Newton Meets Vivaldi: 
Securing Virtual Coordinates by Enforcing Physical Laws

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Virtual Coordinate System (VCS) 
Distributed systems can optimize performance by measuring latencies between nodes, but pair-wise measurements do not scale:

- VCSs embed the Internet onto a coordinate space
- Nodes estimate latencies by calculating the distance between coordinates
- Vivaldi is a popular decentralized VCS where nodes are logically connected via a physical spring
- Nodes update their coordinate according to Hooke’s law (F=−kx)

Attacks on VCS 
Insider attackers can cause other nodes to have bad latency estimations by:

- Lying about their coordinate
- Delaying measurement probes

Previous Defenses and Frog-Boiling Attacks 
Previous defense systems (i.e. Anomaly Detection and Voting Schemes) mitigate attacks by learning good behavior over time and discarding bad behavior:

- Frog-Boiling attackers exploit the learning process by staying underneath thresholds (which indicate an outlier) by lying by small amounts at a time.
- Previous defenses eventually re-learn bad behavior as good behavior

Newton 
- Previous defenses failed because they must learn good behavior
- Invariants give us an unchanging standard

Key observation: Vivaldi is based on a physical system and therefore nodes should follow physical laws

We derive three invariants based on Newton’s three laws of motion:
- Invariant 1: Centroid of coordinates starts and stays at the origin (For every action there is an equal and opposite reaction)
- Invariant 2: Physically close nodes experience similar forces (A body stays at rest unless acted upon by an external unbalanced force)
- Invariant 3: Nodes will decelerate as their springs come to a resting position (F=ma & F=−kx)

Example of Invariant 1

Before attack, centroid is at the origin
After attacker lies about coordinate, centroid moves the same way attacker does, allowing us to pinpoint the attacker

Simulations results using the King data set with 1740 nodes, with 30% attackers conducting a frog-boiling attack