Collective Decisions, Error and Trust in Wireless Networks

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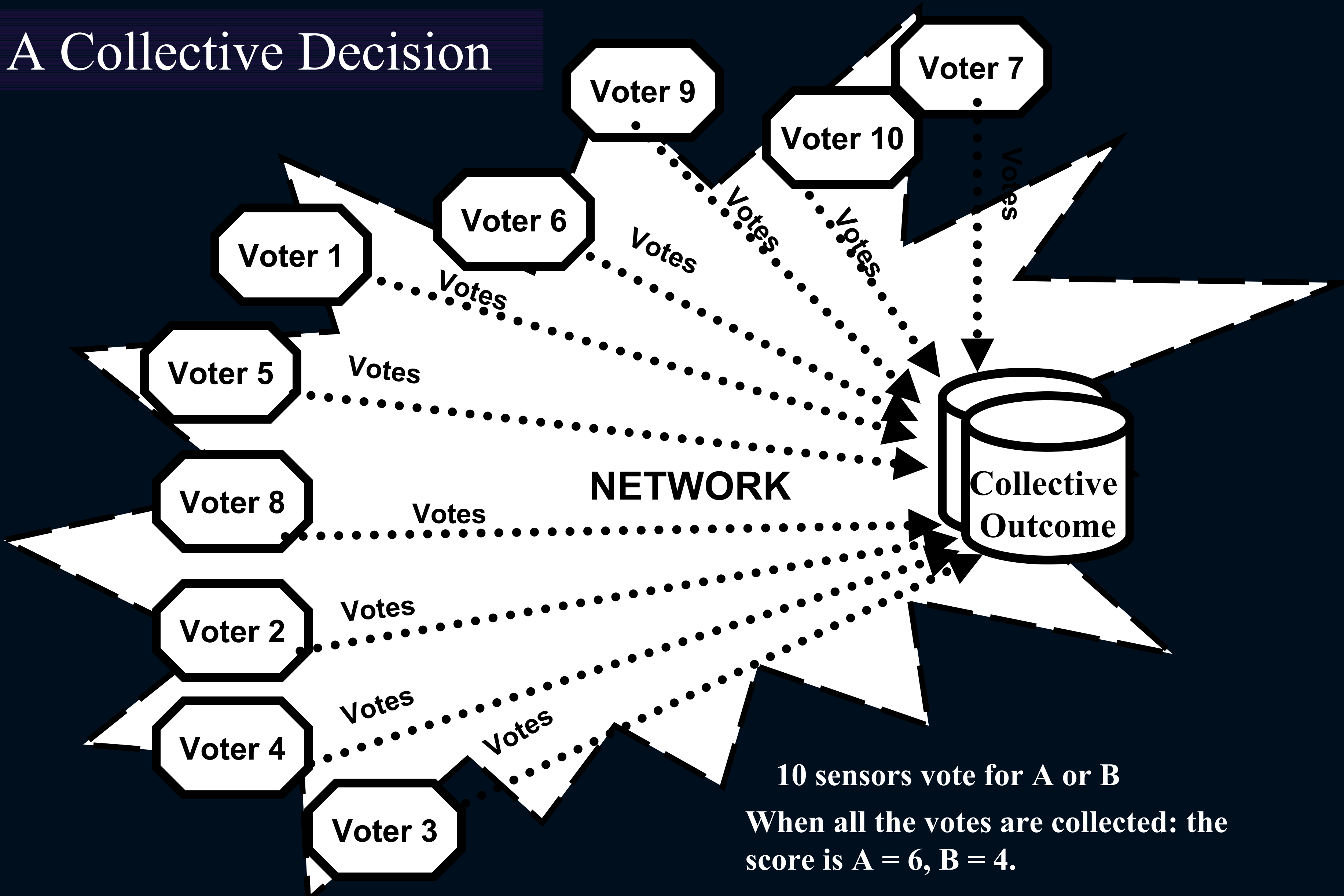
Outline

- What is a collective decision?
- Designing collective decisions that are error resilient (ERCOs).
- Using ERCOs to make collective decisions more trustworthy.

KEY POINTS

- ERCO methodology is a generic form of decision support that uses the communications process to save time and overcome network and decision making errors.
- ERCO analysis works for human and sensor decision making in tactical and strategic situations.
- ERCO’s are
  - computationally lightweight
  - energy efficient
  - rules-based tools for building trustworthy network processes

A Collective Decision



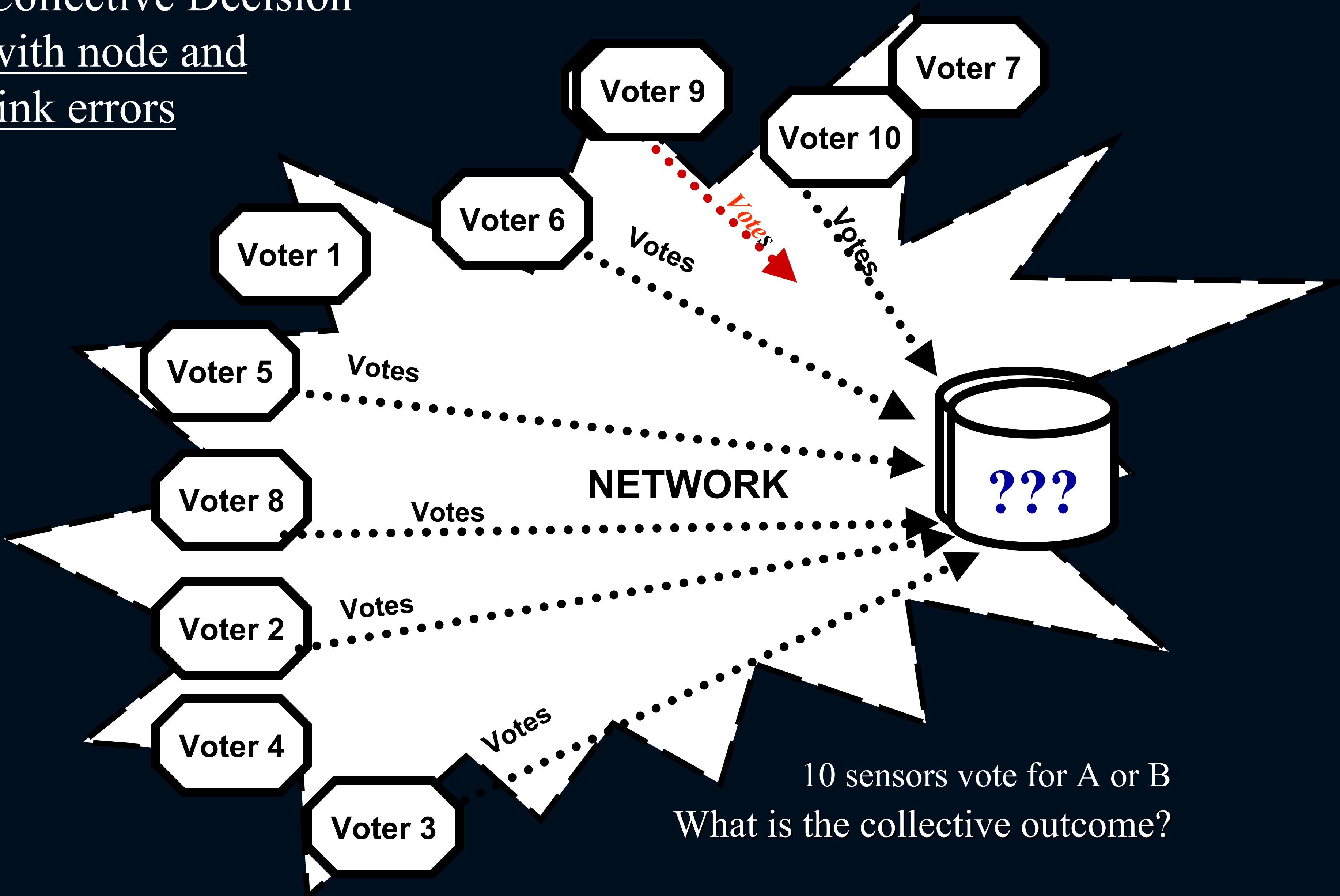
10 sensors vote for A or B

When all the votes are collected: the score is A = 6, B = 4.

Decision Support Problem

- A commander needs to know the number of vehicles in a convoy (between 1 to 3) to decide whether or not to attack.
- The commander depends on 10 sensors to collectively report the correct number of vehicles.
- The commander is waiting for sensor feedback to get the majority consensus.

Collective Decision with node and link errors



10 sensors vote for A or B

What is the collective outcome?

Decision Support Problem
[continued]

- Waiting produces uncertainty
  - Message delay?
  - Network communications failure?
  - Sensor breakdown?
- Generic decision support challenge: manage risks in emergencies to save lives and protect property
- New generic solution: decision support based on error-resilient collective outcome (ERCO) analysis

The *ERCO* (Error-Resilient Collective Outcome) Solution

What is an ERCO?

Definition: An ERCO is a collective outcome based on incomplete and imperfect information that would be produced if information were complete and/or perfect.

An Intuitive Example of an ERCO

- 10 sensors vote for “A” or “B” and send their votes to C2
- 6 votes, a majority, are required to reach a consensus
- C2 has received 6 votes in favor of “A”
- Therefore C2 can take immediate action because
  - The majority requirement has been satisfied
  - The remaining 4 votes will not change the collective outcome
- So “A” is an error-resilient collective outcome (ERCO) because it cannot be changed by errors caused by network breakdown and/or sensor imperfections.

Trustworthy Wireless Decisions with ERCO's

- First, design a voting system to make the decision making process ERCO efficient
- Then use ERCO efficiency to manage trusted relationships

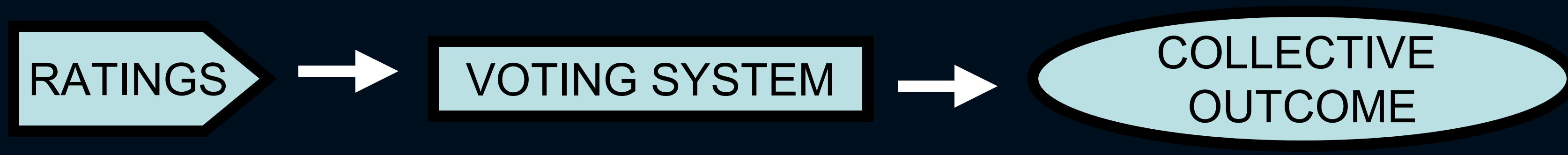
Designing ERCO-Efficient Voting Systems

Voting Systems include rules for

- Vote Endowment: The total number of votes that can be used to communicate preferences/judgments
- Vote Allocation: Constraints on the allocation of votes.
- Aggregation: The total number of allocated votes needed to win.

Designing ERCO-Efficient Voting Systems

[continued]



Examples

	One Voter, One Vote	Approval Voting	Copeland Voting
	OVOV	AV	Cope
Vote Endowment	One Vote	N votes where N = number of choices	N ranks where N = number of choices
Vote Allocation	One Vote	A maximum of one vote for each of the N choices	One or more choices per rank
Vote Aggregation	Plurality, Majority	Plurality, Majority	Plurality, Majority

Designing ERCO-Efficient Voting Systems
[continued]

How Voting Systems Work (an illustration)

1. Input Ratings (Preference Data)

Preference Ratings	Voter 1	Voter 2	Voter 3
Choice A	5	3	2
Choice B	3	5	3
Choice C	2	2	5

Designing ERCO-Efficient Voting Systems
[continued]

2. *Process* Preferences Through Voting Systems to Create Collective Outcomes

(Each voter casts one vote for the most preferred choice.)

OVOV Allocations	Voter 1	Voter 2	Voter 3
Choice A	1	0	0
Choice B	0	1	0
Choice C	0	0	1

The most preferred choice gets one vote.

The collective outcome is a tie!

Designing ERCO-Efficient Voting Systems
[continued]

2. Process Preferences Through Voting Systems to Create Collective Outcomes

AV with Plurality Aggregation => B wins the most votes

(One approval vote cast for each choice that equals or exceeds a voter's average utility, 3 in this case.)

AV Allocations	Voter 1	Voter 2	Voter 3
Choice A	1	1	0
Choice B	1	1	1
Choice C	0	0	1

=> B gets three votes.

Designing ERCO-Efficient Voting Systems

[continued]

Method: Copeland scoring

1. Find the Condorcet score: the number of times each choice is ranked higher than every other choice in voter preference rankings

	A	B	C
A		2	1
B	1		1
C	2	2	
Total Condorcet Scores	3	4	3

2. Then subtract the individual Condorcet scores for each pair of choices to generate a Copeland score

	A	B	C
A		1	-1
B	-1		-1
C	1	1	
Total Copeland Scores	0	2	-2

B is the plurality winner with 2 points.

Designing ERCO-Efficient Voting Systems

[continued]

Modeling Network Communication as a Voting System

Voting Model	**Network Model**
Communication of Votes	Communication of Information
Collective Outcomes	Collection of data on central host or peer

Selected ERCO Control Variables

- The number of voters
- The number of choices
- The number of dimensions on which the choices are rated
- Voter preference distribution (including rating scale)
- Voter competence (reliability) distribution
- Competence (reliability) weighting rules
- The time each vote takes to reach its destination
- Voting system
  - Method for expressing preferences (e.g., One Voter, One Vote (OVOV))
  - Aggregation rule (eg., plurality)
- Tie-breaking: none, random or optimized

Designing ERCO-Efficient Voting Systems

[continued]

Synthesize voting system components to optimize sensor/network performance

Illustrated Scenario

Imperfect sensors, imperfect communications

Imperfect Sensors, Perfect Communications

Sensor Ratings for the Convoy Assessment Collective Decision Task

Convoy Assessment Rating Inputs Voter (sensor ratings)	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3
AC 1		0	5	4	1	0
AC 2		0	10	0	0	0
AC 3		0	5	3	1	1
AC 4		0	1	6	3	0
AC 5		0	3	5	2	0
AC 6		0	1	8	1	0
IR 1		0	0	1	4	6
IR 2		0	0	0	2	8
IR 3		0	0	1	3	6
IR 4		0	0	1	2	7

Imperfect Sensors, Perfect Communications

OVOV => one vote cast for most preferred choice.

Convoy Assessment Problem: OVOV Conversion	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3
Allocation of Votes						
AC 1		0	1	0	0	0
AC 2		0	1	0	0	0
AC 3		0	1	0	0	0
AC 4		0	0	1	0	0
AC 5		0	0	1	0	0
AC 6		0	0	1	0	0
IR 1		0	0	0	0	1
IR 2		0	0	0	0	1
IR 3		0	0	0	0	1
IR 4		0	0	0	0	1

Collective Outcome: No Majority Winner

How Can C2 Avoid Limbo?

Imperfect Sensors, Perfect Communications

Weighting Votes to Fix Sensor/Voter Imperfections

The Grofman-Shapley* theorem suggests weighting individual votes by $ln(p/(1-p))$, where p = probability of a correct choice and

$(1-p)$ = the probability of an incorrect choice

For example,

p	1-p	ln (p/1-p) Weight
0.8	0.2	1.386294361
0.6	0.4	0.405465108
0.5	0.5	0
0.4	0.6	-0.405465108
0.2	0.8	-1.386294361

* Shapley, L. and B. Grofman, "Optimizing Group Judgmental Accuracy in the Presence of Interdependencies", *Public Choice* (1984).

Imperfect Sensors and Imperfect Communications

Initial sensor competencies (p) range from .2 (low) to .8 (high)

Convoy Assessment Voter Confidence Ratings	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3
Sensor Weights						
AC 1		0	0.2	0	0	0
AC 2		0	0.2	0	0	0
AC 3		0	0.2	0	0	0
AC 4		0	0	0.5	0	0
AC 5		0	0	0.5	0	0
AC 6		0	0	0.5	0	0
IR 1		0	0	0	0	0.8
IR 2		0	0	0	0	0.8
IR 3		0	0	0	0	0.8
IR 4		0	0	0	0	0.8

2 or 3 vehicles is the most likely correct choice.

Imperfect Sensors and Imperfect Communications

Votes Weighted by SG weighting ln p/(1-p) formula:

Convoy Assessment Votes Weighted by Confidence Ratings	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3
Weighted Votes						
AC 1		0	-1.39	0	0	0
AC 2		0	-1.39	0	0	0
AC 3		0	-1.39	0	0	0
AC 4		0	0	0	0	0
AC 5		0	0	0	0	0
AC 6		0	0	0	0	0
IR 1		0	0	0	0	1.39
IR 2		0	0	0	0	1.39
IR 3		0	0	0	0	1.39
IR 4		0	0	0	0	1.39
	Vote Totals	0	-4.17	0	0	5.56

2 or 3 vehicles is the most likely correct choice.

How ERCOs can solve C2's Problem →

Imperfect Sensors and Imperfect Communications

C2's Problem Situation

Convoy Assessment Votes Weighted by Confidence Ratings	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3
Weighted Votes						
AC 1		0	-1.39	0	0	0
AC 2		Missing Data				
AC 3		0	-1.39	0	0	0
AC 4		0	0	0	0	0
AC 5		0	0	0	0	0
AC 6		Missing Data				
IR 1		0	0	0	0	1.39
IR 2		0	0	0	0	1.39
IR 3		0	0	0	0	1.39
IR 4		0	0	0	0	1.39
Vote Totals		0	-2.78	0	0	5.56

Why is this collective outcome error-resilient?

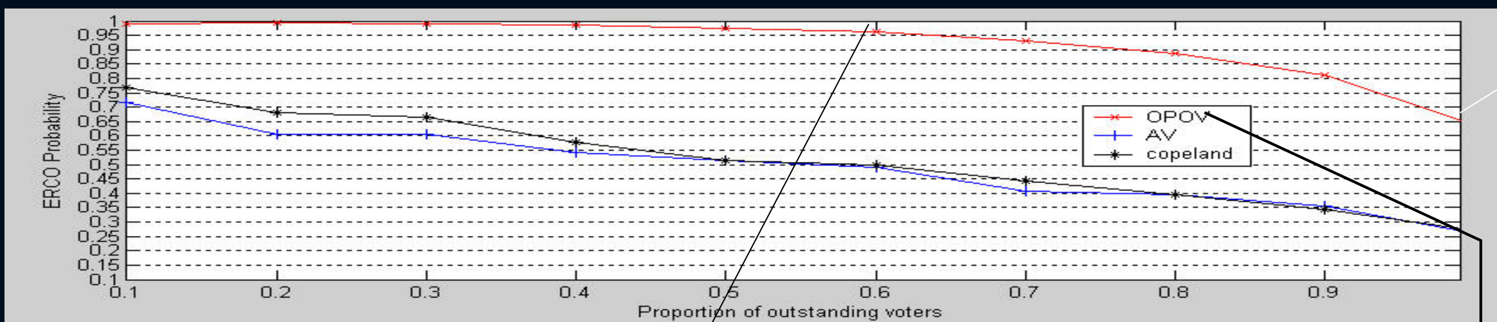
- Other combinations of votes do not change the outcome.
- Competence weightings do not change the collective outcome.
- So "2 or 3" vehicles is an optimized error-resilient collective outcome (ERCO) that allows C2 to take immediate action.

RESULTS FOR 20,000 CASES

Scenario: 100 Sensors,
Homogeneous (Similar) Preferences

HOW MUCH INFORMATION DOES C2 NEED?

DECISION SUPPORT The outcome will be very ERCO-efficient when 70% of the votes are still uncollected.



DECISION SUPPORT Little is to be gained by waiting for more votes to be collected.

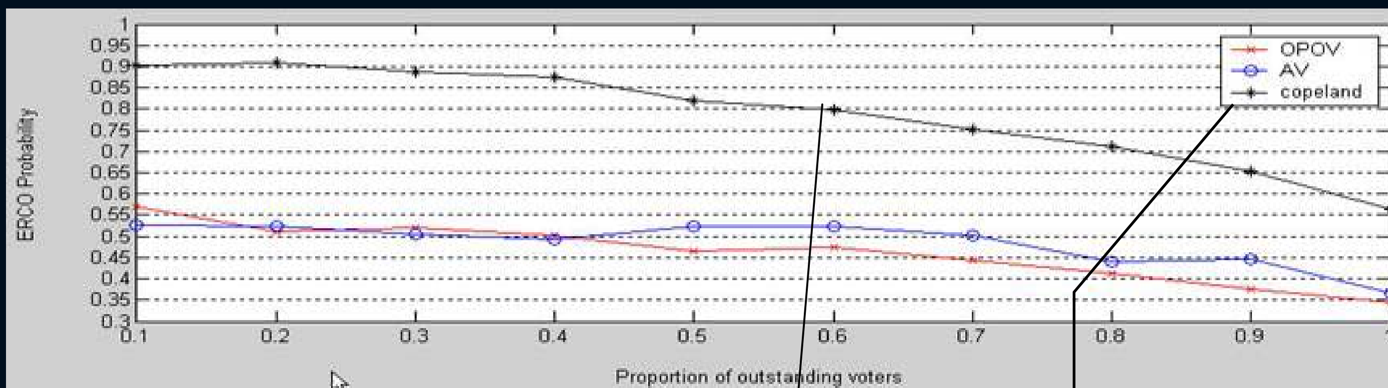
Which choice is top rated?

SIMULATION INPUTS: 75 voters have homogeneous distribution and 0.9 competence and 25 voters have heterogeneous distribution with competence of 0.48, Weighting method: Shapley Grofman, plurality rule, homogeneous dist mean: 2.7333 3.0267 3.24 3.0267 3.32 homogeneous dist std: 1.9686 1.9998 1.9517 1.973 1.9607 heterogeneous dist mean: 3.12 2.72 3.64 3.08 3.52 heterogeneous dist std: 1.9661 1.9498 1.8521 1.9374 1.8999 combined dist mean: 2.9393 2.9676 2.9998 3.0324 3.0641 combined dist std: 0.019998 0.019297 0.019122 0.019201 0.020086, 0.25 voters competence mean: 0.49126 and competence std: 0.041692, 0.75 voters competence mean: 0.9072 and competence std: 0.050745 combined competence mean: 0.80322 combined competence mean: 0.18738 False positive mean 0.0094344 0.011304 0.0082595 0.0093459 0.009574 0.012856 0.0093003 0.011143 0.0092902 0.0087724 False positive std 0.0050145 0.0050293 0.0039013 0.0049028 0.0040402 0.0055101 0.0045386 0.0043665 0.0050777 0.0030632 False negative mean 0.0090609 0.0098397 0.0084995 0.011297 0.0093576 0.0083906 0.0095186 0.012528 0.0099975 0.010192 False negative std 0.004449 0.0036323 0.0036829 0.0054426 0.0031957 0.0049893 0.0029249 0.0034632 0.0061935 0.0057356

RESULTS FOR 20,000 CASES

Scenario: 100 Sensors,
Heterogenous (Diverse) Preferences

HOW MUCH INFORMATION DOES C2 NEED?



ERCO-efficiency will increase by a little over 10% by waiting beyond collection of 40% of the votes.

Little is to be gained by waiting for another 10% of the votes to be collected.

Which choice is most intensely collectively preferred?

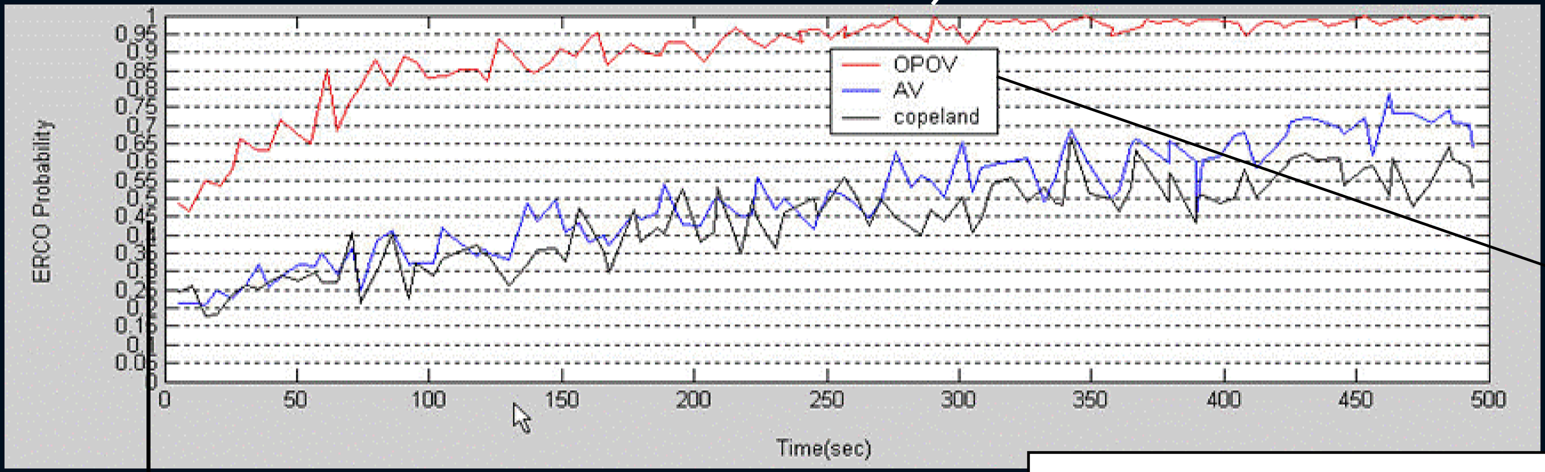
SIMULATION INPUTS: 75 voters have homogeneous distribution and 0.9 competence and 25 voters have heterogeneous distribution with competence of 0.48, Weighting method: Shapley Grofman, plurality rule, homogeneous dist mean: 2.7333 3.0267 3.24 3.0267 3.32 homogeneous dist std: 1.9686 1.9998 1.9517 1.973 1.9607 heterogeneous dist mean: 3.12 2.72 3.64 3.08 3.52 heterogeneous dist std: 1.9661 1.9498 1.8521 1.9374 1.8999 combined dist mean: 2.9393 2.9676 2.9998 3.0324 3.0641 combined dist std: 0.019998 0.019297 0.019122 0.019201 0.020086, 0.25 voters competence mean: 0.49126 and competence std: 0.041692, 0.75 voters competence mean: 0.9072 and competence std: 0.050745 combined competence mean: 0.80322 combined competence mean: 0.18738 False positive mean 0.0094344 0.011304 0.0082595 0.0093459 0.009574 0.012856 0.0093003 0.011143 0.0092902 0.0087724 False positive std 0.0050145 0.0050293 0.0039013 0.0049028 0.0040402 0.0055101 0.0045386 0.0043665 0.0050777 0.0030632 False negative mean 0.0090609 0.0098397 0.0084995 0.011297 0.0093576 0.0083906 0.0095186 0.012528 0.0099975 0.010192 False negative std 0.004449 0.0036323 0.0036829 0.0054426 0.0031957 0.0049893 0.0029249 0.0034632 0.0061935 0.0057356

Collection Time per Vote: Rayleigh Distribution

Scenario: 100 Sensors,
Homogeneous (Similar) Preferences

HOW LONG SHOULD C2 WAIT?

DECISION SUPPORT ERCO-efficiency will not increase significantly after 270 seconds.



DECISION SUPPORT Little ERCO efficiency is to be gained by waiting more than 150 seconds.

Which choice is top rated?

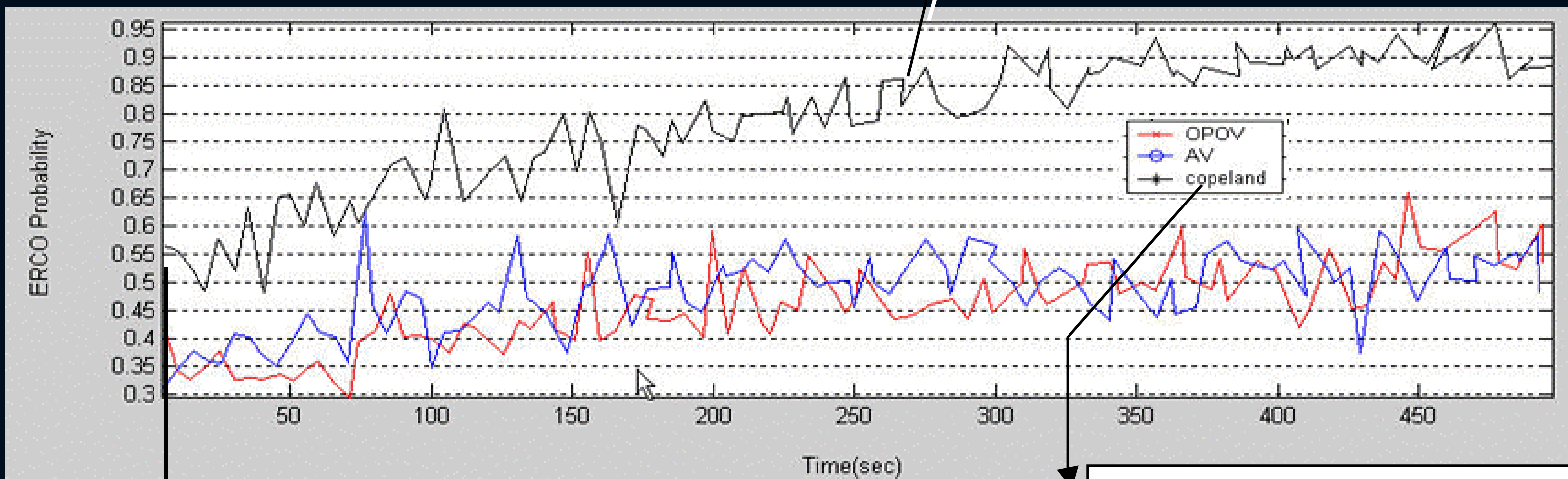
SIMULATION INPUTS: 75 voters have homogeneous distribution and 0.9 competence and 25 voters have heterogeneous distribution with competence of 0.48, Weighting method: Shapley Grofman, plurality rule, homogeneous dist mean: 2.7333 3.0267 3.24 3.0267 3.32 homogeneous dist std: 1.9686 1.9998 1.9517 1.973 1.9607 heterogeneous dist mean: 3.12 2.72 3.64 3.08 3.52 heterogeneous dist std: 1.9661 1.9498 1.8521 1.9374 1.8999 combined dist mean: 2.9393 2.9676 2.9998 3.0324 3.0641 combined dist std: 0.019998 0.019297 0.019122 0.019201 0.020086, 0.25 voters competence mean: 0.49126 and competence std: 0.041692, 0.75 voters competence mean: 0.9072 and competence std: 0.050745 combined competence mean: 0.80322 combined competence mean: 0.18738 False positive mean 0.0094344 0.011304 0.0082595 0.0093459 0.009574 0.012856 0.0093003 0.011143 0.0092902 0.0087724 False positive std 0.0050145 0.0050293 0.0039013 0.0049028 0.0040402 0.0055101 0.0045386 0.0043665 0.0050777 0.0030632 False negative mean 0.0090609 0.0098397 0.0084995 0.011297 0.0093576 0.0083906 0.0095186 0.012528 0.0099975 0.010192 False negative std 0.004449 0.0036323 0.0036829 0.0054426 0.0031957 0.0049893 0.0029249 0.0034632 0.0061935 0.0057356

Collection Time per Vote: Rayleigh Distribution

Same 100 Sensor Scenario
Heterogenous (Diverse) Preferences

HOW LONG SHOULD C2 WAIT?

DECISION SUPPORT ERCO efficiency will not increase by more than 10% for another 170 seconds.



DECISION SUPPORT Wait 350 seconds to double ERCO efficiency

Which choice is most intensely preferred?

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Use ERCO Efficiency to Manage Trust

- Set criteria for trusting voters
- Segment voters into three categories
  - Trusted (satisfy all criteria)
  - Moderately trusted (satisfy minimal criteria)
  - Untrusted (do not satisfy minimal criteria)

Use ERCO Efficiency to Manage Trust
[continued]

- Find the collective outcome for
  - Each trusted segment
  - All segment combinations
- If the collective outcomes are consistent, avoid making risky decisions about trusting voters

Use ERCO Efficiency to Manage Trust

[continued]

- If the collective outcomes are inconsistent
  - Choose the results for the most trusted segment(s)
  - Use automated follow-ups to pinpoint information required to resolve inconsistencies
  - Assess tradeoffs associated with waiting to collect more votes to resolve inconsistent collective outcomes

Using ERCO Efficiency to Manage Trust

Convoy Assessment Votes Weighted by Confidence Ratings	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3	Trusted Relationship
Weighted Votes							
AC 1		0	-1.39	0	0	0	Trusted
AC 2		Missing Data					Trusted
AC 3		0	-1.39	0	0	0	Untrusted
AC 4		0	0	0	0	0	Trusted
AC 5		Missing Data					Trusted
AC 6							Trusted
IR 1		0	0	0	0	1.39	Trusted
IR 2		0	0	0	0	1.39	Trusted
IR 3		0	0	0	0	1.39	Moderately Trusted
IR 4		0	0	0	0	1.39	Trusted

Using ERCO Efficiency to Manage Trust

Convoy Assessment Votes Weighted by Confidence Ratings	Number of Vehicles Observed	0	1	1 or 2	2	2 or 3	Trusted Relationship
Weighted Votes							
AC 1		0	-1.39	0	0	0	Trusted
AC 2		Missing Data					Trusted
AC 3		0	-1.39	0	0	0	Untrusted
AC 4		0	0	0	0	0	Trusted
AC 5		Missing Data					Trusted
AC 6							Trusted
IR 1		0	0	0	0	1.39	Trusted
IR 2		0	0	0	0	1.39	Trusted
IR 3		0	0	0	0	1.39	Moderately Trusted
IR 4		0	0	0	0	1.39	Trusted

Scores wthout	**1 Vehicle**	**1 or 2 Vehicles**	**2 or 3 vehicles**	**Collective Outcome**
Untrusted Sensor	-1.39	0	5.56	**2 or 3 vehicles**
Moderately Trusted Sensor	-2.78	0	4.17	**2 or 3 vehicles**
Untrusted Sensor **and** Moderately Trusted Sensor	-1.39	0	4.17	**2 or 3 vehicles**