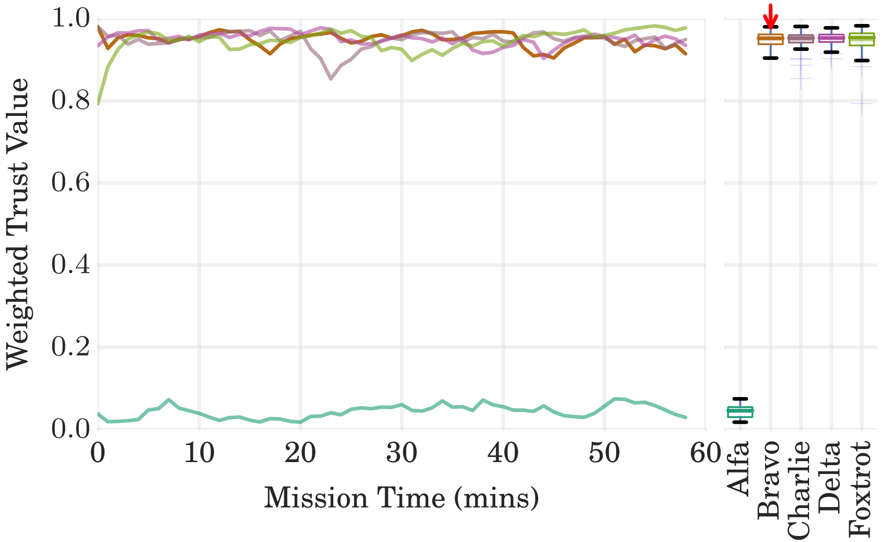

Fig. 33: MPC Full Metric Shadow (targeting non-malicious node)

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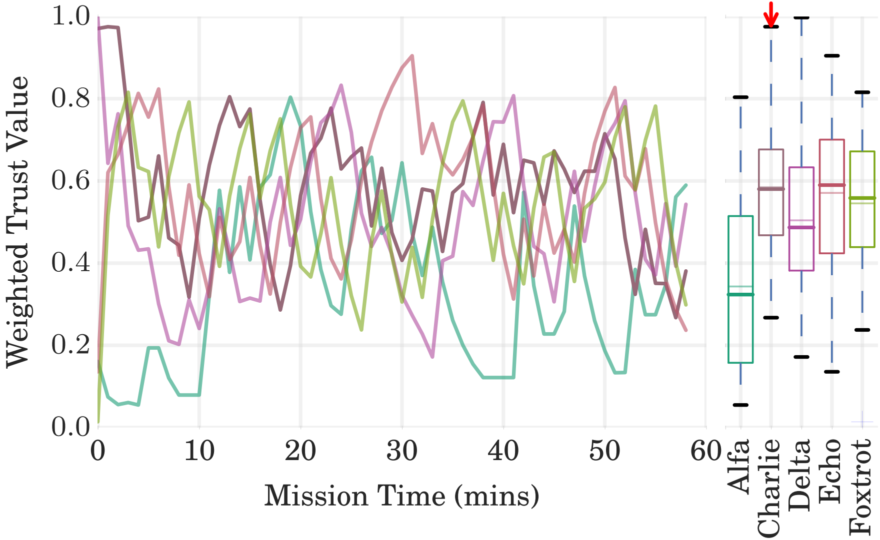

Fig. 34: STS Comms Metric Shadow (targeting non-malicious node)

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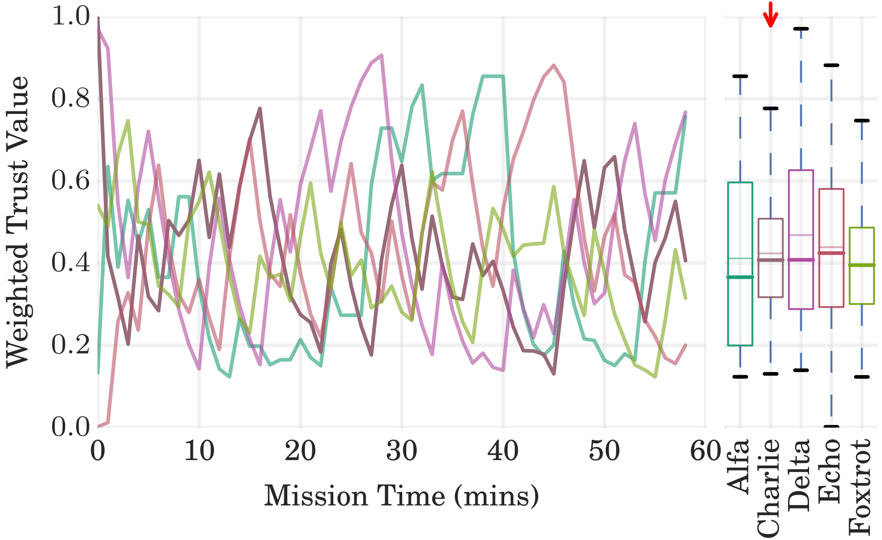

Fig. 35: STS Physical Metric Shadow (targeting non-malicious node)

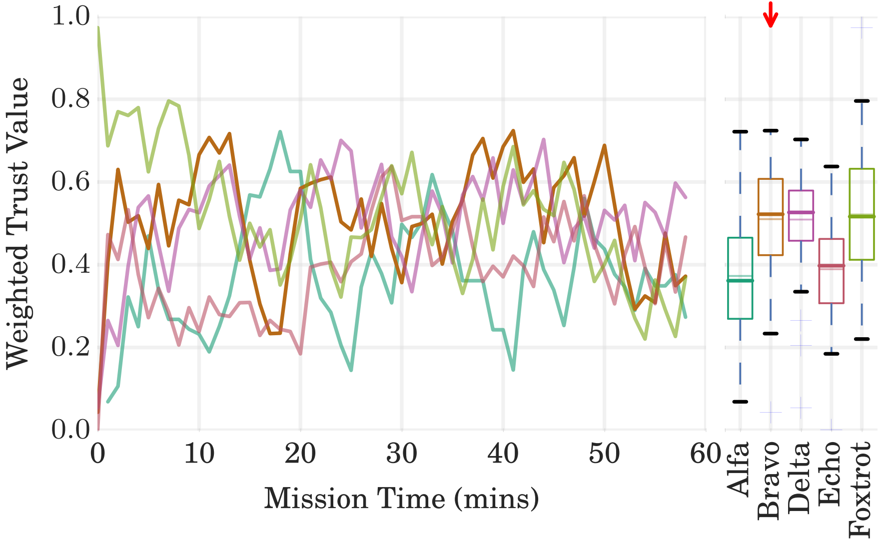

Fig. 36: STS Full Metric Shadow (targeting non-malicious node)

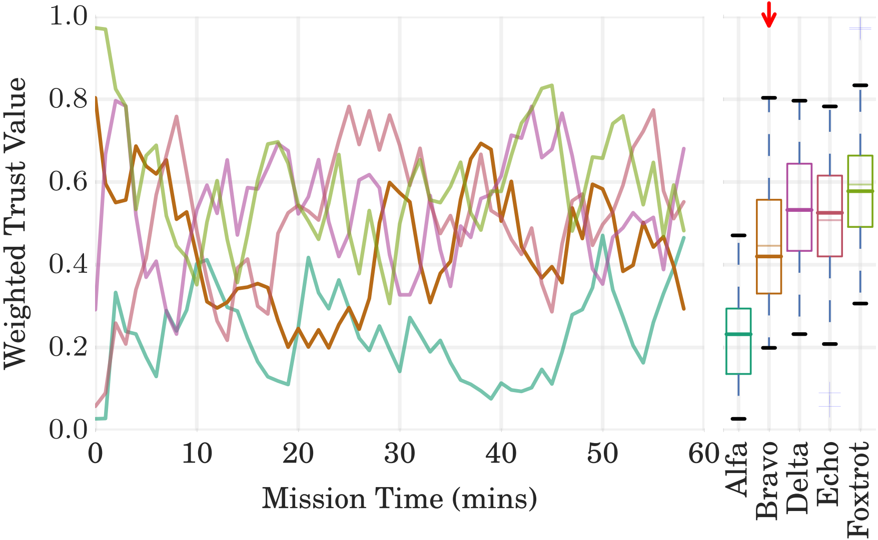

Fig. 37: Shadow Comms Metric Shadow (targeting non-malicious node)

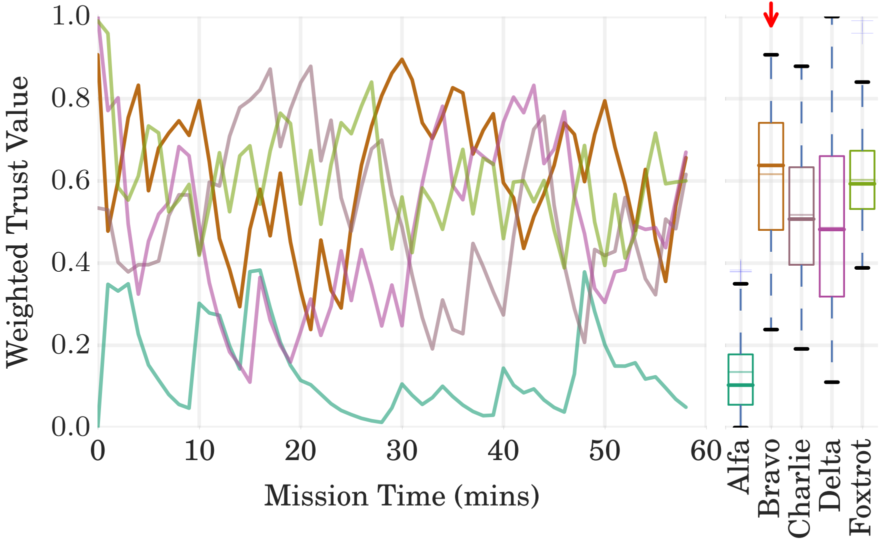

Fig. 38: Shadow Physical Metric Shadow (targeting non-malicious node)

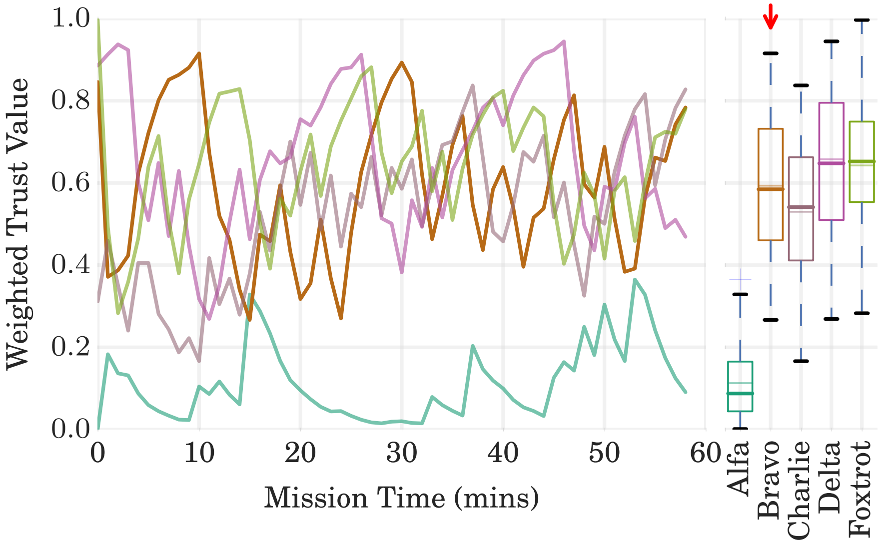

Fig. 39: Shadow Full Metric Shadow (targeting non-malicious node)

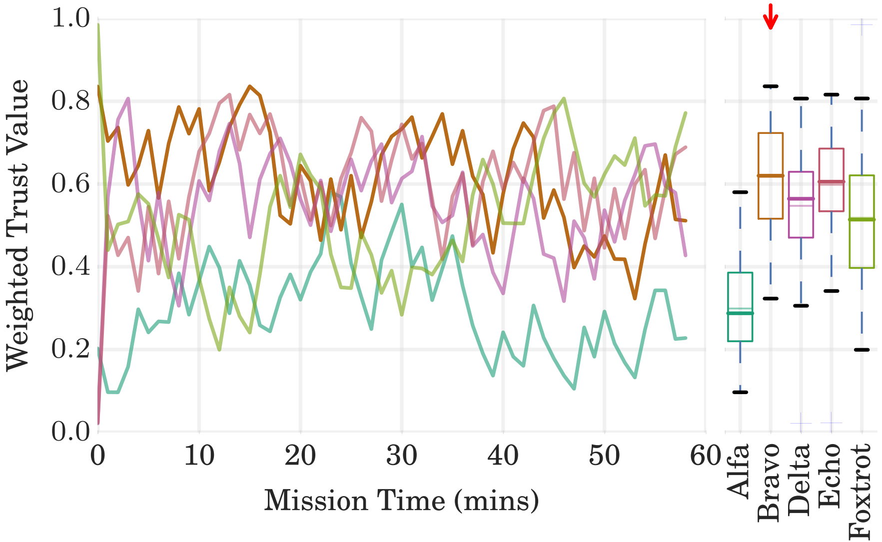

Fig. 40: SlowCoach Comms Metric Shadow (targeting non-malicious node)

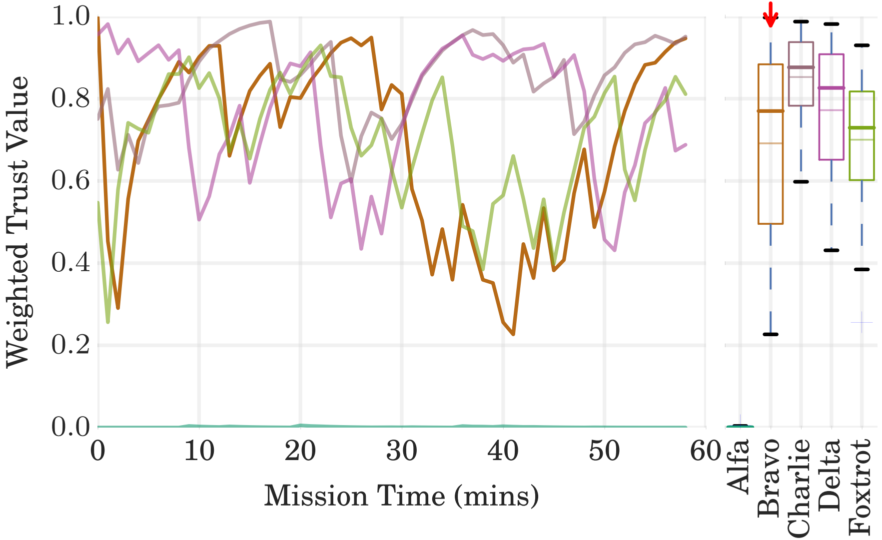

Fig. 41: SlowCoach Physical Metric Shadow (targeting non-malicious node)

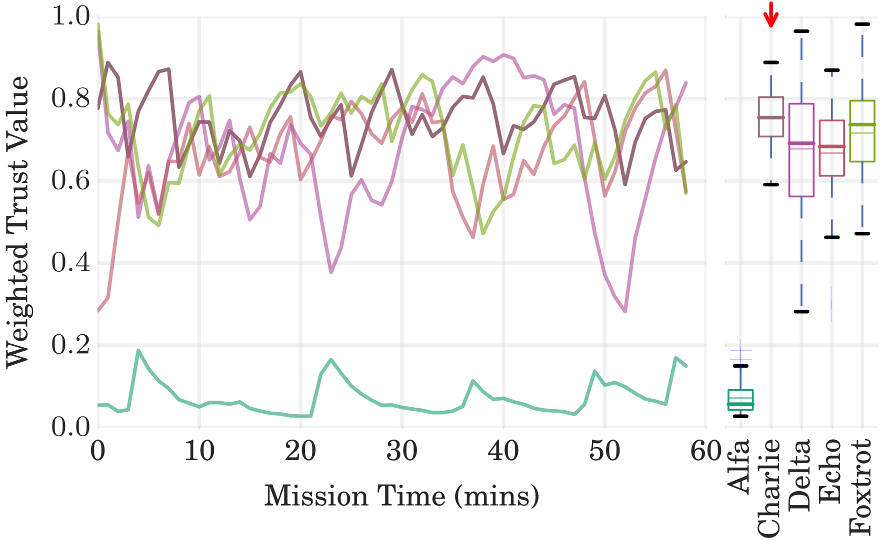

Fig. 42: SlowCoach Full Metric Shadow (targeting non-malicious node)

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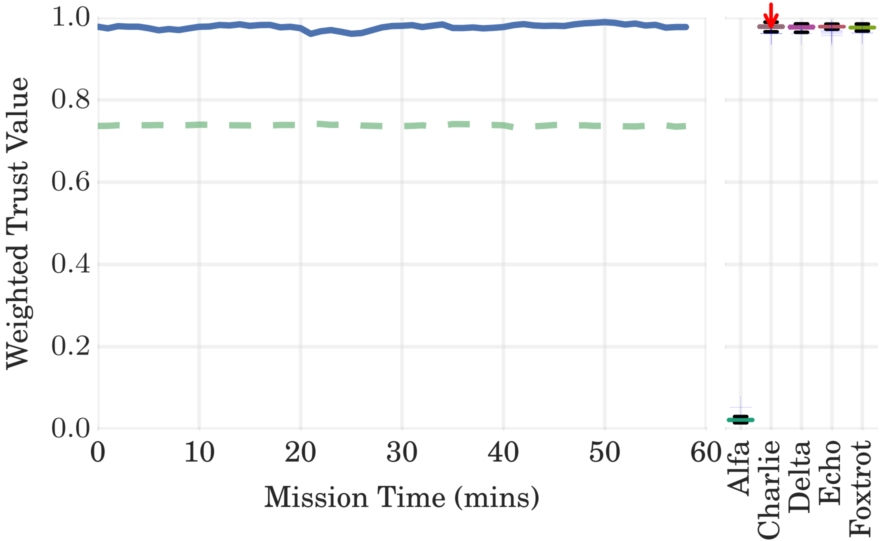

Fig. 43: MPC Comms Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

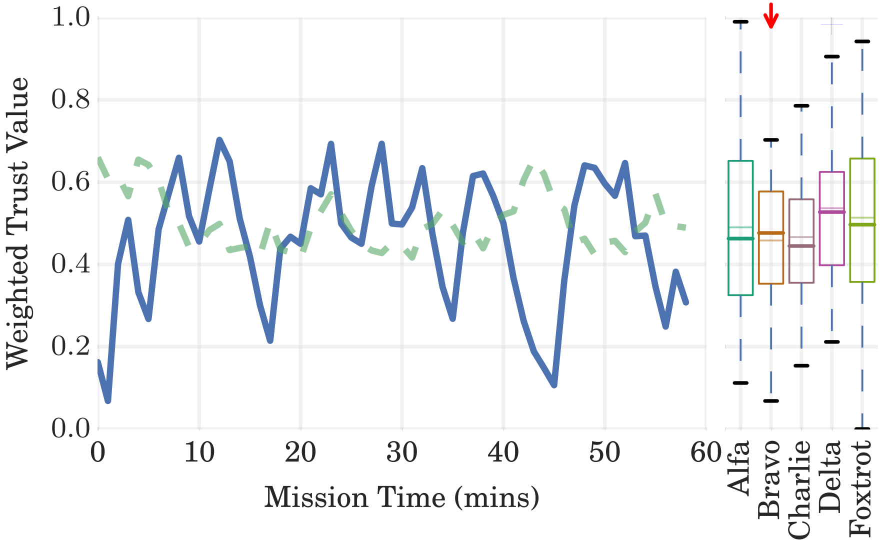

Fig. 44: MPC Physical Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

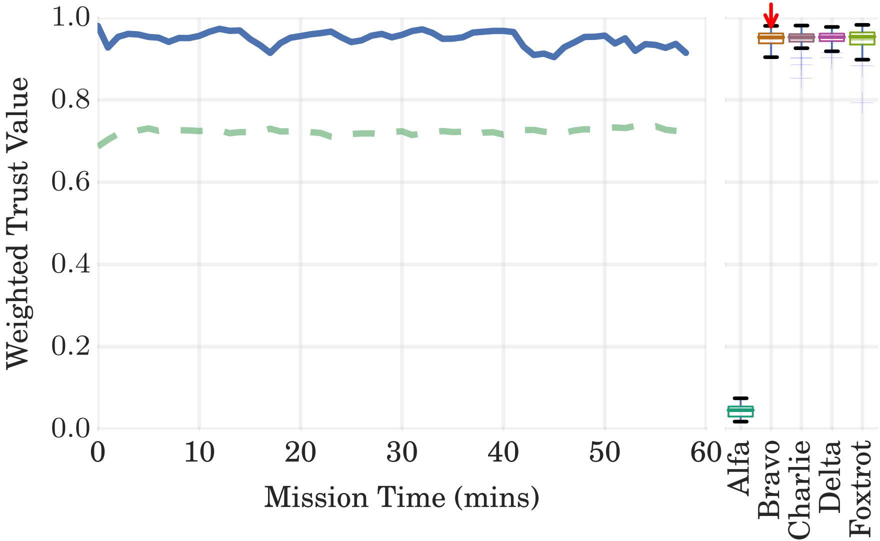

Fig. 45: MPC Full Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

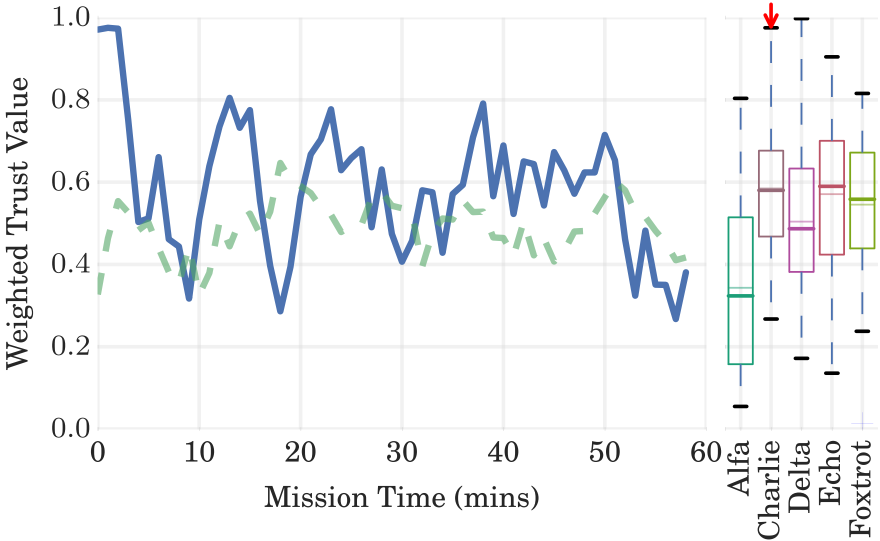

Fig. 46: STS Comms Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

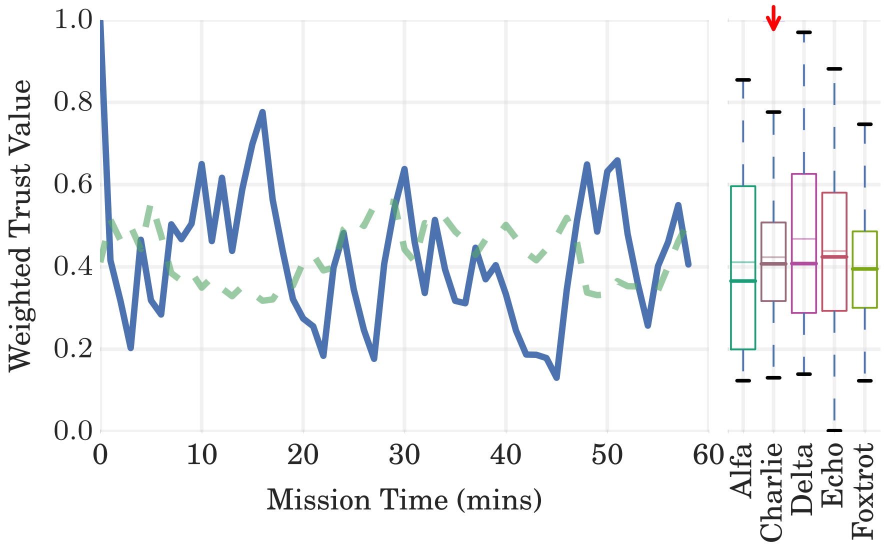

Fig. 47: STS Physical Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

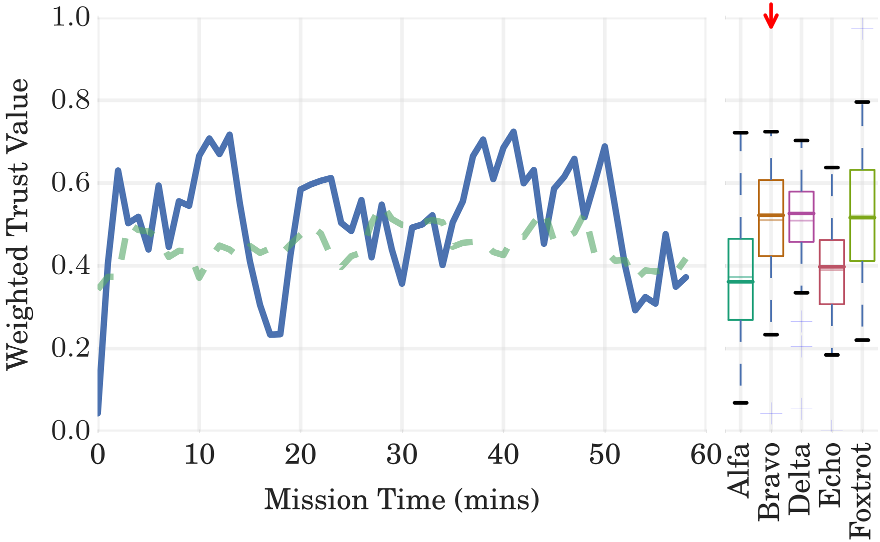

Fig. 48: STS Full Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

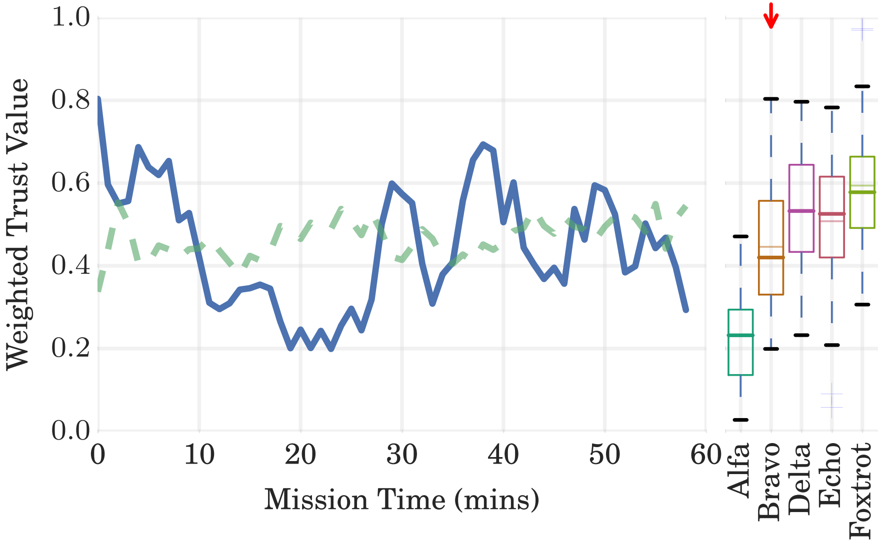

Fig. 49: Shadow Comms Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

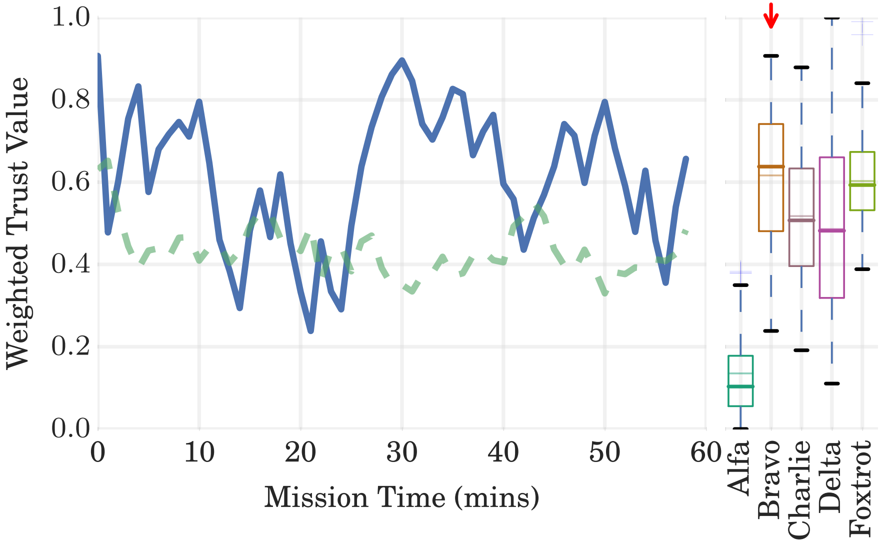

Fig. 50: Shadow Physical Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

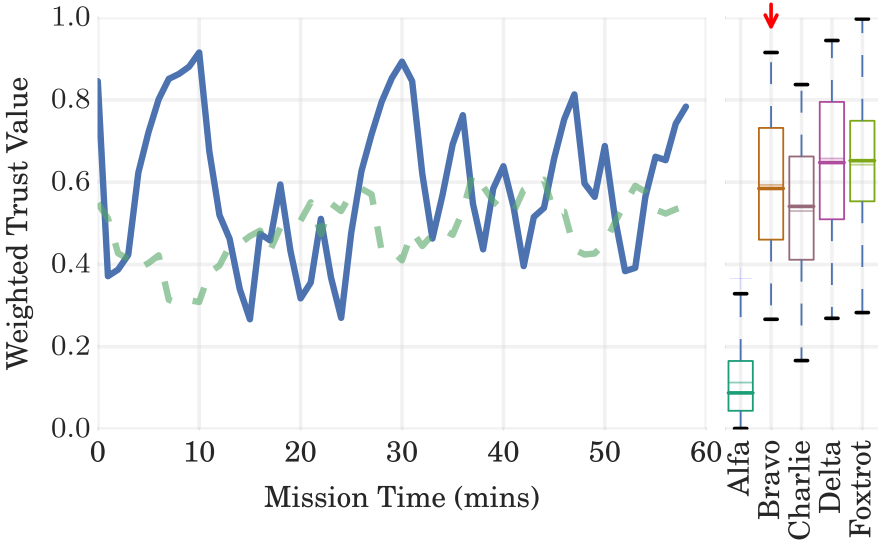

Fig. 51: Shadow Full Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

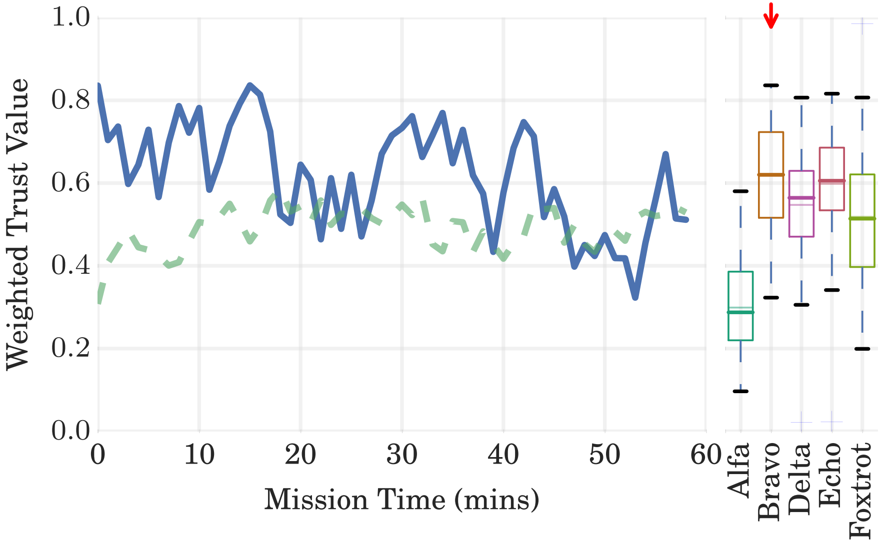

Fig. 52: SlowCoach Comms Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

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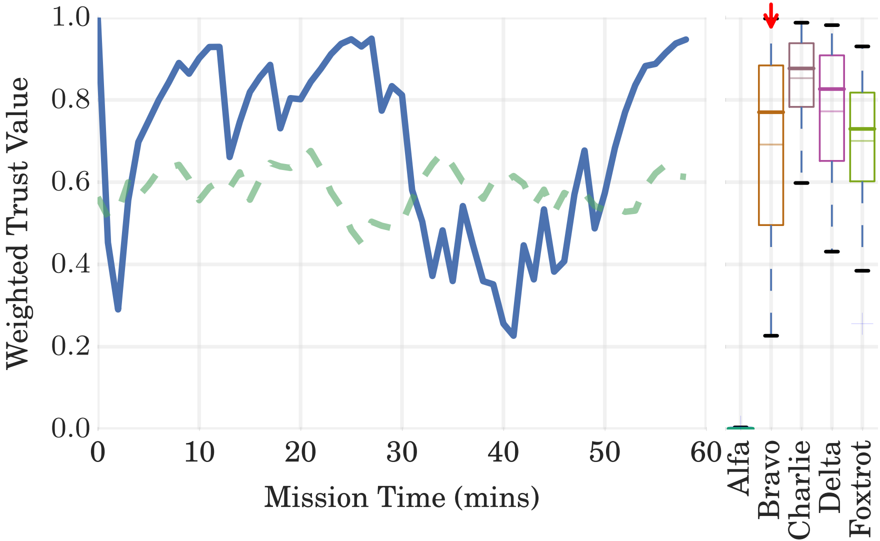

Fig. 53: SlowCoach Physical Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)

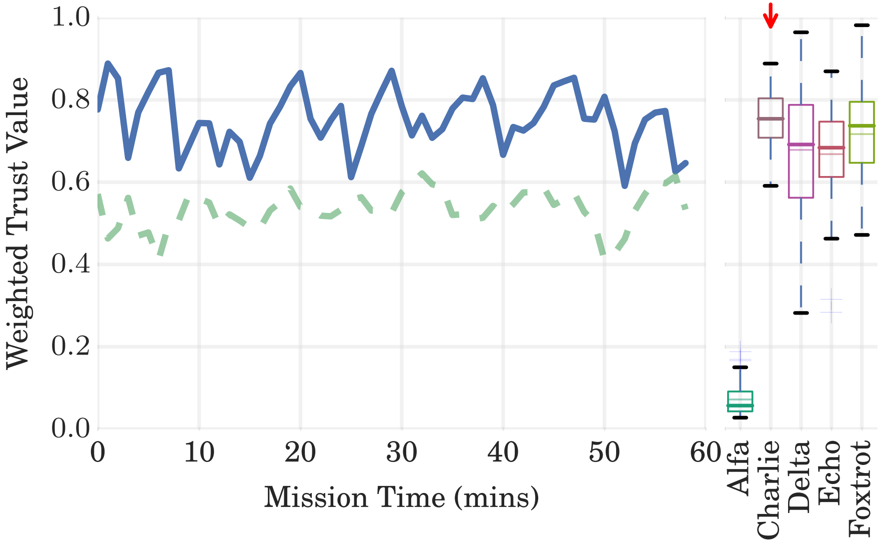

Fig. 54: SlowCoach Full Metric Shadow (targeting non-malicious node, showing mean of remaining cohort including malicious node)